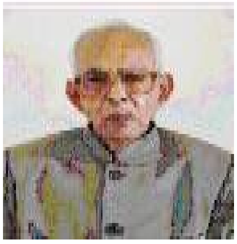
Tea Research Association

SCIENCE AND PRACTICE IN TEA CULTURE

D. N. BARUA

ABOUT THE AUTHOR



Dr. D. N. Barua
(01.07.1916 - 22.01.2012)

Citation while presenting the lifetime achievement award to Dr. D. N. Barua by the Tea Board of India, Kolkata on 28.8.1998 is reproduced below to introduce the author

In a world where knowledge represents power, Dr. Dinanath Barua, whom we are privileged to honour today. represents that absolute power to do good — to influence, guide, educate and shape the destiny not of men who have had the honour of being associated with him but of an entire industry. His illustrious career that began with a brilliant period of learning, culminated in a doctorate from the Cambridge University of England in 1953. This also expressed his life long affair with the world of plants and their physiology, the most striking beneficiary of which was the tea industry, which Dr. Barua has served since the late thirties. In the process Dr. Barua has authored a book, “Science and Practice in Tea Culture”, published by the Tea Research Association in 1989 that is considered among the more authoritative publications on the subject, apart from the more than a hundred papers published in Indian and international journals, sharing his wide knowledge on the intricacies of the tea industry. Crowning glory came his way with the Nuffield Foundation fellowship being awarded to him twice in 1964 and 1972. This took him on study and research trips to Great Britain and other parts of Europe. Starting his life in tea research as a senior scientific assistant at Tocklai Experimental Station, with which he was associated since 1939, Dr. Barua went on to be the plant physiologist at Tocklai in 1955 and had the added responsibility of a senior botanist from 1963. Between 1972 and 1973 he was scientist cum deputy director of Tocklai before he was chosen for a World Bank assignment as adviser of the Assam Agricultural University, a position in which he served from 1973 to 1976. Dr. Barua then went on to be the adviser of the Tea Research Association from 1976 to 1982. Focusing then on writing, he published his book in 1989 and has since been associated with editing Tocklai publications.

In the course of this illustrious career Dr. Barua blossomed as a teacher par excellence as he not only presented papers globally and conducted seminars and conferences but he guided research students for their M.Sc. and doctoral degrees on a variety of facets of the industry that he best knew — tea. At other times, he served on committees of Gauhati and Dibrugarh Universities ,and as a member of the Standing Committee for Agricultural Research of the Indian Council of Agricultural Research.

It is difficult to encapsulate this remarkable career in a short citation but it would be important to recount some of his more remarkable contributions that has a profound impact on the industry. Dr. Barua was recognised as a pioneer investigator of photosynthesis, production and partition of dry matter, seasonal dormancy, stock-scion interaction and the role of mycorrhiza in tea.

On the practical front, Dr. Barua's visible contributions came in the areas of plucking, shade, root growth, nutrient uptake, spacing and tea chemistry. He took special interest in evolving a simple method for vegetative propagation of the tea plant under commercial conditions. Equally significant was his role in simplifying the clonal selection technique and initiating screening of old commercial tea fields for elite clones with the objective of preserving them in a clonal museum. Finally, Dr. Barua is credited with streamlining the tea breeding procedure and was the first to release the improved biclonal seed varieties for commercial cultivation.

We are privileged that Dr. Barua has done us the honour of accepting this citation from us.

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PREFACE TO THE CURRENT EDITION

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PREFACE TO THE CURRENT EDITION

The copies of this book printed in 1989 were used up within about five years. Reprinting got delayed due to various factors, addition of a chapter on pests and diseases of tea being one of them. Chapter 14 on this topic has now been added to the book mainly at the insistence of a large number of tea growers for their ready reference.

I am grateful to Tea Research Association (TRA) for reprinting the book. I also highly appreciate the efforts made by Mr. Sudhir Prakash, the past Chairman of TRA, in getting the book published without further loss of time.

D. N. Barua

PREFACE TO THE FIRST EDITION

Cultivation of tea is expanding rapidly. At present 45 countries grow tea over an area of approximately 1.4 million hectares. The current annual production stands around 2100 million kilograms. These statistics give some indication of the magnitude of the tea trade, the capital invested in it and the number of persons directly or indirectly dependent on this commodity for their livelihood.

More than a dozen institutions in different parts of the world are engaged solely on research for the improvement of production, plant protection and processing of tea. The information generated in some of these institutions often remain inaccessible to scientists of the other institutions. Surprisingly, very few attempts were made in the past to collate the research findings on this crop.

The author undertook to write this book at the behest of late Sir Frank L. Engledow F.R.S., who had a long association with the Indian tea industry and was fully acquainted with the progress of tea research in different parts of the world. Writing got delayed due to various reasons and Sir Frank did not live to see publication of the book. The author will always remain grateful to him for his suggestion and encouragement.

Attempt is made to preserve order and sequence in dealing with different facets of tea culture. Information which fitted into the general scheme of writing was drawn from various publications but, on consideration of space, discretion had to be exercised in their choice.

While dealing with different aspects of tea production, the interest of the general readers and students has also been kept in view. Plant protection and processing of tea fall outside the scope of this book. These will require separate treatment.

The author is grateful to the Tea Research Association for providing facility for writing and for undertaking publication of the book. He also thanks Dr. S. C. Das and Mr. A. C. Dutta for helping him with the drawings and photographs and Mrs. Bharati Kalita for typing the manuscript.

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D. N. Barua

CONTENTS

Abbreviations Used

ITA	for Indian Tea Association
TES	for Tocklai Experimental Station, Jorhat, Assam
TRA	for Tea Research Association, India
TRIC	for Tea Research Institute of Ceylon
TRISL	for Tea Research Institute of Sri Lanka
TRFCA	for Tea Research Foundation of Central Africa
TRFEA	for Tea Research Foundation of East Africa
TRIEA	for Tea Research Institute of East Africa
UPASI	for United Planters' Association of Southern India

Units

mm	millimetre
cm	centimetre
m	metre
km	kilometre
mg	milligram
g	gram
kg	kilogram
q	quintal = 100 kg
t, ton (metric)	ton = 1000 kg
sec	second
min	minute
hr	hour
cm^2	square centimetre
m^2	square metre
ha	hectare = 10,000 m^2
g cm^{-2}	gram per square centimetre
kg ha^{-1}	kilogram per hectare
mg cm^{-2} sec^{-1}	milligram per square centimetre per second
1 lb =	0.4536 kg
1 inch =	2.54cm
1 foot =	0.3048 m
1 lb per acre =	1.1208 kg ha^{-1}

FOREWORD TO THE CURRENT EDITION

Born in the year 1916, Dr. D. N. Barua at the time of this book going for reprint, is 92 years old. He is as sharp and right today as is the Director of TRA who is almost half his age. Although he retired from TRA in 1973, he regularly puts in couple of hours at his study in Tocklai and is available to students and scientists with whom he readily shares his unparalleled knowledge of *Camellia sinensis*.

When I asked him about his knowledge of biotechnology, which is a new science, he answered me in his inimitable style "Biotechnology is nothing but a modern tool of Botany."

In his book the basic facts as well as complex ideas of tea science are explained in a simple but clear language which is the hallmark of a truly great scientist.

I commend this book to all.

Sudhir Prakash
Chairman
Tea Research Association
2007

FOREWORD TO THE FIRST EDITION

In 1982 when Dr. D. N. Barua, having retired from Tocklai Experimental Station, Jorhat, as Adviser to the Tea Research Association (TRA) proposed to write a book on 'Science and Practice in Tea Culture', TRA readily welcomed the proposal. The suggestion for writing a book on tea was in fact made to Dr. Barua by no less a person than Sir Frank L. Engledow, F.R.S., the then Chairman of TRA's London Scientific Committee, when Dr. Barua was still with TRA. However, Dr. Barua could not devote time to writing of the book while he was working for the Association and he proposed to take up the work soon after his retirement. The Council of Management of TRA accepted the proposal and gave him all encouragement and support.

It is an uphill task to write a complete compendium on tea and I am very happy that Dr. D. N. Barua has written a splendidly balanced account of what has been achieved in the science and practice of tea through research, flavouring it with enough details from work done at Tocklai and at some other tea research institutions, to retain his readers' interest.

I have no doubt that the book would be an asset to the science of tea. Dr. Barua had a distinguised career at the Tocklai Experimental Station for over three decades and he can now claim another distinctive achievement.

I am sure the book will be of immense interest to all those connected with tea and will be an indispensible reference for practising tea planters.

H. P. Barooah
Chairman
Tea Research Association

CHAPTER 1

INTRODUCTION TO TEA CULTURE

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EARLY HISTORY

The word tea is derived from *t'e* of the Chinese Fukien dialect. The Dutch introduced it to Europe. In Cantonese, tea is known as *Ch'a*. In this form the name reached Japan, India, Russia, Iran and the Middle East.

Tea-drinking originated in China, but the origin is obscured by a mass of legend. According to Ukers (1935) the first authentic reference to tea is found in an ancient Chinese dictionary which was revised about the year A.D. 350 by Kuo P'o, a celebrated Chinese scholar. At that time a medicinal decoction was made by boiling tea leaves. Use of tea as a beverage commenced towards the close of the sixth century. During the two succeeding centuries tea gained so much in popularity that it attracted the notice of the Government and a duty was levied in the year A.D. 783. The Arabian travellers who went to China in the ninth century spoke of tea as the common beverage of the country (Bamber, 1893).

The first exclusive book on tea was published about the year A.D. 780 by Lu Yu, who was a noted author and expert on tea. The book *Ch'a Ching* or Tea Classic describes various kinds of tea, their cultivation, manufacturing methods, quality of different types of made tea besides giving information about the tea-growing districts of China.

Introduction of Tea into Europe

Despite its extensive use in China and later in Japan, tea-drinking did not spread to other parts of the world until about the middle of the seventeenth century. The opening of a sea route to India and the East by the Portuguese in 1497 facilitated large-scale trading between Europe and the Orient. Other

European nations followed the Portuguese in establishing trading centres in different countries of the East. One such depot was established by the Dutch in Java. They bought tea from Japan and the first consignment of tea was transhipped from Java to Europe in the year A.D. 1610. This marked the beginning of the lucrative tea trade between Europe and the East. Other trading nations came into the scene and keen competition ensued. The Dutch dominated the tea trade for more than a century finally yielding to the British. Tea shipped to Europe came from China, which was the sole supplier of the commodity till the middle of the nineteenth century.

Within about 50 years from its first introduction, tea gained a strong foothold among the affluent sections in the European continent and the British Isles and in about another 100 years it became an article of daily use in a large part of Europe. Tea became popular in America also, which was then a British colony. Due to differences over the taxation policy of the parent Government, Americans boycotted shipments of tea from Britain and dumped some tea in the ocean. Many regard this act as the immediate cause of the American War of Independence.

Discovery of the Assam Tea Plant

The honour of discovery of the Assam tea plant is usually attributed to Robert Bruce who is supposed to have seen the plant growing wild in some hills near Rangpur (near present Sibsagar), then the capital of Assam, which he visited in 1823 on a trading mission (Ukers, 1935). At that time he made arrangement with a Singpho Chief to supply him some tea plants during his next visit in the following year. Assam was then under Burmese occupation and war broke out with the Burmese in 1824. Robert Bruce also died in the same year before he had a chance of collecting the tea plants. C.A. Bruce, brother of Robert Bruce, was ordered to Sadiya, located at the easternmost point of the Brahmaputra valley, in charge of a division of gunboats. After completion of his mission, C.A. Bruce interviewed the Singpho Chief who supplied him some tea plants and seeds. Most of the seeds were planted in Bruce's garden at Sadiya and some were sent to Commissioner Jenkins at Gauhati. A few leaves of these plants were sent to the Botanical Gardens in Calcutta. Dr. Wallich, who was then the Superintendent of the Botanical Gardens, identified the leaves as belonging to the *Camellia* family but did not consider them to be of the same species as tea, meaning the China tea plant.

In 1834, Lord William Bentinck, Governor-General of India, appointed a Tea Committee to advise on the possibility of commercial cultivation of tea in India. The Committee issued a circular asking for information on areas suitable for tea cultivation and despatched its secretary, G.J. Gordon, to procure tea seeds, plants and workmen from China. In response to the circular, the Commissioner of Assam, F. Jenkins made a strong case in favour of tea cultivation in Assam where tea plants were found growing wild in forests. He also collected complete specimens of the local plant and forwarded them to the Government Botanical Gardens in Calcutta. On this occasion Wallich had no difficulty in identifying the specimens as tea "not different from the tea plant of China". Upon this, the Tea Committee recommended that the indigenous plant "under proper management could be cultivated with complete success for commercial purposes".

A scientific commission was constituted in 1835 with Dr. N. Wallich, Dr. W. Griffith and Dr. J. McLelland to report on the Indian indigenous tea and to advise on the most favourable localities for starting experimental tea gardens. The Scientific Commission visited Assam in early 1836. C.A. Bruce, acting as guide, took the members to a number of tracts at the foot of the Naga and Patkai hills as well as to a few in the river valleys where the indigenous tea plant was growing in clumps. Having seen the tea bushes Wallich expressed the view that there was no need any more to import tea seed from China, while Griffith favoured importation of the China seed because “a wild plant is not likely to give as good a produce as one that has been cultivated for centuries”. It was finally decided that the “China plant and not the degraded Assam plant” should be used for the Government experiments. The Commission failed to come to a general agreement regarding the most favourable localities for establishing experimental gardens. Wallich favoured the Himalayan region while the other two favoured Upper Assam where ‘wild’ tea existed. So Gordon was again sent to China in 1836 and for many years China tea seed was imported regularly into India.

From seeds brought by Gordon, nurseries were raised in the Government Botanical Gardens in Calcutta and the plants were sent to Upper Assam, Dehra Doon, Kumaon and the Nilgiri hills. The site selected for the experiment in Assam at Saikhowa near Sadiya was not a happy one where many plants died. The surviving plants were moved to a new site near Chabua about 25 kilometers east of the present town of Dibrugarh. Seedlings sent to the Himalayan region were planted at two sites near Bhimtal and Almora. Later on, experimental gardens were successfully established with China plants in Kumaon, Garhwal and Kangra districts on the Himalayan foothills. Of the plants sent to the South, a few survived in the Nilgiris and a small lot ended up in Wynaad on the western coast.

Besides establishing experimental plots of tea with the China plants and seeds received through Calcutta, C.A. Bruce who was then appointed as the Superintendent of Government tea plantations, raised nurseries of the indigenous tea plant. He also explored a large part of the territory from Sadiya to Gabru Parbat in Upper Assam and discovered numerous tea tracts inside forests. Some of these tea tracts were cleared and the leaves gathered from the bushes were manufactured with the help of workmen brought by Gordon from China. The first experimental samples of tea from the indigenous plant were sent to Calcutta in 1836. The samples received favourable comments, whereupon an invoice of eight chests of Assam tea was forwarded to London in 1838 which was auctioned in London on 10 January 1839. This was a momentous occasion because not only did it establish the worth of the Assam tea plant but determined the future course of tea cultivation throughout the world. Currently more tea is made from the Assam type of bushes than from the China type.

Controversy Regarding the Discoverer of the Assam Tea Plant

The question of real discoverer of the Assam tea plant has not yet been satisfactorily settled and it is doubtful whether it could ever be done. C.A. Bruce was awarded the medal from the English Society of Arts, presented through the Agricultural and Horticultural Society of Bengal, for his part in the discovery. Major Jenkins and Captain Charlton disputed this decision and staked their claims for the honour. Acrimonious correspondence followed but eventually these two also received a medal each from the Agricultural and Horticultural Society of Bengal. The only person who did not receive any award was Robert Bruce who is considered to be the real discoverer of the plant (Ukers, 1935). According to some sources (Baildon, 1877) the tea plant of Assam was discovered by a local Assamese nobleman, Maniram Dewan, who later worked in the Assam Company for some time. It is possible that Maniram Dewan brought the plant to the notice of Robert Bruce during his visit to Rangpur in 1823.

The role of the Singphow tribe of Assam in bringing the local plant to the notice of the outside world cannot be ignored. It was a Singpho Chief who supplied seeds and plants of tea to C.A. Bruce. Another Singpho Chief prepared 35 out of the 130 chests of tea, which C.A. Bruce sent to Calcutta in 1841 (Ukers, *loc. cit.*). This clearly shows that the Singphows must have been familiar with the plant and were making and drinking tea from antiquity.

NOMENCLATURE AND CLASSIFICATION

Nomenclature

Description of the tea plant in a form acceptable to the botanists does not appear in the ancient Chinese literature. The first scientific description of the China tea plant found in Japan was given by Kaempfer (1712), who was a surgeon of the Dutch East India Company stationed in Japan. However, Kaempfer did not collect any specimen but made a few drawings of the plant. In 1753, Linnaeus used Kaempfer's illustrations to typify the China plant under the name *Thea sinensis* in Vol. I of his Species Planterum, while describing the two ornamental species known at that time as *Camellia sasanqua* and *Camellia japonica* in Vol. II. The generic name *Camellia* was derived from Kamel, George Joseph Kamel, a German missionary stationed in the Philippines, who wrote about plants, found in Asia during the latter half of the seventeenth century.

In 1762, Linnaeus distinguished two kinds of tea and named them *Thea viridis* and *Thea bohea*. The former was supposed to produce green tea and the latter black tea. The specific name *sinensis* was dropped. When it was found that green and black tea could be made from the same plant, the name *Thea viridis* was dropped, retaining the name *Thea bohea* for the tea plant. This started the confusion and botanists working on tea began using different names for the plant, influenced apparently by the wide range of cultivated intergrades between the China and the Assam races. Wight and Barua (1939) counted as many as eleven names in the literature. To avoid confusion and discordance, the Tea Research Institutes of India, Ceylon and Java approached the International Botanical Congress for a decision on the correct nomenclature of tea. The Botanical Congress in its session held in Amsterdam during 1935, decided to unite the two genera *Thea* and *Camellia* into a single genus, *Camellia*, and appointed a special committee to consider the nomenclature of tea and a number of other economic plants.

The committee decided *Camellia sinensis* (L) to be the correct name of the tea plant. Technically, '*Camellia sinensis* (L) O. Kuntze' is the full name of the tea plant, since it gives recognition to the authority responsible for the union of the old name *sinensis* with the new genus *Camellia*.

While nomenclature of the tea plant was finally settled, the position of the two taxa represented by the China and the Assam plants remained open. The genus *Camellia* of which tea is a member; belongs to the family *Theaceae*, tribe *Gordonieae*, along with eight other genera, among which *Camellia* is the largest. Sealy (1958) listed 82 recognised species within the genus *Camellia* and 16 other imperfectly known species whose status was not decided. The recognised species were arranged into 12 sections on 'the basis of affinities of floral characters. The tea plant came under the *Thea* section along with four other species, viz. *C. irrawadiensis*, *C. taliensis*, *C. gracilipes* and *C. pubicosta*. All tea plants were placed under one species, *C. sinensis*. The large-leaf Assam plants were considered to be a variety of the *sinensis* species and were included in Var. *Assamica* as described by Kitamura (1950). Among the small-leaf plants, Sealy distinguished two forms, *macrophylla* and *parvifolia.*

Wight (1962) disputed this classification and advocated specific rank for the Assam tea plant. He proposed the name *C. sinensis* L. for the China plant and. *C. assamica* (Masters) for the Assam plant, Masters (1844) being the first to describe the Assam plant as a separate type. The 'southern form' of tea referred to as *Cambodiensis* by Kingdon-Ward (1950) has long been recognised at Tocklai as a distinct type. Others familiar with tea cultivated in different parts of the world also favour recognition of this third race (du Pasquier, 1924; Kingdon-Ward, 1950; Harler, 1964; Sharma and Venkataramani, 1974). An account of this tea was first given by Watt (1908), who agreed with Planchon that it was different from the species originally named *Thea sinensis* by Linnaeus. However, the difference between the Southern form and *assamica* is much less than that between *assamica* and *sinensis*. Wight (1962) does not consider this race of tea to merit a separate specific rank and has treated it as a sub-species of C. *assamica*. As it resembles Planchon's *Thea lasiocalyx*, the name *Camellia assamica* sub-sp. *lasiocalyx* (Planch. MS) is proposed for the Southern or Cambodiensis form of tea.

Classification

Wight (1962) gave a concise description of the China and the Assam varieties of tea while proposing their specific ranks. Barua (1963) provided morphological and anatomical description of the three races of tea, which was later elaborated by Bezbaruah (1971). A summary of the morphological characters of the three races of tea, using Wight's nomenclature, is given below:

Camellia sinensis L. or the China tea plant is a big shrub, 1-3 m tall with many virgate stems arising from the base of the plant near the ground. Leaf hard, thick and leathery; surface matt, marginal veins indistinct and appear sunken in lamina. Blade elliptic with obtuse or broadly obtuse apex; base cuneate, margin bluntly serrulate to sinuate-serrulate with more or less incurved teeth, glabrous above and villose below when young, becoming sparsely villose as the leaf ages, ultimately becoming glabrous. Young leaves garnet-brown through ox-blood to purple in colour. Petiole short, 3-7 mm long, stout, usually giving the leaf an erect pose.

Flowers are borne singly or in pairs in the cataphyllary axils. Pedical 6-10 mm long, clavate, glabrous with 2-3 sub-opposite scars little below the middle, marking the position of caducous bractioles 2-5 mm long. Sepals 5-6, imbricate, persistent, leathery, ovate or orbicular, 3-6 mm long, glabrous, green. Petals 7-8, shallowly cup-shaped, 1.5-2 cm long, broad-oval to sub-orbicular, generally white sometimes with pale pink pigmentation. Stamen numerous, arranged in two whorles, inner ones shorter and fewer in number, outer longer and more numerous, 8-13 mm long, united at the base for a few mm with the corolla lobes. Ovary white, densely hairy, 3 locular, ovules 3-5 in each loculus, placentation axial. Style generally 3, sometimes upto 5, free for the greater part of their length, occasionally free upto the base of the ovary. Stigma apical. Capsule l, 2, or 3, coccate, containing 1 to 3 nearly spherical seeds, 10-l5 mm in diameter.

On the basis of leaf sizes Sealy (1958) recognised two forms of *C. sinensis* (a) f. *macrophylla* (Sieb.) Kitamura, with leaves 4-14 cm long, 2-2.5 cm wide and (b) f. *parvifolia* (Miq.) Sealy, with leaves 1.5-I .6 cm long and 1-1.2 cm wide.

Camellia assamica (Masters) or the Assam tea plant is a small tree, 10-15 m tall with a trunk sometimes upto one third of its height, possesses a robust branch system. In typical plants leaf dependent, thin, and glossy with more or less acuminate apex and distinct marginal veins. Leaf blade usually broadly elliptic, 8-20 cm long and 3.5-7.5 cm wide, base cuneate, margin obscurely denticulate to bluntly wide-serrulate, glabrous or persistently hairy on the midrib below.

Flowers single or in pairs on the cataphyllary axils; pedicels with scars of 3 caducous bracteoles, smooth and green. Sepals 5-6 unequal, leathery, persistent. Petals 7-8 white, occasionally with pale yellow pigmentation at the base of petals. Stamen numerous as in *C. sinensis*.

Camellia assamica sub sp. *lasiocalyx* (Planch. MS) or the *Cambodiensis* or Southern form of tea is a small fastigiate tree, 6-10 m tall, with several upright, almost equally developed branches. Leaf more or less erect, glossy; yellowish-green when young, light green at maturity changing to coppery-yellow or pinkish-red from autumn till the end of the season. Petiole pinkish-red at the base. Leaf size intermediate between *sinensis* and *assamica*, broadly elliptic, marginal veins not very prominent.

Ovary 3-4, sometimes 5-locular. Style 3-5, free nearly upto half the length, adpressed, straight with apical or linear stigma.

On other floral characters, it resembles the Assam plant, with the difference that 4 or more bracteoles are found on the pedicel of flowers (Fig 1a, b, c).

Anatomical Features

Selereids, also known as stone cells with strongly thickened walls, develop in leaves and other organs of many plant species. Normally, living contents are absent from the cavity or lumen of these cells. The minute holes on the walls of sclereids are known as pit canals. The long axis of sclereids inside the lamina of tea leaf is deposed almost at right angles to the mid-rib. Barua and Dutta (1959) found that sclereids were either absent or very rare in the leaves of plants typical of the China race and present in large numbers in the leaves of the other two races of tea. The few sclereids present in the China plant are long and slender with a relatively smooth wall and narrow lumen. Sclereids of the Assam plant are characterised by a short body, acuminate upper end, thick secondary wall, a lumen that is constricted at several points on the body and a few spicules i.e. out-growths. In plants of the Southern race, sclereids are characterised by a dense covering of large spicules and a broad lumen without constriction. In other respects these sclereids resemble those of the Assam plants (Fig.2).

A

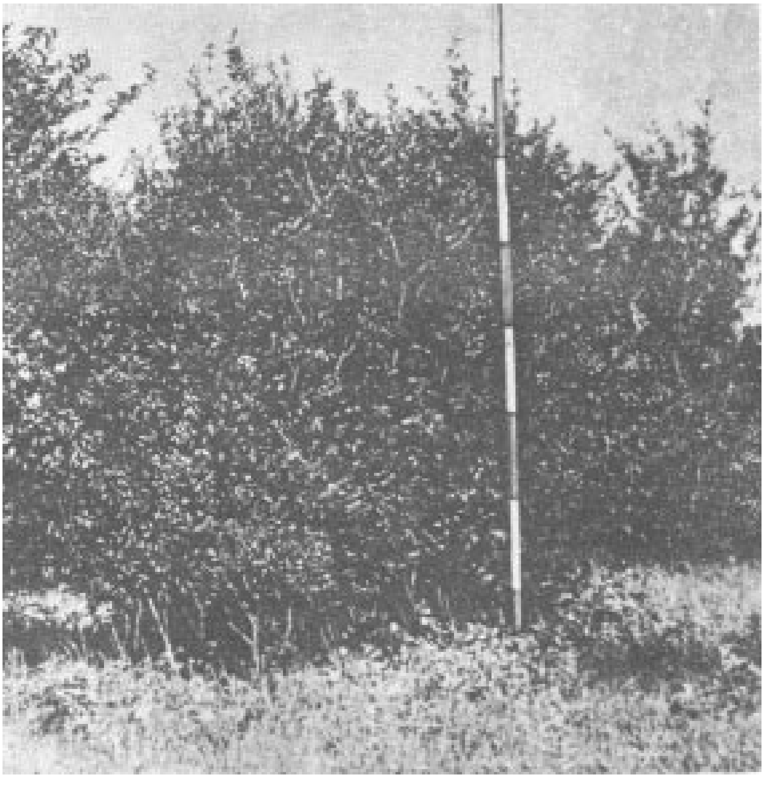

Plate 1

In the China kind of tea the pallisade parenchyna usually consists of two layers of cells and occasionally three, whereas in the Assam and Cambod plants one, rarely two, layers of pallisade cells are present.

B

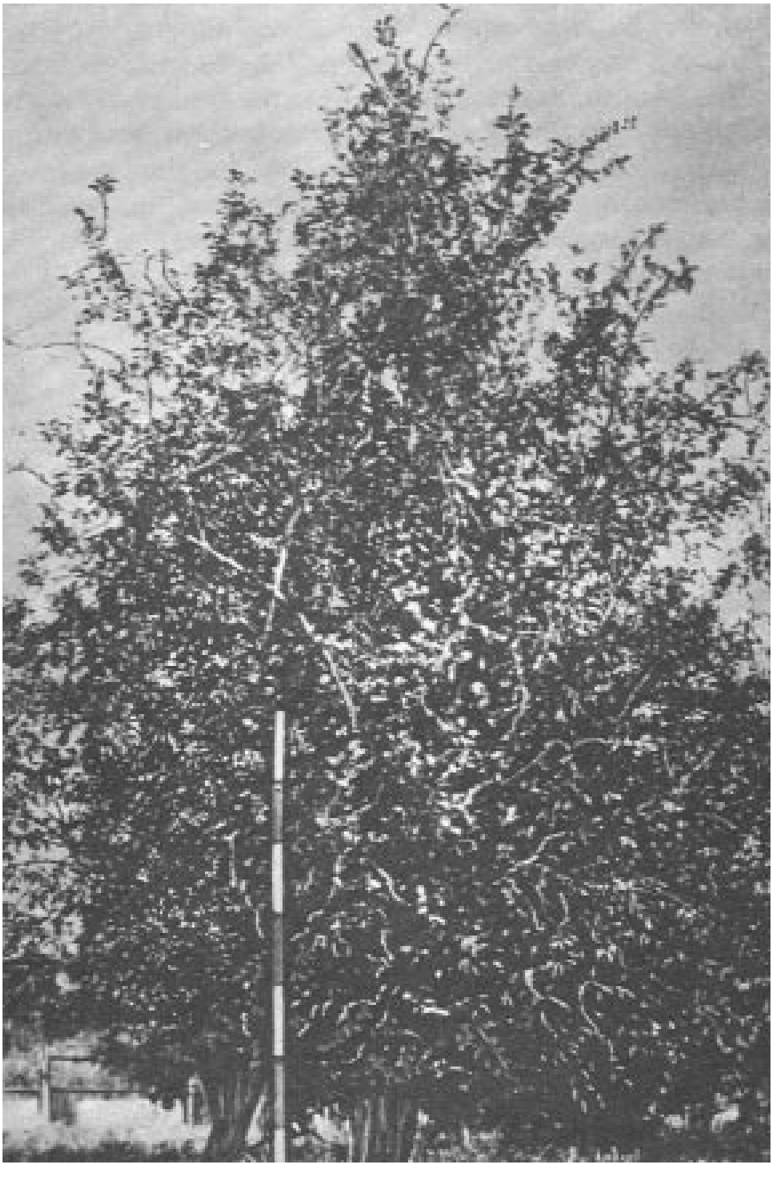

Plate 1

C

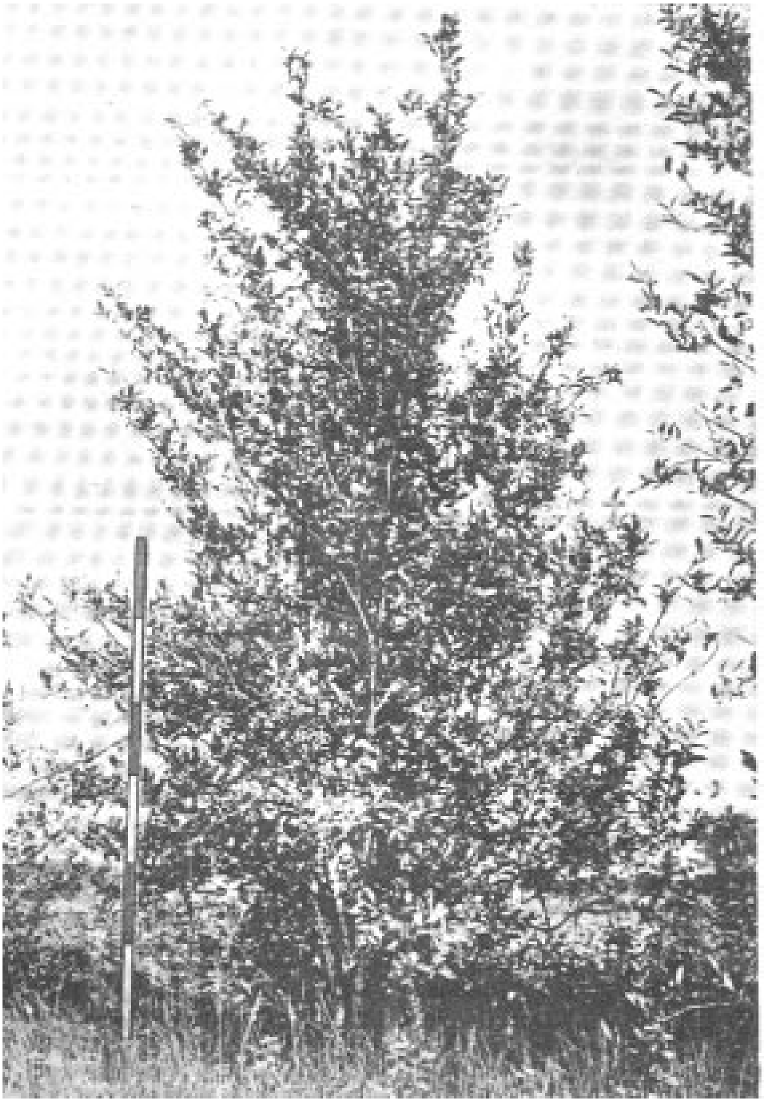

Plate 1 Full grown plants of the three races of Tea : A. *Camellia sinensis* (China), B. *Camellia assamica* (Assam) and C. *Camellia assamica laxiocalyx* (Cambod or Southern form). The sacle alongside each plant is three meters tall.

Fig. 1(a) China tea: *Camellia sinensis* (L) O. Kuntze A. Flowering shoot (natural size). B. Pistil (4 X), C. Fruit (natural size)

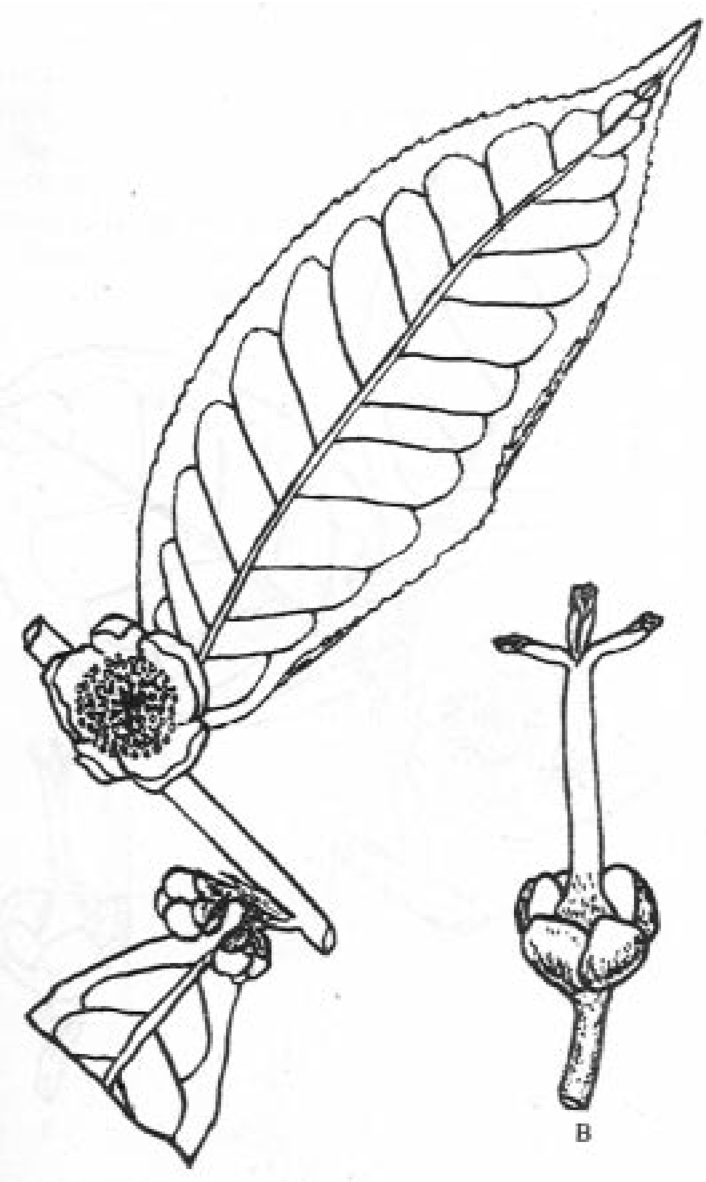

Fig. 1(b) Assam tea *C. assamica* (Masters) Wight. A. Flowering shoot (natural size), B. Pistil (4 X).

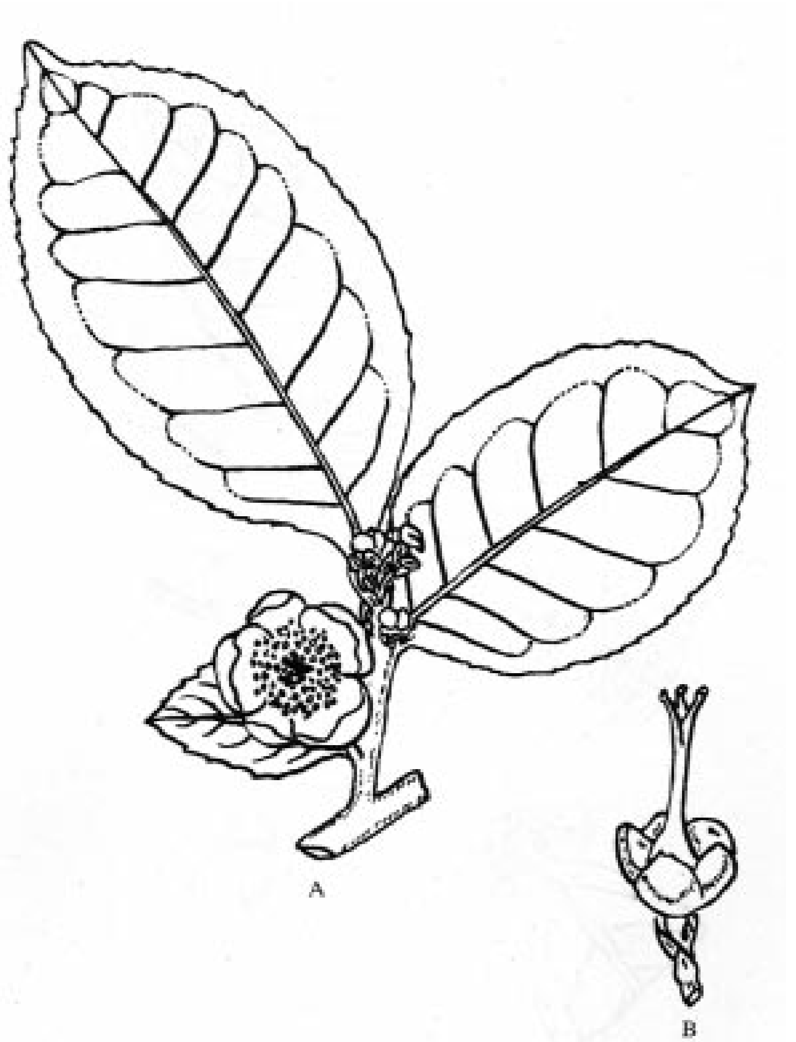

Fig. 1(c) Combodiensis or Southern form of tea: *C. assamica* sub sp. *lasiocalyx* (Planch, MS). A flowering shoot (natural size), B. Pistil (4 X).

Chemical Composition

Roberts *et al.* (1957) analysed the phenolic constituents in the shoots of different kinds of tea and other species of *Camellia* by paper chromatography, to examine whether chemical analysis could throw some light on morphological classification. They observed that the species within the *Thea* section of the genus *Camellia* are closely similar in chemical composition but different from the non-*Thea Camellias*. Triglycosides of quercetin and kaempferol are found only in the China tea plant and not in the other two kinds of tea. An unknown phenolic substance designated IC is found in the Southern race of tea and not in the other two races. Anatomical and chemical observations are summarised in Table 1.

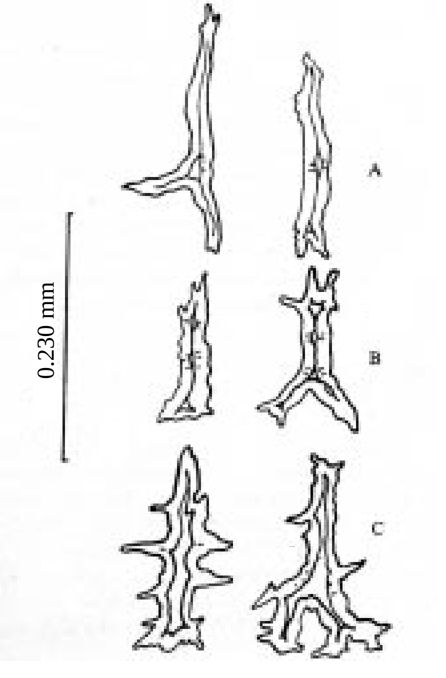

Fig. 2. Typical sclereids of (A) China (B) Assam and (C) Cambod plants. Upper ends of sclereids are pointing to the upper leaf epidermis

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Table l. Distinguishing anatomical and chemical characters of the three races of tea (After Barua, 1963)

China	Assam	Southern Form
Sclereids absent or rare	Sclereids numerous	Sclereids numerous
Sclereids slender, almost without spicules	Sclereids stout with a few spicules	Sclereids stout with numerous spicules
Lumen of sclereids almost completely closed	Lumen of sclereids of irregular width, closed in places	Lumen of sclereids of irregular width but not closed
Triglycosides present in fairly large amount	Triglycosides absent	Triglycosides absent
IC absent	IC absent	IC present in fairly large amount

According to Wight and Gilchrist (1961) the three races of tea differ in their liquor characteristics.

It is clear that the sclereid features and chemical composition together with the morphological differences make a strong case in favour of the classification proposed by Wight (1962) for the three races of tea. Whatever may be the ultimate verdict of the taxonomists, the existing evidence cannot be ignored and, for that reason, Wight's nomenclature has been retained.

PLACE OF ORIGIN

The place of origin of tea is still a matter of speculation. Our knowledge of tea in the distant past is derived from China but information available from the Chinese sources does not throw much light on its place of origin, Discovery of a wild prototype of the plant cultivated in China would have assisted the search for its original home but no wild tea plant appears to have been discovered in China, nor can such a discovery be expected now, after the plant has been in cultivation for nearly 2000 years over a wide part of the country.

The situation is different for the Assam and the Cambodia races of tea. Since the early part of the nineteenth century, discovery of ‘wild’ plants of these two races has been reported from Assam, Manipur, Mizoram, Burma, Thailand and the entire Annamite chain from the extreme north of the gulf of Tonkin to South Vietnam and Laos. It is, however, not certain whether the plants were wild or relics of plantations abandoned by the migratory tribes of these regions.

The tea tracts discovered by Bruce in Assam were almost certainly clumps of cultivated tea abandoned by the migratory hill tribes. Watt and Mann (1903) seemed to hold the same view. It is worth mentioning in this connection that these tribes usually followed a shifting system of cultivation known as *jhumming*. After raising crops in a virgin forest clearing for a number of years, the community would abandon the site and move on to another virgin area. This system of cultivation is dying out but not yet extinct. The inhabitants of northern Burma on the other side of the mountain range that divides Assam from Burma, were known to have used tea as a vegetable (Letpet tea), for chewing as well as for making a drink out of it (Watt, 1896). In the Indo-China peninsula, tea was an important village industry for many centuries long before the discovery of the Assam plant (du Pasquier, 1924). Hence it is doubtful whether the plants discovered in these regions were truly wild. Nevertheless, these discoveries, irrespective of whether the plants were wild or not, have helped in our understanding of the pattern of dispersal of the three races of tea.

The problem of origin and dispersal of the tea plant was examined in depth by Wight who made his views known to Kingdon - Ward, which the latter duly acknowledged (1950). According to Wight, tea might have originated in the region around the point of intersection of latitude 29°N and longitude 98°E, near the source of the river Irrawaddy, which is the meeting ground of Assam, North Burma, South-West China and Tibet. The great rivers of South-East Asia flow through this region; Yangtze Kiang to the east, Mekong to the south-east, Irrawaddy and Salween to the south and Luhit, an important tributary of the Brahmaputra, to the west. In its dispersal from the centre of origin, Wight suggested that tea followed the courses of these rivers in two axes, one running from east to west (actually north-east to south-west) and the other from north to south. The dispersal took the form of a 180° arc south of the NE-SW axis extending from Yellow Sea in the east to Nepal in the west, implying that the circumference of the arc passed through South-East China, Indo-China, North Burma, Mizo hills, (Mizoram), and Garo hills (Meghalaya), ending up in the Sikkim Himalayas. The area enclosed by the semi-circle is considered to be the zone of origin and dispersion of the genus *Camellia* as a whole (Vavilov, 1926; Sealy, 1958).

While making the observation that for an understanding of the origin of tea, exploration must be conducted in the region of South China and Upper Indo-China adjoining the border of Tibet and India, Cohen Stuart (1918) must have entertained views similar to those of Wight. A number of expeditions were undertaken by Kingdon-Ward before and after the Second World War into upper Indo-China, North Burma, southern Tibet and the mountainous regions of North-East India is search of wild tea as well as to test the hypothesis of Wight. He did not succeed in discovering wild tea but the explorations put him in a position to examine critically all available information on the subject in the light of his own experience.

Kingdom-Ward arrived at the conclusion that it would not be possible to know whether the races of tea reached the terminal areas as races (species) or whether they evolved from a single uniform race *in situ*. According to him the Assam type is the most widespread race of tea. He accepted the observations later reported by Wight (1959) and by Barua (1963) that the China race is the most divergent type while the Assam and the Cambodia races are far less unlike in appearance. Taking these factors and the dispersal pattern of the races of tea into consideration, Kingdon-Ward postulated that the primary centre of origin of tea must have been located as far north as the 60th parallel or even within the Arctic Circle. On the other hand, it could have been further south, in the Altai, or somewhere in the Mongolian plateau. During the glacial shakeout, it is possible that the China race came down by the Pacific seaboard along with other elements of the flora while the Assam race took the more direct route from Central Asia to reach the secondary centre near the source of the Irawaddy as shown in Fig. 3.

If this view is correct, then clearly the China type had one origin and the Assam and Cambodia types together, another common origin. From the secondary centre, the Assam race moved south-east to Indo-China and south-west to Assam. The small differences observed between these two races must then be attributed to long geographical isolation under diverse conditions of soil and climate and also perhaps to introgression of characters from allied species of *Camellia*.

All the three races of tea hybridise freely. Through the activities of men, the geographical barriers had broken down in the course of time making it almost impossible now to find any of the races in pure state even in the terminal areas of their dispersion. The only exception could perhaps be the China type, populations of which may still exist in a relatively pure form in the northern provinces of China. In the south of China, the Assam and China races have already intermingled to a considerable extent.

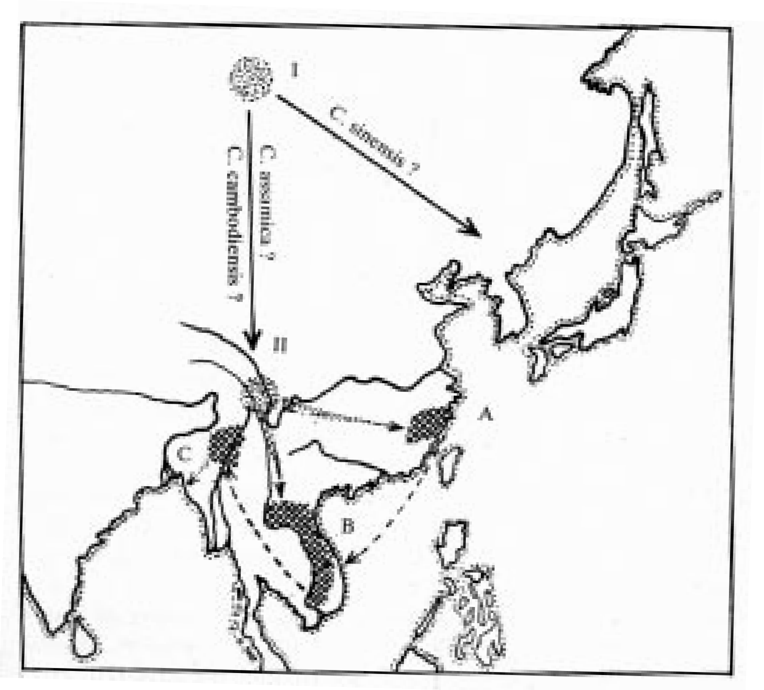

Fig. 3. Map of South-East Asia showing the centres of origin and dispersal of tea I. Primary centre? II. Secondary centre? (A) Area I, (B) Area II, (C) Area III.

The above account will show that the problem of origin of tea has not yet been finally settled. During the last 30 years or so no new fact that can throw more light on the matter has come to light. Under the circumstances Kingdon-Ward's interpretation of the existing evidence appears to be the most plausible until fresh evidence warrants its revision.

TEA CULTIVATION IN THE MAJOR TEA-GROWING COUNTRIES

South-East Asia is the original home of tea and China is the first country to use tea as a beverage. From this region, tea spread to different parts of the world. At present more than 45 countries spread over all the continents except North America, within the latitudinal range of 45°N to 34°S, cultivate tea. Tea is a very important export commodity and source of revenue for some of these countries. The region where tea is cultivated on a large scale is shown in Fig. 4 and their area and production are given in Table 2. A brief account of tea cultivation in the main producing countries is given below:

CHINA

Use of tea as a beverage started in China some 1500 years ago. Its use as a medicinal plant goes back to antiquity, but where the plant was first discovered and cultivated is still uncertain. According to some, tea was first found in the Bohea hills in the province of Fukien while others claim that the plant was found in the Szechwan province.

Tea is grown in the twelve provinces of Central and South China between 23° and 31°N latitudes. A few northern provinces also grow some tea upto 35°N latitude although production in the north is hardly 5 per cent of the total. In the north, temperature in winter occasionally drops below the freezing point and average rainfall is also low, about 1000-1100 mm annually. Only the small leaf bushes of the China type can thrive under these extreme conditions. Climate is somewhat milder in the Yangtze Kiang valley of Central China but still too severe for bushes of the Assam type. On the other hand, South-East China enjoys a mild winter, temperature dropping below 10°C at times and a warm summer, when the maximum rarely rises above 35°C during the warmest months of July-September. This region receives 1700-2000 mm of rain in a year, most of which falls during the months of May to September. Thus a wet, warm summer and a dry, mild winter are the characteristic features of this region; somewhat similar to the conditions prevailing

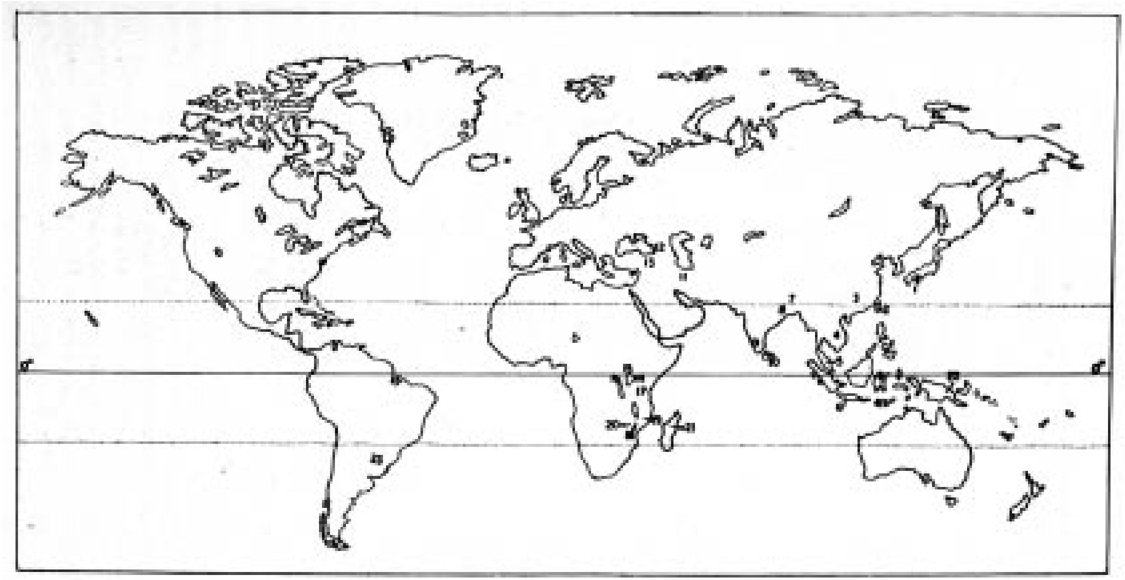

Fig 4. World map indicating the major tea growing regions 1. Japan 2. Taiwan 3. China 4. Vietnam 5. Malaya 6. Indonesia 7. North-East India 8. Bangladesh 9. South India 10. Sri Lanka 11. Iran 12. USSR 13. Turkey 14. Kenya 15. Uganda 16. Rwanda 17. Tanzania 18. Malawi 19. Mozambique 20. Zimbabwe 21. Madagascar 22. New Guinea 23. Argentina.

Table 2. Area and production of tea in different countries during 1982 (After Tea Board, India, 1984)

Country	Area in ha	Production in thousand kg
India	394,866	560,782
Bangladesh	44,472 (a)	40,947
Sri Lanka	242,141	187,816
Indonesia	61,815	73,558
Taiwan	29,300	24,051
Iran	30,200 (e)	23,500
Japan	61,000	98,503
Malaya	2,457 (a)	3,500
Turkey	52,167 (a)	68,038
Vietnam	49,600 (b)	22,000
Burundi	4,790 (a)	2,500
Cameroon	1,083 (b)	2,000
Kenya	81,081	96,033
Malawi	18,515	38,482
Mauritius	3,799	5,354
Mozambique	15,935 (c)	21,000
Rwanda	9,507	7,050
South Africa	5,500	Not available
Tanzania	18,500 (c)	16,230
Uganda	20,095	2,337
Zaire	10,300 (d)	5,500
Zimbabwe	4,989	10,799
U.S.S.R.	78,700	139,800
Argentina	41,450	36,855
Brazil	5,013 (a)	10,000
Peru	4,000 (b)	3,000
Papua New Guinea	3,909 (f)	6,219
China	Not available	397,000
Equador	“	2,600

Note: Production for 12 months but the production year does not begin and end everywhere at the same time.

Figures for (a) 1981 (b) 1980 (c) 1979 (d) 1977 (e) 1976 (f) 1975. In addition to the above, the following countries are also growing tea: Thailand, Ethiopia, St. Helena, Peru, Paraguay, Colombia, Bolivia, Mexico, Fiji, Martinique, Carolina, Australia, New Zealand, Burma, Malaysia, Corsica.

in a large part of North-East India where the Assam type bushes are cultivated on a large scale. Climatic conditions in South-East China are, therefore, favourable for the Assam type bushes and, in fact, Assam hybrids are cultivated in the southern provinces bordering North Burma and the Indo-China peninsula.

Tea cultivation in China is a village industry. Peasants grow tea as one of many crops, generally on steep hill slopes where other crops cannot be grown profitably. The holdings are small, sometimes containing only 100-200 bushes. Cultural practices do not follow any set system as in countries where tea estates are large, self-contained units. In the northern and central provinces, leaf is harvested three to four times in a year. The first picking is done in April before the main rains, second in mid-May to early June and the third in August. About 50 per cent of the crop is made from the first two pickings, about 30 per cent from the third and the balance is made from the fourth picking towards the close of the harvesting season in September-October. In warmer regions of the south, harvesting is done more frequently upto eight times in a year.

Peasants usually initiate the process of manufacture after which it is taken over by *hongs* or factories, which are found almost in every village. The leaf manufactured in these village factories pass through several intermediaries who carry out further processing and grading before sending the product to the home market or for export. The Government has now stepped in to regulate processing and marketing.

Because of small size of the holdings, it is difficult to get accurate estimates of the area under tea and production. Notwithstanding the small holdings, China was the sole supplier of tea to the entire world until the middle of the nineteenth century. In 1855, China exported 90 million kg of tea when Indian production was barely 40,000 kg, production in Java was negligible and Sri Lanka had not planted tea yet. Chinese export rose to 136 million kg by 1888 when Indian production was barely 40 million kilograms. The Chinese share of the tea trade declined gradually as production in India, Sri Lanka and Indonesia increased. By 1930, export fell to 45 million kilograms. Reliable figures for export are not available since the War as these do not include the quantity sent to the U.S.S.R. and Eastern Europe.

Several kinds of tea are produced in China. Of these green tea forms the main bulk and black tea accounts for about-20 per cent of the total production. Brick and Tablet teas, semi-fermented Oolong and Scented teas are the other products. Green tea is produced mainly for home consumption but some of it is exported along with the other kinds of tea. Brick and Tablet teas are not as popular today as they used to be in the early years of the present century.

JAPAN

Tea was introduced into Japan from China by the Buddhist monks in the early part of the eighth century. Then followed a period of inactivity until the Buddhist priest Yeisai reintroduced it and in A.D.119l, wrote the first Japanese treatise on tea. By about the fourteenth century the custom of drinking tea spread to the high society. The current style of drinking green tea was established in Japan about 350 years ago and tea became a popular drink among people in all walks of life.

In 1859, when Government abandoned its policy of isolation and Japan was opened to international trade, tea became one of the most important exportable commodities along with silk. Production of green tea increased rapidly to about 24 million kg in the closing years of the nineteenth century. Till then tea leaf was rolled by hand, a tedious and time-consuming method, which restricted production. With the invention of machines for processing and mechanical shears for harvesting leaf, tea production improved rapidly until the Second World War. Production in 1937 reached 54 million kg of which a little over 18 million kg of green tea and 6 million kg of black tea were exported. After the War; the tea industry was quickly rehabilitated during

1950-55. Area under tea expanded to about 60,000 hectares and production soared to 100 million kg at an average production rate of 2000 kg per hectare, the highest average reached by any country at that time. While green tea was the main product, some black tea was also made but increase in internal consumption and attractive prices realised by green tea in the home market made black tea production unremunerative. Since 1960, production in Japan has been limited to green tea only, which is consumed within the country (Takeo, 1975).

Tea is grown in the two southern islands of Kyushu and Shikoku and in the southern part of the main island Honshu, between 31° and 36°'N latitudes. About 50 per cent of the tea area is located in the Shizuoka prefacture of the main land and 20 per cent in the Kagoshima and Miyazaki prefactures in the Kyushu island just south of the 32°N latitude. Other important areas are Kyoto, Shiga, Nara and Miya prefactures on the southern part of the main island.

The following figures quoted from the National Research Institute of Tea (Takeo, 1975), give an idea of the temperature and rainfall conditions in the main tea growing areas of Japan. The figures are decennial averages for the period 1951-60.

	Mean Max. Temp.^{0}C	Mean Min. Temp.^{0}C	Mean annual rainfall, mm	Wet Days
Shizuoka	20.2	10.2	2612	162
Kagoshima	21.5	13.7	2378	183

Although the rainfall pattern is favourable for the growth of tea, temperature, particularly in the northern tea areas, drops below freezing, occasionally as low as -10°C, during the winter months of December to February. The maximum may rise upto 30°-32°C during the summer months of July-August.

Only the China type bushes, which can withstand such low temperatures, are cultivated in Japan. However, a number of frost tolerant hybrid clones with bigger leaves have been developed and are being increasingly used. Among the twenty odd clones so far approved for planting, Yabukita, possessing a very high level of quality, is the most popular. About 30 per cent of the total tea area has already been brought under clones.

As in China, tea in Japan is a peasant cultivation, the average size of holdings being less than a hectare. Those having more than a hectare of tea generally do not cultivate other crops but those having less, grow other agricultural crops like rice.

Tea grows from March to November and remains dormant for the rest of the year. Leaf is harvested thrice in a year and each harvesting period lasts for about two weeks. In Shizuoka, the first plucking is done between 5 and 20 May, second between 1 and 15 July and the third and the last plucking between 1 and 15 August. In warmer climate of the south, harvesting periods advance by about 15 days.

Green leaf from 30-40 ha of tea, amounting to 20,000 to 30,000 kg per day, is manufactured in co-operative factories owned by the growers. These co-operative societies are members of a co-operative association of a prefacture, which, in turn, are members of a central association located in Tokyo.

The best quality green tea is made from the first crop growing under artificial shade of straw or synthetic fibre nets, which cut out upto 90 per cent of sunlight for about two weeks. This kind of high quality green tea is called Gyokuro. The roasted green tea, known by the name Hozicha, has a brown colour and a characteristic flavour. Sencha is common green tea made from unshaded tea bushes. Roughly 50, 30 and 20 per cent of the tea is made from the first, second and third harvests (Takeo, *loc. cit.*). After every plucking, bushes are skiffed, levelled, mannered and sprayed for the control of diseases and pests. Manuring is very liberal, 600-800 kg nitrogen, 300 kg phosphate and 300 kg potash per hectare is the normal dose.

The main Tea Research Station of Japan is located at Shizuoka. Apart from the main station, a number of prefactural Tea Research Stations exist in Japan. Although the main activities of the prefactural stations are advisory, some research is carried out at these stations on different aspects of tea culture. Some investigations on chemistry and biochemistry of tea are conducted in a few universities of the country.

TAIWAN

The stages of development of the tea industry in Taiwan (Formosa) is, to some extent, linked with its political history. The island belonged to China but following the Sino-Japanese War, it was ceded to Japan in the year 1894. In 1945, the island was restored to China. Commercial propagation of tea began in 1868. As in China, tea is cultivated by peasants in small plots using the type of plant grown in China proper. Formerly the leaf was used for making Green and Oolong teas, of which the latter became particularly famous. The peasants found Oolong flavour to be marked in certain kind of bushes which they propagated by layering to preserve the unique quality.

The Japanese started the manufacture of black tea in Formosa and by 1930, black tea was produced in quantity. The Assam type of plant and machinery for black tea manufacture were introduced about the same time. By 1939, the black tea production rose to about 9 million kg including Pouchong, which is a black scented tea. The production has again picked up after the War. At present tea occupies about 29000 ha with a production of approximately 24.5 million kg in 1980, the major portion of which was exported. The island of Taiwan is approximately 350 km long from north to south and a range of mountains runs down its entire length. The island is situated between 22° and 25°N latitudes, some 150 km away from the eastern coast of the Chinese mainland. Tea is grown on table land and broken foothills on the northern part of the island between the mountain range and the alluvial plains bordering the north-western coast. The elevation of tea areas ranges from 80 m to 300 m above sea level

The tea areas receive about 2400 mm rain in a year, distributed in such a way that at least 50 mm rain occurs even during a comparatively dry month. The mean maximum temperature does not rise above 32°C during the two hottest months of July and August.

Taiwan Tea Experiment Station, Pushin, Yangmei, Tooyuan, looks after the interest of the tea industry.

INDIA

North-East India

An account of the discovery of the tea plant in Assam and the experiments conducted by the government for the cultivation of tea in India has already been given. After successful completion of these experiments, it was decided to invite private enterprise to undertake cultivation of tea. The first private-owned tea company, the Assam Company, was formed in 1839 and the government handed over its tea holdings to the newly formed Company in 1840, with the exception of Chabua, which was sold to a private person. During the first ten years, the Assam Company had to face many difficult problems but it triumphed over the initial difficulties and finally emerged as the first successful tea company of the world. The company declared its initial dividend in 1852. Confidence generated by the performance of the Assam Company attracted others to invest in tea and cultivation spread rapidly throughout the Brahmaputra Valley. Thus, within twenty-five years from the appointment of the Tea Committee by the Governor-General of India, the Indian tea industry was set on a firm footing.

In 1856, tea was discovered in the Khasi and Jaintia hills and in Sylhet. At that time Sylhet was a district of Assam but it became a part of Pakistan since 1947 (now Bangladesh). In the same year, the first tea estate was planted in the Cachar district of Assam in the valley of the river Barak on the south of the Barail mountain range. The *teelas* (hillocks), which are characteristic of the district, were planted next and, in 1875, cultivation began in the *bheels* (swamps) after these were drained.

The hill district of Darjeeling in West Bengal embarked on tea cultivation about the same time. By 1856, tea had been planted at Tukvar and in a few estates on the Kurseong flats as well as on the hill slopes between Kurseong and Darjeeling. After the industry was established as a commercial enterprise in Darjeeling, planting was extended first to Terai and then to the Dooars, which together constitute the narrow strip of land, approximately 300 km in length, at the foot of the Darjeeling and Sikkim Himalayas from the eastern border of Bihar to the river Sankos on the Assam border. Champta was the first tea estate to be opened in Terai in 1862 and planting extended to the Dooars region on the east of the river Teesta during 1874. Darjeeling, Terai and the western part of the Dooars were planted with the China kind of tea but as planting extended eastward, more and more of the Assam plant was used.

So far as tea is concerned, Assam with the valleys of the Brahmaputra on the north and of the Barak on the south, Darjeeling, Terai and the Dooars of West Bengal and the State of Tripura constitute North-East India which, until 1947, also included Sylhet. The figures for area and production given below illustrate the growth of the tea industry in Assam and Bengal.

	Area in thousand ha		Production in million kg	
	Assam	Bengal	Assam	Bengal
1885-89*	85.4	30.2	30.3	8.3
1924*	167.0	73.5	107.5	39.5
1980	200.6	93.5	300.7	133.2

*including Sylhet.

The tea areas of N.E. India lie between 24° and 27°N latitudes and 88°-95°E longitudes. In the district of Darjeeling, tea is planted on hill slopes upto a height of 2000 m above sea level while flat or slightly undulating land at elevations ranging from 20 to 250 m is where tea is cultivated in a major part of the plains of N.E. India. The *teelas* of Cachar are low hillocks, which rarely rise above 150 m while elevation of a few estates at the foot of the Himalayas goes upto 500 metres. Nowhere else in the world such an extensive area of flat land and at such low elevations is utilised for planting tea.

The south-west monsoon causes heavy precipitation throughout this region during the summer months, leading to problems of disposal of the surplus water. On the other hand for about six months of the winter and early spring, bushes suffer from a deficit of water in the soil due to insufficiency of rain. This is the general pattern throughout N.E. India including the hill district of Darjeeling. The total amount of precipitation, however, varies from place to place. For instance Tocklai Experimental Station located in Upper Assam receives, on an average, approximately 2100 mm of rain in a year of which 1800 mm fall during the months of April to September. Average precipitation at Nagrifarm, Darjeeling, is 2400 mm, Terai 2800 mm, Nagrakata in Central Doars 4000 mm and Silguri, Cachar, 3000 mm, with virtually the same pattern of distribution as at Tocklai.

In the plains, the monthly average maximum temperature fluctuates between 28° and 32°C during the main cropping months of April to September, although occasionally it rises upto 36°-37°C. A difference of about 10°C is maintained between maximum and minimum temperatures throughout the year. Even during the coldest months of December and January, the mean maximum temperature does not drop below 22°C while the minimum remains around 10°C, although it may sometimes drop to 7°C or a little lower.

The average elevation of the tea estates in Darjeeling is about 1200 metres. At this elevation the mean maximum temperature in any of the summer months does not exceed 25°C and the average minimum in the months of December and January remains around 8°C with a difference of 5° to 8°C between the maximum and minimum temperatures throughout the year. Snow and frost sometimes occur at elevations of 1500 m and above.

Thus, a wet, hot summer and a dry cool winter are the characteristics of the tea-growing areas of N. India. Tea bushes remain dormant during the dry, cool months of the winter season and no leaf is harvested for three to four months.

Tea is also grown in the state of Tripura adjoining Cachar. The Tropic of Cancer passes through the State and its climate is a little warmer than that of Cachar. However, the tea industry here has remained stagnant both in area and production, but greater attention is now being paid to improve ‘the working of the industry. At present approximately 6000 ha are under tea in Tripura with an annual production of less than 4 million kg of tea.

North India

Success of the experiments conducted by the Government with seeds imported from China encouraged cultivation of tea on a commercial scale in Dehra Doon and Kangra at the foot of the western Himalayas. Planting began with China seed in the forties of the last century and importation of seed from China continued upto 1857. The China bushes flourished in these regions but despite the favourable start, the industry languished for a number of reasons, not the least among, which was the big earthquake of 1905, which caused widespread devastation in this region. Many experienced planters lost their lives and those who survived sold their properties and moved to other areas.

The total area under tea at Dehra Doon and Kangra has remained almost static around 6000 ha and the production a little less than a million kg of green and black tea, roughly in 35:65 ratio. Many of the tea estates in this region are small and are owned by peasant cultivators. Efforts are now under way to revive the industry.

A few tea estates were opened in the Ranchi district of Bihar but the estates have not flourished, as the climate is too hot and dry for tea.

South India

The tea plants sent from the Calcutta Botanical Gardens were reported to be growing luxuriantly in the Nilgiris in 1839 but it was 15 years later that attempt was made to grow tea there on a commercial scale. At about the same time tea was growing well in the Wynaad. That tea could be grown in Travancore was known by 1859. Tea planting on a commercial scale started in the Nilgiris by 1853 but until the end of the last century, little progress was made in the cultivation of tea in South India. In 1893, the area under tea was estimated to be about 1,200 ha in the Nilgiris, 100 ha in the Wynaad; 130 ha in the High Range, Kerala, and 2000 ha in the rest of Travancore. Of the 46,900 ha of tea planted in South India until 1927, at least 42,000 ha was planted after 1893.

Most of the tea of South India is grown in the States of Tamil Nadu and Kerala. The State of Karnataka accounts for about 2.6 per cent of the 75,000 ha of tea currently grown in South India. Many estates in South India raise, besides tea, one or more of other crops like rubber, coffee, cardamom, pepper and cinchona. Coffee and rubber respectively occupy 50 and 70 per cent more area than tea. Cardamom comes next to tea with a planted area of approximately 16,000 hectares. Other plantation crops are grown on a relatively smaller scale. While large estates account for more than 80 per cent of the tea area in South India, a large number of small holdings varying in size from a fraction of a hectare to a few hectares exist alongside the big estates.

The tea areas of South India lie between 8° and 13°N latitudes. Being situated near to the equator and exposed to both the monsoon currents, the climate is very different from that of North-East and North India. Tea is planted on the slopes of the Western Ghat mountain ranges and the adjoining plateaus at an elevation range of about 300 m to 2000 m, although small areas occur above and below this range. Much of the tea in the Nilgiris and the High Range is planted at 1500 m and above. Perhaps the highest grown tea in the world is in the High Range at the foot of the Anaimudi peak (2695 m) at an elevation of approximately 2400 m above sea level. The average elevation of the tea areas of Anamallais is around 1000 m and further south the elevation drops to 300 m or even less.

Rainfall varies widely from 1000 mm to 6000 mm in different tea-growing districts of South India. Wide variations within the same district and from year to year are not uncommon. Most of the tea areas are fed mainly by the south-west monsoon, causing heavy precipitation during the months of June to September. In some years very little rain may be brought by the north-east monsoon. When this happens, the winter becomes very dry and the tea suffers. There are areas and pockets in the Nilgiris and the High Range, which get more rain from the north-east than from the south-west monsoon during the months of October-December.

The average maximum temperature even in the low-grown areas rarely exceeds 30°C in any month and the minimum seldom drops below 12°C in the winter. At elevations of the Nilgiris and the High Range, the maximum does not usually rise above 25°C while the minimum drops to 5°C and occasionally even lower. Under those conditions frost occasionally causes damage to tea.

The China type bushes and their hybrids were initially used in the South Indian plantations but a gradual change over to the Assam hybrids took place over the years, particularly in estates at lower elevations. At present vegetative clones are being used in new plantings. ‘

In South India tea bushes do not remain completely dormant at any time and plucking continues throughout the year. However, the crop harvested in different months of the year does not remain constant and two distinct peaks are observed in the annual crop curve. Only black tea is manufactured in South India.

Tocklai Experimental Station Jorhat, Assam, the oldest research station in the world, devoted exclusively to tea, looks after the problems of culture and manufacture of tea for the growers of N.E. India. The station was established by the Indian Tea Association in the year 1900 and was moved to its present site at Jorhat in Upper Assam during 1911. In 1964, the management of the station was taken over from the Indian Tea Association by Tea Research Association, which is a statutory co-operative research organisation.

The United Planters Association of Southern India owns a research station for tea, which is now located at Cinchona in the Coimbatore district of the State of Tamil Nadu. This station looks after the interest of the tea growers of South India.

Each station maintains a number of sub-stations and advisory centres in different soil-climatic zones.

BANGLADESH

In Bangladesh, tea is grown in the district of Sylhet, which was a part of Assam until partition of the country in 1947. The start of tea cultivation in Sylhet has already been mentioned under N.E. India. The climatic conditions of Sylhet do not differ markedly from those. of the adjoining district of Cachar in Assam. The same type of bushes are grown in both places on flat land at low elevations, usually below 50 metres. Heavy rain is experienced during summer but rainfall is scanty during the months of November to March. Tea bushes remain dormant during the winter season, restricting plucking to about nine months of the year.

In 1979, Bangladesh had a little over 45,000 ha under tea and the production was nearly 40 million kilograms.

Bangladesh has a tea research station located at Srimangal in the Sylhet district.

INDONESIA

The first attempt to grow tea in Indonesia was made in 1728 with seeds imported from Japan but the attempt did not succeed. Nothing further was done until 1826 when seeds and plants were again imported into the island from China and Japan. The second attempt could convince the Netherland government to seriously consider the prospect of growing tea in their island possessions. The Government took over such small areas as were under tea and imported more seed and some workmen from China. However, the tea manufactured in 1833 was reported as unsatisfactory. To improve the product, the Government in 1838 founded an establishment in Batavia (Djakarta) for finishing manufacture of the tea collected from the neighbouring areas. This arrangement also did not help to improve quality of the product, as the tea after initial processing did not reach the finishing establishment sometimes for months which caused serious deterioration of quality. This state of affairs continued for more than two decades during which the Government incurred heavy losses. In 1860, the Government finally abandoned its direct connection with tea and rented its tea areas to private firms and individuals. Many new estates were opened in the Preanger plateau as well as near Djakarta in the western end of the island but low quality of the product and poor yield continued to plague the infant industry.

By this time the tea industry in Assam was established on a firm footing and the Indian planters were making increasing use of seed of the Assam type produced in locally established seed baries. The news of superior performance of the Assam plant must have induced the planters in Java to import in 1878 the first consignment of Assam tea seed. This met with immediate success and proved to be the turning point for the languishing tea industry of Java. The Assam tea plant became so successful that it came to be accepted as the standard type for Java. About this time, machinery replaced hand manufacture, which effected further improvement of the product. By the end of the last century, the tea industry was firmly established in Java. In 1902, an Experimental Station for tea was founded at Buitenzprg, which was taken over by the Government in 1912. A Tea Export Bureau was also formed in 1905 to advise on market requirement. Area under tea expanded rapidly and export of tea jumped from 7.5 million kg in 1901 to 32.5 million kg in 1914.

Planting of tea in Sumatra began in the year 1911 with seeds from Assam, supplemented by a small quantity of seed produced in Java from Assam type of plants and a still smaller quantity imported from Sri Lanka. The first tea estates were planted in the Siantar district on the north-east coast of Sumatra but subsequent planting extended southwards to a few districts.

The Indonesian tea industry suffered severely during the Second World War. In 1941 Indonesia produced nearly 90 million kg of tea from an area of approximately 1,80,000 ha in Java, including peasants holdings of about 75,000 ha and 33,000 ha in Sumatra. Out of this quantity, 83 million kg were exported. This constituted 18.5 per cent of the world export of tea. During the War, thousands of hectares of tea, especially at low elevations, were uprooted and used for the production of food crops. More areas were neglected during the period of political unrest following the War. In 1958, the Indonesian government took over the companies owned by the Dutch and efforts were initiated to rehabilitate the industry. As a result of these measures, the Indonesian tea industry started recovering since the mid sixties although it has not yet regained its pre-war position. In 1979, 96,000 ha was under tea in Indonesia of which 39,000 ha was owned by the Government, 19,000 ha by private companies and 38,000 by ‘productive’ smallholders (Haryono, 1976; Bezbaruah and Barbora, 1979). About 81 per cent of the tea was located in Java and 18 per cent in Sumatra. Production in 1975 was 50 million kg of black tea, of which 40 million kg was exported, and 25 million kg of green tea, which was consumed internally.

The island of Java lies between 5° and 9°S latitudes with its long axis of 950 km along the east-west direction. The breadth of the island varies between 50 and 200 kilometres. Cultivation of tea is chiefly confined to the western end of the island at elevations of 300 m to 1800 m but most of the tea estates are located 1000 m above sea level.

Java as well as Sumatra enjoys a tropical climate, which is tempered by the surrounding sea. Great extremes of temperature do not occur. The difference between winter and summer temperature is indeed very small. The average maximum temperature in Djarkata, situated at an elevation of only a few metres above sea level, is slightly below 27°C while 25° to 26°C is the average minimum. The mean temperatures of different places in Java decrease at the rate of 0.57°C for every 100 m rise of elevation above mean sea level (Hope, 1916). At an elevation of 560 m in the Preangers plateau, where most tea estates are located, the mean air temperature remains close to 22.5°C throughout the year with a variation of about 6.0°C between the maximum day and minimum night temperatures.

The rainfall in the tea districts is high but its even distribution favours the growth of tea and does not cause serious water disposal problems. The average quantity of rain received by different tea estates in a year ranges from 2500 mm to 5000 mm. June to September are relatively drier months in most localities, but there is not a really dry period in the tea districts any time of the year as some precipitation occurs in every month.

The island of Sumatra lies between 6°N and 6°S latitudes with its long axis in the NE-SW direction. The island is three and half times the size of Java but is sparsely populated. While the scope for expansion of tea area in densely populated Java is very limited, expansion is possible in Sumatra and also perhaps in a few other islands of the Indonesian archipelago.

Most tea estates in Sumatra are located in the northern part of the island at elevations of 200 m to 1000 m above sea level where temperature and rainfall conditions approximate closely to many tea estates in Java.

The tea estates in Indonesia are planted with Assam jats. At present vegetatively propagated clones are being used for new clearings and replanting. The clones have been selected locally but a few clones have also been imported from Sri Lanka. Plucking in Indonesia continues throughout the year at 7-8 day intervals with little variation in the weight of crop harvested in different months of the year.

Research activities in the country came practically to a halt during the period 1942-65. A new research institute for tea and cinchona was established in 1973 by a decree of the Government and the institute started functioning from 1974. The institute is located at Gamburg, 35 km south of Bandung.

SRI LANKA

The tea plant was introduced into Sri Lanka as early as in 1837-40 and the plant grew well in the Botanical Gardens at Peradeniya. However, commercial cultivation did not begin until 1869, the year of appearance of the dreaded coffee blight, *Hemileia vastatrix*, in the coffee plantations of Sri Lanka. Until the appearance of the blight, coffee was a flourishing industry in Sri Lanka but the disease completely wiped out coffee within a few years from its first appearance. This was a great blow to the coffee planters and the Government alike and no time was lost in starting the cultivation of tea as an alternative to the ruined coffee industry. Importation of tea seed began in 1869 and continued for many more years. By 1875, approximately 400 ha was planted with tea. Thereafter the expansion of tea area was very rapid-approximately 3,700 ha by 1880, 1,23,400 ha in 1895, 1,50,000 ha in 1900 and 1,62,000 ha in 1920. During 1980, 2,44,715 ha was under tea in Sri Lanka with a production of 191.4 million kg of black tea of which 184.5 million kg was exported (Tea Board, India 1984). Next to India, Sri Lanka is the second biggest exporter of tea in the world today, although for a few years since 1965 export from Sri Lanka exceeded that from India.

The island of Sri Lanka falls between 6° and 9°N latitudes. The tea areas occur mostly around 7°N latitude in the mountainous country on the south-western part of the island. Most of the tea is situated above 900 metres. Tea planted above an altitude of 1200 m is known as ‘high grown’ which constitutes about 40 per cent of the total planted area while little less than 20 per cent is put out in low country below 600 m elevation.

The mean temperature at different locations in Sri Lanka varies but little throughout the year. The mean annual temperature at Ratnapura in the low country is around 26°C, at Kandy (504 m) 24°C, at Nuwara Eliya (1889 m) 19°C and at Badula (673 m) in the Uva district it is 23°C. The maximum and minimum vary somewhat at each location.

The tea areas of Sri Lanka, where the rainfall rarely falls short of 50 mm in any month, do not experience serious drought. The areas like Kandy, Ratnapura and Nuwara Eliya to the west of the central mountain divide receive copious rain from the south-west monsoon from May to September and some rain also from the north-east monsoon. The areas like Uva situated on the east of the central mountain range receive heavy rain from the north-east monsoon during the months of October to January. The total annual rainfall varies from approximately 1800 mm in the relatively dry areas to 6000 mm in the very wet areas.

In the high elevation tea districts of Sri Lanka where frost is experienced, the China plant and its hybrids were cultivated in preference to the Assam *jats.* After the selection of clones suitable for different soil-climatic situations, only vegetatively propagated clonal plants have been used for planting in different areas.

In Sri Lanka, plucking continues throughout the year. March, April, May and November are usually heavy cropping months in the western districts while November, December and January are good months in the eastern districts.

An ordinance for the establishment of a Tea Research Institute in Sri Lanka was passed in 1925. An office was opened in Kandy and a temporary laboratory at Nuwara Eliya in the following year. St. Coombs estate was purchased in 1928 where the laboratories and staff quarters of the Tea Research Institute were constructed. During the last 25 years a number of sub-stations were opened in different soil-climatic zones of Sri Lanka.

U.S.S.R.

Cultivation of tea started in the U.S.S.R. towards the end of the last century with seeds imported from China. By 1905, 400 ha was under tea and the area was gradually increasing until the First World War, when the infant industry suffered a serious set-back. Since 1923, concentrated efforts were made to increase area and production of tea and modernise methods of production. The total planted area was 34,000 ha in 1933, which increased to 72,000 ha by 1972. During 1980, area under tea was nearly 79,000 ha with a production of 130 million kg of tea.

Initially tea was planted on the eastern shore of the Black Sea in the Republic of Georgia. Planting was later extended to the Republic of Azerbaijan and the Russian Republic of Krasnodar. Georgia accounts for 87 per cent of the tea area, Azerbaijan 10.5 per cent and Krasnodar, 2.5 per cent (Dey, 1972). These tea areas, situated between 40° and 45°N latitudes, are at the northernmost limit of commercial tea cultivation. Planting is done on flat terraces and gentle slopes of low hills upto an elevation of 700 m above sea level but two thirds of the tea is located below 300 m elevation (Gokhale, 1958). Planting on steeper slopes of more than 30 per cent is not advocated, to minimise erosion hazards and to facilitate mechanisation.

Because of their location at such high latitudes, the tea areas of the U.S.S.R. experience extremely low temperature during the winter season. The average temperature recorded at the All Union Institute for Tea at Anaseouli, Georgia, is around 4°C during January and February and about 22°C in the warmest months of July and August. In Georgia, the minimum temperature at times drops to —8°C during winter while at Krasnodar and Azerbaijan, a minimum of —12°C is occasionally reached. Frost is of common occurrence and tea bushes remain covered with snow sometimes for 2-4 weeks during a part of the winter season (Gokhale, *loc. cit.*)

The total quantity of rain received annually varies from less than 1000 mm in Azerbaijan to nearly 2500 mm in the western parts of Georgia. Northern and eastern parts of Georgia get relatively less rain than the western parts. The distribution of rainfall in different months of the year is not uniform although some rain falls in every month. There is generally more rain in the autumn and winter while May is the driest month. In certain areas irrigation becomes necessary in the summer because of insufficiency of water in the soil.

Only the China type of tea and its small leaf hybrids can thrive under such low temperature conditions. A number of useful China varieties have been evolved from the material earlier imported from China and Japan. The Assam and Indo-China strains of tea have not met with much success in the U.S.S.R. but these strains have been utilised for the purpose of hybridisation. In recent years, a few clones have also been selected and released for commercial cultivation.

Tea estates in the U.S.S.R. are run either as collective farms or State farms but the green leaf is manufactured in factories owned by the Government. Plucking season lasts for six months from May to October. About 30 per cent of the crop is harvested in May and 2-3 per cent in October. Harvesting is done partly by hand and partly by machine. To make the best use of the raw material, four types of black and green teas are manufactured in U.S.S.R., including brick tea (Dey, *loc. cit.*).

The All Union Institute for Tea and its sub-stations conduct researches on breeding and selection of tea, anti-erosion measures, agro-chemistry and agro-technique of tea and also on extension of tea to the northern regions. The All Union Institute of Tea Industry at Anaseouli deals with the problems of tea manufacture, including development of new technology for tea making. The State Designing Bureau located in Tibiliai, Georgia, looks after researches in field machinery. Fundamental investigations on biochemistry and plant physiology are carried out at the U.S.S.R. Academy of Sciences in Moscow. It may be mentioned that the first self-propelled plucking machine was developed in the U:S.S.R. in the mid fifties. This machine, which can also be adapted for pruning, has since been used in the tea plantations.

TURKEY

Cultivation of tea in Turkey started in the year 1939-40 with seeds, obtained from the U.S.S.R. Planting commenced in Rize contiguous to the Russian border on the Black Sea coast and gradually extended through Trabzon (1950) and Giresun (1956) to Ordu (1959) over a distance of nearly 300 km in that strip of land which lies between the Iranian plateau and the Caspian Sea at 40°-42°N latitudes. Tea is put out on flat land and hill sides upto an elevation of about 500 m above sea level.

As in the U.S.S.R., the tea in Turkey experiences very low temperature. Snow and frost are common during the winter. Rize, situated on the Black Sea coast, receives the maximum rainfall of approximately 2300 mm annually while precipitation gets progressively less as one moves towards Ordu. The distribution of rainfall conforms to the same pattern as in the U.S.S.R. Under these severe conditions, only the China type of bushes can be grown. The plucking season lasts for six months from May to October and the quantity of leaf harvested in different months follows the same pattern as in the U.S.S.R.

The tea holdings are small and the government restricts the maximum size of holdings to 4 ha but the average size of a holding is only 1.25 hectares. In 1980, nearly 54,000 ha was under tea with an output of approximately 96 million kilograms.

There are two research stations for tea, one at Rize and the other at Giresun.

IRAN

Cultivation of tea started in Iran in the late twenties on the strip of territory lying between the southern shore of the Caspian Sea and the Elburz mountains on the north of the Persian plateau, between 36° and 37°N latitudes. About 2000 ha was planted by 1936 (Mann, 1936). The tea areas experience severe cold during winter when tea bushes remain covered with snow for weeks but the weather gets hot and dry between April and July. Rainfall varies from 1200 mm to 1500 mm in a year. Conditions are much too severe for all but the China type of bushes and its small-leaf hybrids. The cropping pattern is similar to those of Turkey and the USSR

In 1980, the total area under tea was 30,200 ha and production was 20 million kilograms.

AFRICA

Malawi

Tea was first put out in the Botanical Gardens at Durban in South Africa during the third quarter of the l9th century but commercial cultivation of the crop started first in Malawi. In 1878, tea was successfully planted near Blantyre on a mission farm. Following this successful attempt, tea seeds were obtained from Kew and Edinburgh Botanical Gardens in 1886 and 1888 and planted in a small area at Lauderdale at the foot of the Mlanje mountain. This was the beginning of the African tea industry. From 1908 onwards tea estates were opened in the

Mlanje district and then in the neighbouring district of Cholo. Expansion continued in the two districts and spread to the northern district of Nkhata Bay in 1960. The first export of about 730 kg of tea in 1945 had grown to about a million kg by 1960 and to 17 million kg by 1967. In 1980, Malawi produced nearly 30 million kg of black tea from an area of 18.3 thousand hectares.

Mlanje and Cholo are situated around 16°S latitude and Nkhata Bay, around 12°S. In the Mlanje district, tea is planted between 700 m and 1000 m elevation while the tea estates of Cholo are located 200 m and 300 m higher. Out of a total annual rainfall of about 1700 mm in Mlanje and 1200 mm in Cholo, more than two thirds occur during the summer months of November to March. Nkhata Bay receives about 2100 mm rain annually with a more favourable distribution than in the other two districts. The winter is cold and from August to November the weather is hot and dry, when tea bushes suffer from low humidity and deficit of water in the soil. The maximum temperature occasionally rises upto 36°C or a little higher during the dry months preceding the rains while the winter minimum drops to 7°C or a little lower.

Early planting was done with China hybrids; Assam types were introduced at a later stage. Seed was produced locally. Now vegetatively propagated clones and seeds from polyclonal stocks are being used for planting.

The tea areas of Ma1awi do not experience complete winter dormancy but the crop harvested drops drastically during the cold and dry months.

Mozambique

The successful cultivation of tea in Malawi induced neighbouring Mozambique to plant tea. Planting began in the early twenties in Milange, a district bordering Mlanje. However, it was soon found that Gurue and Socone districts were more suited to tea than Milange. Most of the tea estates are now located in these latter districts. Tacuane is another district where tea is now grown. Planting of tea expanded very rapidly in Mozambique from 2,800 ha in 1940 to 12,000 ha in 1960. In 1980, nearly 16,000 ha was under tea with a production of 19.5 million kg of black tea.

The tea areas lie between 15° and 17°S latitudes at an altitude of 300 m to 1000 metres. Gurue receives about 2300 mm of rain in a year and its distribution is also more even than in Milange. Tacuane and Socone are even better placed than Gurue both in respect of total rainfall and its distribution. The range of maximum and minimum temperatures and the plucking pattern are nearly the same as in Malawi.

In Mozambique, the scope for expansion of tea cultivation is considered to be very wide.

Zimbabwe

Commercial planting of tea began in Zimbabwe in 1925 in two districts, Chipinga and Inyanga on the Mozambique border. Area under tea is larger in the former than in the latter district.

These tea areas lie between 18° and 20°S latitudes. Planting is done between 800 m and 1100 m elevations. The average maximum temperature during the months of September to March remains around 28°-29°C and the minimum around 15°-16°C. In the winter season, the mean maximum drops to 21°-22°C and the mean minimum to about 10°C and even lower. The temperature conditions are, therefore, favourable for the Assam type of plant. However, rainfall is not adequate to support a healthy stand of tea. The New Year's Gift tea estate in the Chipinga district has irrigation facilities as it receives a meager 650 mm of rain in a year (Harler, 1964).

Zimbabwe produced nearly 10 million kg of tea in 1980 from an area of slightly less than 5000 hectares.

South Africa

Commercial planting of tea was first started in northern Transvaal during 1964. Cultivation was extended to Natal, Zululand and Transkei in 1967. By the end of 1967, 1500 ha was planted out with tea which increased to over 5000 ha by 1980.

These tea areas, situated below 25°S latitude, experience periods of high day temperature, low night temperature and strong winds. Rainfall is marginal which varies from 600 mm to 1500 mm per annum in different regions. In Transvaal, Natal and Zululand, tea is planted above 900 m while 300 m is the average elevation of tea in Transkei.

Uganda

In the year 1900, some tea plants were sent from Kew and Edinburgh Botanical Gardens to the Botanical Gardens in Entebbe. The plants grew successfully to provide the first seed for large-scale trials. In 1909, five mounds (181 kg) of seed of the Dahootea *Jat* was imported from Assam and grown in Government plantations in Kampala. The plants grew well and seeds produced by these plants were used for starting a commercial estate in 1931. Some of the seeds were distributed to a number of places for trial. About this time, the Uganda Government introduced three more Assam *jats*, Dangri Manipuri, Rajghur and Betjan for trial. Dangri Manipuri is a hardy hybrid and Betjan is an Assam jat, which used to be widely cultivated in Assam. Betjan proved to be the most successful jat in Uganda. More land was brought under tea and by 1939, the planted area increased to nearly 1300 hectares. Since then a steady rate of expansion has been maintained. By 1980, nearly 21,000 ha had been planted with tea. The country produced approximately 22 million kg of tea in 1974, but accurate figures for production are not available for the recent years.

Tea is planted in Mengo, Toro, Mityana, Masaka, Ankole, Kigezi and Bunyoro districts. Of these Mengo and Toro carry the maximum tea. All these tea areas are situated on either side of the equator to the north and west of Lake Victoria. The average elevation of the tea estates is approximately 1300 m except in Toro, where the elevation is nearer 1800 metres. The average annual rainfall of the tea areas is around 1500 mm but some rain falls every month. A pronounced period of drought is not experienced although there usually is a deficit of water in the soil during the relatively drier months of June-August and December-February. At an altitude of approximately 2000 m, the maximum temperature remains within 25°C and the minimum around 9°-10°C. The tea bushes here do not pass through a dormant season and plucking continues throughout the year with little fluctuation of the crop from month to month.

Kenya

Commercial cultivation of tea in Kenya is a comparatively recent venture but today she heads the list of the African tea-growing countries both in area and production. In 1980, Kenya produced 76.6 million kg of tea from an area of nearly 80 thousand hectares. Two British companies pioneered tea cultivation in Kenya and it is their success, which attracted other companies and private planters to open up tea estates. Subsequent expansion was very rapid.

On the recommendation of the Commonwealth Development Corporation, a scheme for the assistance of small growers was introduced in 1960 which later, in 1964, was named Kenya Tea Development Authority (KTDA). Assistance given under this scheme has increased the area of tea under small holdings very considerably. It is estimated that small holdings account for approximately 40 per cent of the total tea area in Kenya. Similar small holder schemes are now operating in a few other African countries.

The principal tea-growing districts of Kenya are located in an area lying between Mount Kenya and Lake Victoria on either side of the Rift Valley. Kericho is the main tea-growing district in the west foIlowed by Nandi, Sotik and Kisii around Kericho. Tea planting has expanded to Kitale district north of Nandi. Limuru is the main tea-growing district in the east although some tea has also been planted in Meru and Nyeri near Mount Kenya.

The tea estates are located on either side of the equator. Planting is done at an elevational range of 1600 m to 2250 m, the average elevation of tea in the eastern part being higher than that in the west. The total quantity of rain and its distribution vary somewhat between different tea-growing districts. The Tea Research Station at Kericho receives approximately 1900 mm of rain in a year. The average annual rainfall at Nandi is about 1500 mm, at Sotik it is 1400 mm while at Meru near Mount Kenya only about 1300 mm of rain falls in a year. At Kericho, maximum precipitation occurs in April-May followed by a lesser peak in July-August. December to February are relatively drier months although mean rainfall does not usually fall short of 50 mm in any month (Othieno, 1983). The rainfall pattern is almost the same in the other tea districts of western Kenya. In the eastern districts June-September is usually a dry period.

At the Tea Research Station, Kericho, the monthly average maximum and minimum temperatures are 23.1°C and 9.6°C, respectively with little variation at different times of the year. (Othieno, *loc.cit.*) The crop is evenly distributed from April to November but December to March are comparatively lean months.

Tanzania

Tea was first planted on a small scale in the Usambara mountains during the early twenties of this century. The experiment proved successful. From 1931, planting began on a large scale in Usambara mountains as well as in Mufindi and Rungwe districts in the southern highlands. Later on tea planting was extended to Bukoba district on the western shore of Lake Victoria, approximately 2° south of the equator. The other three tea districts lie between 5° and 8°S latitudes. In 1934, tea occupied about 900 ha which jumped to little over 7,000 ha by 1960 and to 18,500 ha by 1980 with a production of some 17 million kg during that year.

In the Usambara district, tea estates are located at altitudes of 900 m to 1400 m while at Mufindi and Rungwe some tea is grown at an elevation of 2100 m or a little higher. Elevation of the tea areas in Bukoba is around 1200 metres. The pattern of rainfall in Usambara is similar to that of Kenya highlands. In southern Tanzania more than 80 per cent of rain falls between November and May, June-October being the dry period.

The original plantings were with hybrid seed but large-leaf types were used subsequently. Tea bushes remain in plucking throughout the year.

Zaire

The main tea-growing centres are in the mountainous Kivu district of Zaire, west of Lake Kivu. Temperature and rainfall pattern are similar to Uganda and crop is gathered throughout the year. Area and production of tea in 1977 were 10,500 ha and 5 million kg, respectively.

Rwanda

Tea is grown in south-east of Lake Kivu at 1500 m to 2000 m elevations. Climatic condition and cropping pattern do not differ from those in Uganda. In 1979, about 7 million kg of tea was produced from an area of 8.3 thousand hectares.

Burundi is another country in Africa where some 2000 ha tea had been planted by 1974-75. Nearly 4000 ha of tea exist in the island of Mauritius in the Indian Ocean, about 800 km east of Madagascar.

There are two tea research institutes in Africa: The Tea Research Foundation of Kenya with headquarters at Kericho, and the Tea Research Foundation of Central Africa, Mulanje, Malawi.

NEW GUINEA

After experimenting for more than a decade, large-scale planting of tea was started from 1954. At present tea is grown in the flat Wahgi Valley in the western highlands. The mean elevation of the tea areas is approximately 1600 m where the average maximum temperature is around 24°C and the minimum is 13°C, with a variation of some 3°-4°C at different times of the year. The night temperature may fall well below the minimum at certain times. Annual rainfall fluctuates between 1800 mm and 2500 mm and its distribution is fairly even. During 1980, New Guinea produced 8 million kg of tea from an area of nearly 4000 hectares.

AUSTRALIA

Commercial planting of tea has also been started in Australia since 1960 near Innisfail, close to the coast of North-East Queensland. Elevation of the tea area is 160 m approximately. The area receives a rainfall of about 3700 mm annually but most of it falls during the first six months of the year, which makes irrigation a necessity in the dry season. The area and production figures of Australian tea industry are not available.

SOUTH VIETNAM

The native populations of Indo-China, North Burma, Thailand and South China are supposed to have used the leaf of the tea plant growing extensively in these regions, as a vegetable, for chewing and for preparing medicinal drinks. Preparation of a beverage from tea appears to be a later development among these people.

Tea was an important article of trade in Indo-China until the eighteenth century. From the early years of this century, the French tried to organise a tea industry in the country on lines similar to those in India and Java. Growing conditions are favourable for all types of tea. In fact, the Cambodiensis or the Southern form of tea appears to have originated in this region.

Among the countries of South-East Asia, South Vietnam possessed 8000 ha of tea in 1976 with a production of 5 million kilograms. Reliable statistics for the other countries are not available.

MALAYA

Tea was first planted in Malaya during 1935 with seeds from a few well-known Assam jats. However, compared to rubber and oil palm, the area under which had expanded remarkably, tea cultivation has remained virtually stagnant during the last five decades. In 1971, the area under tea was 3035 ha (Dutta, 1972) which has not shown any increase during the last ten years. Most of the tea plantations are located in the Cameron Highlands at an altitude of 900 to 1600 m above sea level, but a few tea estates exist also at lower elevations in the coastal region.

Malaya enjoys a tropical climate, being situated within 6°N of the equator. The annual mean maximum and minimum temperatures in the Highlands are around 29°C and 18°C, respectively, which rise by 3° to 4°C at the lower altitude of Kuala Lumpur. The rainfall is well distributed throughout the year but intensity is Higher during April-May and September-October. The total annual rainfall is of the order of 2400 mm at lower altitudes and 3000 mm in the Cameron Highlands.

The area under tea and production in 1980 were nearly 2500 ha and 4 million kg, respectively.

ARGENTINA

A few small tea plantations existed in Argentina before 1946 but tea-growing was not taken up as a commercial enterprise until 1946-48, when cultivation was started in the northern province of Misiones. This is a long strip of territory bordering Brazil and lying between the rivers Parana and Uruguay. A few tea plantations exist in Corrientes, south of Misiones. From a meagre 1500 ha in 1950-51, the tea area expanded within ten years to 31,000 ha and to 41,000 ha by 1980 (Jones, 1961). From about 1.9 million kg in 1960, tea production increased to 34 million kg in 1980. The first consignment of Argentina tea was sold in the London market during 1958.

The tea areas lie between 26° and 34°S latitudes, this currently being the southernmost limit of tea cultivation. Misiones is a hilly country where tea is planted at an average elevation of 300-400 m while 100-150 m is the average height .of plantations in Corrientes. Very wide diurnal fluctuation of temperature is a characteristic of this region. A difference of 20°-25°C between maximum day and minimum night temperatures is maintained throughout the year. The monthly average maximum temperature during the summer months of December-February varies between 32° and 38°C while 0° to 3°C is the usual average minimum for the winter months of June-August. Even during the winter months, the maximum day temperature rarely falls bellow 25°C. Frosts occasionally occur between May and September.

The distribution of rainfall is irregular and the total varies approximately between 1500 mm and 2000 mm from year to year. The winter is generally wet and cold and summer is hot and dry, broken by intervals of thunderstorms which bring down the temperature and provide some light rain. Growing conditions, though slightly more favourable in the northern province of Misiones than in Corrientes, are not very congenial for tea. The plucking season lasts for six months, from October to April, and the bushes remain dormant during the winter season. According to Jones (*loc. cit.*) a large majority of the bushes is of Indo-China (Cambodia) type, although China type bushes and Assam hybrids are not infrequent.

The tea industry in Argentina is making progress in recent years which is reflected in higher yield and improved quality of the product. The interest of the tea industry is served by a research station at Carvo, Azul.

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CHAPTER 2

THE TEA PLANT OF COMMERCE

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HYBRID ORIGIN OF CULTIVATED TEA

Tea is essentially an out-breeding crop and its three races are highly interfertile. Kingdon-Ward (1950) referred to the existence of hybridity among the cultivated populations of southern China, The tea plant discovered in Assam became the source material for many seed orchards (baries) planted therein since the second half of the last century. The seed trees of these baries were selected as seedlings in nurseries raised with seeds collected from the ‘wild’ sources. Many of these seed trees were evidently of hybrid origin. After their visit to some seed baries, Watt and Mann (1903) remarked that the China tea plant had found its way into Assam long before its deliberate introduction. The tea plants discovered in Cachar and Sylhet (now in Bangladesh) and in the Khasi-Jaintia hills also proved to be of mixed origin. These and similar observations suggest that perhaps because of geographical proximity of the three races of tea and migration of the inhabitants of South-East Asia (who made use of tea in some form) from one region to another, the three races hybridised under natural conditions. It is, therefore, doubtful if any tea plant discovered in Assam or elsewhere since the early years of the last century is genetically pure. Description and nomenclature of the three races of tea given in the previous chapter are based on the terminal plants of each race.

Species Hybrids

The process of hybridisation apparently did not remain confined to the three races of tea; it extended to other related species. One such species is *Camellia irrawadiensis* which was discovered and named at the TES (Barua, 1956). A plant of this species was raised at Tocklai from a sample of seeds collected in North Burma. From examination of the chemical constituents of the specimens collected subsequently in the same locality and of progenies raised by crossing tea with *irrawadiensis*, Wood and Barua (1958) arrived at the conclusion that *C. irrawactiensis* had crossed with tea in its native habitat.

Certain populations known loosely as China and China hybrid were cultivated extensively in the early years of the tea industry in North-East India. A large part of the hill district of Darjeeling is planted with these populations and their remnants can still be seen in some estates in the plains. These progenies are commonly believed to be the resultant of crosses between the Assam and the China races of tea. However, in sclereid types and their distribution as well as in chemical composition, some of these populations appear to be complex hybrids derived from at least four texa *viz*. Assam, China, Southern form and *Camellia irrawadiensis* (Wight and Barua, 1957; Barua and Wight, 1958; Wood and Barua, 1958; Barua and Dutta, 1959). Unusual variation in the floral structures of plants belonging to some of these hybrid populations led Barua (1965) to the inference that they originated in wider crosses involving species of *Camellia* other than the four named above. Plants of all the three races of tea can be crossed easily with a number of *Camellia* species besides *C. irrawadiensis* (Ackerman, 1971; Bezbaruah, l97l; Bezbaruah and Saikia, 1977): The genus *Camellia* as a whole is endemic to South-East Asia. It is, therefore, quite possible that interspecific hybridisation took place when different species of *Camellia* were growing in close proximity in their natural habitats. The uncommon size and colour of flowers borne by some tea plants is also an indication of interspecific hybridisation under natural conditions. Tea flowers are usually white, but plants bearing flowers in all shades of pink are found in the Southern form of tea. Some of these flowers are unusually big, sometimes with twice the diameter of a normal tea flower.

NEED FOR STANDARD SEED

In N.E. India, cultivation of the imported China plant and the indigenous Assam plant side by side extended the scope for hybridisation. There appears to have been a few deliberate attempts at hybridisation by interplanting the two types of tea. Whether intentional or otherwise, the two types crossed and back crossed, giving rise to innumerable hybrid forms. A few of them are arranged in a cline in Plate 2.

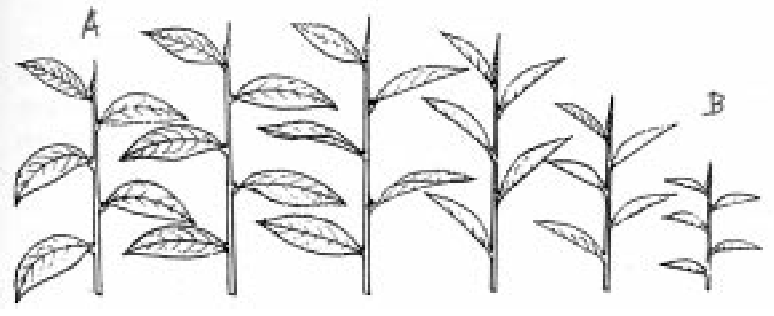

Plate 2. Cline of phenotypes selected from Assam X China crosses and back crosses. The phenotype A at extreme left is typical of *Camellia assamica* and the type B at extreme right resembles *C. sinensis*. From A to B the *sinensis* characters come more and more into prominence.

The hybrid forms have been assigned to the Assam or the China type on subjective judgement based mainly on shape, size and colour of leaf, nature of the bush frame and its size. For instance, the three hybrid forms close to the *assamica* end of the cline shown in the plate will be recognised as Assam while the three near to the *sinensis* end will be regarded as China. The term China hybrid is commonly used to designate hybrids with leaves larger than those of the extreme China type.

The Southern form of tea was not cultivated in Assam but presence of petiole pigmentation in some apparently Assam plants indicates hybridisation between the Assam and the Southern form in the distant past (Wight, 1956). When these hybrids crossed with the China race, elements of the Southern race entered into the *assamica* X *sinensis* hybrid complex.

Controversy on the merit of the indigenous plant of Assam compared to the plant imported from China had been raised till about the third quarter of the last century. Meanwhile, individual and company preferences decided the choice of planting material. Some preferred seeds from the indigenous plant while others opted for China seed. Interplanting of the two races had produced hybrid seeds, because plants of the China race bear large quantities of seed even when they are under plucking. A third group of planters showed preference for the hybrid seeds. Thus, the tea estates of Assam became populated with plants of the apparently Assam and China races of tea as well as with the extremely variable hybrid swarms.

Towards the middle of the last century, there was a strong body of opinion against the use of the China plant in the plains of N.E. India. By that time the Assam plant was getting increasingly popular. Large shoot size, strong liquor, relative ease of processing and higher yield appear to have been the main factors contributing towards the popularity of the Assam plant. Increased use of the Assam plant also revealed its drawbacks. The plant thrived well in some parts of the Brahmaputra valley but not so well in the Surma Valley and North Bengal, where prolonged periods of drought are not infrequent. This realisation as well as the extremely variable nature of the cultivated tea populations prompted a few pioneers to think in terms of standard sources of seed for different soil-climatic regions.

Tea Seed Baries of Assam

The issue was given a practical turn by the German brothers, Amos and Jullian Stiefelhagen, who established a seed bari in the Cachar district of Assam about the sixties of the last century, with seeds specially collected in Burma. Seed bearers were selected from among the seedlings raised from the Burma seeds. The seedlings were assignable to the Assam type but the plants were much more hardy than plants originally found in Assam. The progeny of the new seed bari inherited the characters of hardiness from the parents. and thrived well in the drought-prone districts of Surma Valley where the *jat* was widely used. The bari supplied seeds to regions like North Bengal and South India and some of its seeds were exported to other countries.

Stiefelhagen's example was followed by others and many seed baries sprang up in different parts of Assam. In some of these baries, attempt was made to preserve the characters of the indigenous plant of Assam, while in others effort was made to isolate the seemingly desirable hybrid variants found among the cultivated plants. Seeds collected from the marked sources were planted in nurseries. Potential seed bearers were identified among the nursery seedlings, mainly on the basis of shape, size and colour of leaf, and transplanted away from plucked tea. This way a large number of big and small seed baries were established in the later years of the last and early years of the present century. Although their exact number is not known, yet from records available at Tocklai it appears that more than 50 commercial seed baries existed at the time of the First World War. Keen competition ensued between the producers of seed. Companies and estates solely engaged in the production and marketing of seed were formed and they specialised in the technique of handling and packing seed for transport over long distances. Care was taken to ensure a high percentage of seed germination and the buyers were assured of minimum failure. Seeds produced by about a dozen companies and estates became very popular. These seeds were sold both within and outside India, from Africa to Argentina. It is on record that tea plantations in Java were a failure until the Dutch imported seeds from Assam.

JAT AND AGROTYPE

The seeds produced in a bari is known as a *jat*. *Jat* is an Assamese word meaning caste or pedigree. The *jat* names are derived almost invariably from the names of the places where the seed baries are located. Because of permanency of the source, a *jat* should essentially be a horticultural variety or cultivar. However, the composition of a cultivar remains unchanged over the years, but this has not been the case with the *jats* of tea. In a tea seed bari, the parent seed trees had undergone changes over the years. When a tree died, it was replaced with another seedling, usually of the same *jat*. If a part of a seed bari was destroyed by natural calamities, it was replanted with selected seedlings. The same procedure was followed in extending the seed bari. There had been reports of entire bari being transferred to a new site without any change in the name of the bari or the *jat*. Such acts were perhaps inadvertent and committed without realising their significance, but there were seed producers who actively pursued a policy of replacing seed trees by seedlings of the same *jat*, possessing those morphological characters, which they considered desirable. These activities changed the character of the *jats* and the changes continued throughout the life of the baries. Another feature of importance in this regard is the close phenotypic similarity of a number of *jats* known by different names whereas, according to international convention, the same name should apply to all closely similar *jats*. Under these circumstances a *jat* cannot be equated with a horticultural cultivar.

Due to the hybrid ancestry of the parents, a *jat* is a mixture of phenotypes. However, the range of phenotypic variation is not as wide in some as in other *jats*. Where intensive mass selection narrowed the differences among seed trees in those vegetative characters, which the amateur breeders preferred, the progenies became more uniform. In other words, those vegetative characters bred true to a large extent. For example, continuous selection for large leaf produced unusually big leaf in the progeny.

Yield of plucked shoots and the quality of tea made from the shoots differ between phenotypes within a jat population. In practice, shoots from all bushes in a population are weighed and manufactured in bulk. Thus, the normal process of bulk weighment and manufacture integrates the attributes of individual phenotypes within a population and the integrated values of yield and quality become the yardsticks by which a *jat* is known and judged.

Since botanical or horticultural nomenclature is not applicable for describing *jats* of tea, sporadic attempts were made in the past to categorise *jats* on the basis of such morphological characters of the leaf as shape, size and venation, but these attempts did not meet with much success.

A large number of calcium oxalate crystals are found in different organs of the tea plant. Wight (1958) considered these crystals to be of importance in defining clones and populations of tea. The number of crystals occurring in the phloem parenchyma cells in a transverse section of mature leaf petiole were counted in a few clones drawn from different *jats* as well as in the progenies resulting from crosses between pairs of the same clones. Crystal counts varied significantly between clones and also between progenies. However, the mean number of crystals in the pairs of clones showed a close positive correlation with the mean crystal counts of their progenies.

Encouraged by these results, the mean crystal frequency of many *jat* populations was determined on samples of bushes and the term agrotype was applied to a *jat*. The mean crystal frequency associated with a *jat* was called 'agrotype index'. Wight (1958, 1959) suggested that agrotype index would fix the positions of *jat* populations on a scale with a genetic base.

The usefulness of a numerical index that can fix the position of each *jat*, progeny of clonal crosses and clone in an array of hybrid forms cannot be denied. The point is whether a count of the calcium oxalate crystals in a section of the leaf petiole would serve the purpose of such an index. In a population of tea, the index varies from plant to plant (Wight, 1958) and, to a lesser extent, between different leaves of the same plant as well as between sections cut from the same petiole. A properly devised sampling technique may reduce these variations, provided other cultural and environmental factors do not affect crystal frequency. In practice, crystal count was altered by fertilisers (Wight and Barua,1954; Barua, 1956; Green, 1971). This being the case, it is queried if crystal count could be an index of the genetical constitution of a plant or a population of plants (Visser, 1969).

Vegetatively propagated clones and progenies of clonal crosses are gradually replacing the old *jats* everywhere. Very soon these *jats* will go out of production. However, the *jats* sustained the tea industry in many parts of the world for nearly 100 years. The *jat* populations are now acting as foundation stocks for clonal selection and plant improvement programmes of different countries. The contribution of these *jats* towards improvement of yield and quality have also been quite significant (Wight and Gilchrist, 1961). But for these *jats*, the tea industry in many countries would not have reached the present advanced state of development.

Botanical Composition of *Jats*

Jats are mixtures of phenotypes. The vegetative features distinguishing one phenotype from another within a population are sometimes subtle and sometimes explicit. As mentioned earlier, the phenotypes are assigned either to the Assam or the China race on a subjective judgement based on their vegetative features. The same procedure is followed in respect of whole populations by taking into account the aggregate vegetative features of the constituent phenotypes. The seed *jats* of Assam, with very few exceptions, can be nominally assigned to the Assam race because of their predominantly *assamica* character. The few seed baries producing China hybrid progenies went virtually out of production years ago, as these *jats* fell into disfavour with the growing popularity of the large leaf Assam *jats*.

KINDS OF TEA UNDER CULTIVATION

The foregoing account shows that tea cultivated in different countries are mostly hybrids resulting from *assamica* X *sinensis* crosses, with introgression of characters of the Southern race. Other species like *C. irrawadiensis* close to tea seem to have contributed to the hybrid complex.

In colder climates of Japan, China, U.S.S.R., Iran and Turkey as well as in the high elevation estates of the tropical and sub-tropical belts, where winter frost occurs, the small-leaf China type and its hybrids are cultivated. The Assam kind of tea predominates in all those regions where the climate is not so cold. Besides, big and light-leaf Assam kinds of tea, known as ‘high jat’ in Sri Lanka, are usually more susceptible to damage by drought and heat than the ‘low jat’ hybrids with smaller and darker leaves. Only the latter type of bushes are preferred for planting in areas prone to prolonged spells of dry weather.

Regional Kinds of Tea

Climatic constraints limited the choice of planting material for different regions but this constraint is responsible for some unexpected effects. Climate acting in conjunction with the kind of plant adapted to a region has evolved a few well-known brands of tea noted for their special characteristics. For example, ‘Darjeeling tea’ is made from China and China hybrid bushes. The Assam kind of plant grown under Darjeeling conditions do not produce the characteristic flavour of Darjeeling teas (TES Ann. Rep.,1957). Representative Darjeeling plants brought to Assam do not make Assam tea as it is known in the trade. Similarly, flavoury Darjeeling clones when transferred to the plains lost their capacity for producing flavour. The Chinery bushes under high elevation conditions of Sri Lanka produce tea with an aroma distinct from the aroma of Darjeeling tea. The 2000 series of popular vegetative clones of Sri Lanka were developed from a handful of seeds collected from a seed tree at Tocklai (Richards, 1965). Besides high yield, these clones produce teas with an acceptable level of quality by Sri Lanka standard. However, teas made from these clones or progenies of the same seed tree, have not been found acceptable by Assam standard. The Assam kind of plant grown in East Africa produces brighter teas than elsewhere. These examples should suffice to show that the type of plant material and climate, acting together, have produced brands of tea well-known in the trade. Variation of soil types may also have been involved in this process.

According to Wight and Gilchrist (1961) a certain kind of odour and a certain balance of quality and strength define a kind of tea. The strength: quality ratio is low in China and high in the Assam *jats*. Decisive odour appears to have come as a result of hybridity between the races of tea and other allied species (Barua and Dutta, 1959; Wight and Gilchrist, *loc. cit.*)

Development of regional characteristics in the teas from Darjeeling, Assam, Sri Lanka etc. was not the result of conscious efforts by the growers. These characteristics evolved in the course of time through chance combinations of plant and environment. The tea trade encourages preservation of these characteristics, because the consumer is accustomed to these brands and their mixtures (blends). To satisfy the trade, the producers also have been trying to preserve and improve their regional brands of tea, by manipulating cultural and manufacturing practices. While this has been necessary from economic considerations, strict adherence to the traditional kinds of tea is bound to limit the scope of plant breeders and designers of new processing machinery. The tea trade is capable of absorbing changes in the product. Support given by the trade to the CTC (Cutting, Tearing and Curling) system of manufacture since the early fifties of this century vindicates its capacity for adjustment. Times are changing fast and more and more people are buying packet teas. It is a matter of time before good samples of soluble tea appear in the market. Under these circumstances, it is necessary in the long-term interest of the tea industry that the plant breeders are not inhibited from evolving plant types different from the traditional and the machinery designers from producing non-conventional processing machinery.

LONGEVITY OF TEA POPULATIONS

It is usual for deaths to occur continuously in a plant population. In a newly planted section of tea, dead plants are replaced within a year or two. After that the section should not show appreciable number of vacancies for many years unless environmental conditions and cultural treatments become very unfavourable. Even under favourable conditions, bushes continue to die, primarily due to competition for space. Competition becomes intense as the bushes increase in size. Those bushes which are least adapted to the particular soil-climatic conditions die first. Adaptability varies from *jat* to *jat*. In general, populations assignable to the China type can adapt to a wider range of soil-climatic conditions than those of the Assam type. In a study at Tocklai on 54 *jats* of tea (Barua, 1971), maximum vacancy was observed in the Assam *jats* than in the hybrid populations after 50 years from planting. The relative value of a *jat* in respect of surviving bushes is, however, modified considerably by the conditions under which the bushes are cultivated (Wight and Gokhale, 1955). For instance, inadequate nutrition as exemplified by deficiency of potash in the soils of Sri Lanka and South India caused debility and death of bushes. Potash manuring rectified the situation.

It has been the practice in the tea industry to replace dead and dying bushes by new seedlings known variously as supplies or infills. Infilling is costly and special care is required to bring the infills to maturity in the face of competition from the mature neighbouring bushes. Beyond a certain point, infilling becomes uneconomic and uprooting and replanting become necessary. Life of a section, therefore, implies the economic duration of the section from its planting to uprooting. The life is prolonged in proportion to the success of the infills but infilling alone cannot ensure economic viability of a section indefinitely. Besides, other considerations discussed below determine the economic age of a section of tea. It is to be noted that the age of bushes at the time of uprooting a section of tea is very variable. Some of the bushes are as old as the section itself while infills differ widely in age.

NEED FOR REPLANTATION

Economic considerations alone determine the age at which a section of tea is to be uprooted and replanted unless natural mishaps cause death of a large number of bushes making its continuance unremunerative. The considerations that determine the age of uprooting will differ from region to region and also between estates in the same region. There are sections of the tea in N.E. India which have either not been infilled at all or infilled unsuccessfully which, after 50-60 years, contain about one half of their full complement of bushes. Some of these sections are still regarded as satisfactory, presumably because the cash return per hectare remains an economic proposition. On the other hand, sections yielding much above the regional average have been uprooted and replanted.

Replanting became customary in N.E. India, particularly in the Brahmaputra Valley of Assam, since the early years of the present century. In other old tea-growing countries replanting had not been a regular practice. It is to be noted that N.E. India was first planted with the imported China race of tea and their hybrids. The seed baries established with selected plants produced better progenies or *jats* of tea, which made distinctive teas now associated with the name of Assam. The tea trade preferred these teas and came to expect from this region teas with such distinctive characters. As a result teas made from the old populations began to suffer in price. The growers saw the economic advantage of the new *jats* and started a programme of replacing old tea with the new *jats*, although many of the old sections were giving reasonable yields. In other words, better *jats* forced the growers to discard the poor *jats*. The time limit at which a section must be replaced with more remunerative bushes to make it viable will, therefore, be a better definition of the life of a section of tea.

The current phase of planting activity noticeable throughout the tea-growing world is a logical consequence of the selection of vegetative clones and clonal seed varieties possessing superior cup characters and high yield potential. In an industry as competitive as tea, it will be in the interest of the growers to make use of the improved planting material after properly testing them under field conditions.

Introduction of improved varieties has brought vast improvement in other crops. In annual and short duration crops, impact of varietal improvement is felt within a very short time, but not so in perennial, long-duration crops like tea or coffee. It is neither possible nor desirable to uproot at a time large part of a tea estate for replanting with better clones or seed progenies. Apart from heavy loss of crop and revenue, uprooting and replanting of large areas of an estate with the material currently available will limit the use of better planting materials as and when they are developed, due to non-availability of land. Unlike short duration crops, practical considerations preclude uprooting and replanting of a section of tea at frequent intervals.

Alternative is to plan replanting programme in such a way that a certain fraction of an estate is uprooted every year for replanting with improved material. However, the area to be uprooted depends on many factors. Soil and climate of the place, yield and quality of the existing tea, the material that will be available for replanting and the state of economy of the estate-all these have to be taken into account. In N.E. India, where replanting has been an accepted practice for decades, the recommended replanting rate for the estates in the plains is 2.5 per cent per annum. This recommendation is based on the premise that the Assam type of tea cultivated there has an economic life-span of 40-50 years. In practice, the average replanting rate for the region as a whole has not reached the 2.5 per cent target (TES Ann. Rep.,1967-68). Although there cannot be any hard and fast rule regarding the area to be uprooted and replanted every year yet setting up of a target, which naturally will vary with local conditions, has its own merit. It is a constant reminder of the need to replant.

The problem of unremunerative sections of old tea is not so acute till now in countries which started planting tea within the last 40-50 years as in those countries where the crop has been in cultivation for a century or more. It is a question of time before the problem becomes serious even in the countries taking up tea cultivation in more recent times. Therefore, all countries embarking on tea cultivation should try to profit from the experience of the older regions and introduce programmes of uprooting and replanting as regular features of estate management.

Logically, systematic replanting should be started when an estate, as a whole, has attained half its potential life. But, as already stated, age cannot be the only consideration for uprooting a section of tea. Despite its age, a section might be too valuable to uproot. Uprooting for the sake of fulfilling a target is also meaningless unless superior material is available for replacing the old tea. These are matters of serious consideration by proprietors of tea estates and by Governments, whose duty it will be to define the future policy. Crop economists will then be in a position to work out the economics under different situations.

So far extension of tea areas has not been discussed for the simple reason that it is very doubtful whether many countries can afford to spare more land for tea cultivation when the demand for the production of larger quantities of food and other essential commodities is mounting everywhere. In the older tea-growing countries like India, Sri Lanka, Java and Japan, the scope for expansion of tea cultivation is extremely limited. In fact, land originally earmarked for tea has now been diverted to other uses, at least in some countries. In countries where scope for expansion still exists, the policy should be to utilise the new areas in a phased manner for growing improved varieties of tea, partly for expansion and partly as replacements of the old, uneconomic stands of the existing tea.

A good clone or seed variety cannot be a substitute for poor soil and soil which is prone to suffer from drought, high water table, flooding etc. This fact is sometimes obscured by the enthusiasm for bringing new areas under tea. Tea planted in poor and problematic soil can never be expected to thrive long and produce the level of yield expected of a modern plantation. Such land could be best utilised for raising other crops or forest trees to augment the finances of tea estates.

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CHAPTER 3

GROWTH CHARACTERISTICS OF THE TEA PLANT

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PERIODICITY OF TOP GROWTH

Freely growing tea shoots pass through alternating states of growth and dormancy. The amount of growth made between two states of dormancy is known as a flush. In N.E. India, upto four flushes were recorded on unpruned seed trees in a growing season and upto five flushes on pruned bushes, although the fifth flush was rare and found only in a few genotypes (TES Ann. Rep., 1935). Bond (1942) observed upto four flushes in tea bushes of Sri Lanka.

The apex of an elongating tea shoot, commonly known as the bud, is tightly wrapped in a foliage leaf which is not different from any of the expanded leaf except that it is not unwrapped. Therefore, growing apex will be a more appropriate term for the bud but to align with the common parlance, the term bud is retained. Leaves unfold from the bud one after another. Unfolding of the ultimate leaf of a flush discloses a small bud known as the banjhi (sterile) bud which is much smaller than a growing bud (Fig. 5).

A banjhi bud is enclosed generally by two, occasionally by more than two, cataphylls or bud scales known in N.E. India as 'janam' (birth scale). The banjhi bud does not show any visible sign of growth and may remain in that condition for the rest of the season. If, however, it is going to produce a new flush, then the meristem at the shoot apex, the apical meristem, becomes active and lays down initials of new janams and leaves inside the banjhi bud. With the increase in the size of these initials, the bud swells up and after reaching a critical size, starts throwing out janams and foliage leaves of the next flush.

Fig. 5. A, Growing and B, Banjhi (dormant) tea shoots. **a,** Growing and **b,** Banjhi bud

The first visible sign of growth of a new flush is the unfolding the outermost janam wrapping the bud; this is followed by the other janams. These janams drop off almost immediately, leaving behind scars or traces on the stem, separated by very short internodes. Another appendage intermediate in form between a janam and a fully separated leaf usually appears between the janam at the base of a flush and the first normal leaf. Several transitionsal forms of this appendage can be recognized depending upon its affinity to a normal leaf. In the absence of any marked affinity to a foliage leaf, this appendage becomes deficient in chloryphll, possesses a feebly developed venation and is cast off like a janam. With a more pronounced affinity to a normal leaf, the appendage is of rich green colour with a more prominent venation and is often partially serrated and persistent like a foliage leaf. Such appendages are known as 'fish leaf' or '*gol pat'* (round leaf) (Fig. 6).

Fig. 6. A developing tea shoot with a, *janams* (Cataphylls) **b,** Fish leaf and **c**, Foliage leaves.

After unfolding of the fish leaf, foliage leaves unfold one after another until the banjhi bud is exposed. The whole process is repeated in due course to produce the next flush of growth.

A banjhi bud may not be formed between flushes on every shoot on a tea bush. In some vigorously growing shoots, particularly in the central zone of a bush, janams or scars of fallen janams are not observed and the stems, at first sight, appear to bear a succession of normal leaves. However, if the size relation between the leaves and the internodes is examined on such 'aperiodic' shoots after full expansion of the leaves, it is seen that the leaves are smaller and internodes shorter in a zone of the stem which is homologous with the dormant zone on less vigorous shoots that have produced a succession of banjhi buds. Goodchild (1986) observed that the time intervals or phyllochrons between the expansion of successive leaves on the so called a periodic shoots clearly formed recurring patterns. He concludes from his observations that these shoots are not truly aperiodic.

The cause of flushing and dormancy in tea was investigated by Bond (1942; 1945) in Sri Lanka. He observed that the initials of leaves and janams, not less than five in number, were preformed in a bud before it broke for a new flush. The number of initials dropped to less than three in a dormant bud just after its exposure. Secondly, the vascular area below the bud was less in an elongating shoot than in a dormant shoot. These observations imply that the growth of vascular tissues below the bud cannot keep pace with the rapid elongation of a flushing shoot. The consequent reduction in the area of the vascular tissue causes a 'bottleneck' and the apical meristem does not receive adequate supply of water and nutrients to lay down initials of new appendages in replacement of the unfolded janams and leaves, the initials of which were formed in the previous state of dormancy of the bud. Thus, after unfolding the full complement of preformed appendages, the bud comes to a state of apparent rest while the vascular area below it continues to increase in size. After sometime, when the vascular area has enlarged sufficiently, the bud starts getting the required quantum of water and nutrients, new initials are formed and, in due course, it starts unfolding janams and foliage leaves of the next flush. So the process continues. Supporting evidence for this is found in the observation that water content of the stem below a dormant terminal bud is less than that under a bud before it starts flushing (TES Ann. Rep., 1932). Barua and Das (1979) working in N.E. India on a large array of clones, counted initials of 3.25 ± 0.02 appendages in a banjhi bud soon after its exposure and 6.17 ± 0.09 appendages in a bud at the commencement of flushing. They also showed that the 'bottleneck' in the supply of water and nutrients to the growing bud, caused by the slow developments of the xylem, started about two internodes below and not immediately below the growing bud.

The area of the xylem tissue in the stem of a growing shoot increased eightfold between the apex and the base of a flush. The corresponding increase of phloem area was only 50 per cent, although it occupied twice the area of the xylem 5 mm below the growing bud. These results indicate that the apical bud does not suffer from a restricted supply of metabolites at any stage in the growth of a shoot and hence phloem transport cannot be a factor influencing periodicity of shoot growth.

Lengths of the flushing and dormant periods as well as the interval between unfolding of successive leaves and janams (leaf periods) vary significantly between clones, although none of these factors could be retated to yield of plucked shoots. The clones that produced more appendages in a flush generally took longer time to complete the flush. No correlation was observed between number of appendages in a flush and the length of the dormant period, although such a correlation could be expected since initials of all appendages of a flush are preformed in the bud during the period of its dormancy. Its absence suggests that some clones take longer time to lay down new initials in the dormant phase than others. The suggestion that the rate of development of the xylem below the bud is slower in these sluggish clones (Das, 1977) was confirmed by subsequent experiments (TES Ann. Rep., 1978-79). A strong negative correlation (—0.95) exists between length of the dormant period and growth rate of the xylem tissue.

Mention has already been made of vigorous shoots placed centrally on a bush which continue to unfold leaves without forming banjhi buds between flushes. In vigorous sections of commercial tea, the incidence of banjhi shoots is less than in weaker sections. Thus, it appears that limitations imposed by reduction of the vascular tissue area below the growing bud could be overcome, at least to a certain extent, by providing the bushes with congenial conditions for growth and ample supply of water and nutrients. Shoots formed in the central zone of a bush are more favourably placed for growth as they are in the direct line of flow of the sap.

Periodicity of Flush Shoot Growth

Shoots harvested from plucked bushes are produced by axillary buds with the exception of the tippings i.e. tips of stems arising from the pruned bush frame. Shoots are usually harvested at two to three leaf stage before they get the chance of completing a flush. However, some shoots become banjhi after producing one, two or three leaves. Adverse growing conditions increase their number but even under conditions favourable for growth, banjhi shoots are formed on a plucked bush. To study the pattern of banjhi formation on plucked bushes, Wight and Barua (1955) developed the concept of 'dormancy index', based on the knowledge that the size of a growing bud diminishes as it approaches the state of dormancy. The dormancy index is a measure of the length of the terminal bud in relation to the length of the topmost leaf. In practice, the number of plucked shoots are divided into two lots; those in which the terminal bud is less than half the length of the topmost leaf and those where it is more than half. The number of the former divided by the latter gives the dormancy index. A high ratio indicates that the buds are nearer to a state of dormancy while a low ratio indicates the reverse.

From observations made on contiguous plots of plucked and unplucked mature bushes of the same *jat*, they showed that the morphological conditions in the buds of the two sets of bushes proceeded simultaneously in the same direction (r=0.84), even though the magnitude of the index was reduced in the one set of bushes due to repeated regeneration under the influence of plucking. They concluded from these observations that reduction in the vascular tissue below a growing bud leading to bottleneck in the supply of water and nutrients to the bud could be the immediate cause of dormancy, but a remote cause must exist to influence the bushes under plucking to exhibit a pattern of growth in sympathy with that existing in the permanent leaders on separate unplucked plants. It was postulated that condition of the buds was caused by factors inherent in the proximal parts of the plant, which remained, behind when the shoots were plucked away. In this context, attention was drawn to the periodicity of feeder root growth in tea (Barua and Dutta, 1961). This could be indicative of periodic rise and fall in the uptake of water and nutrients by the plant, which may well be linked with the periodicity of shoot growth.

Hormonal Regulation of Growth Periodicity

Evidence from subsequent studies indicate that besides water and nutrients, other factors provided by the roots are responsible for influencing shoot growth. From the results of grafting experiments in which shoots having active and banjhi terminal buds were grafted on six month old nursery plants in the state of growth or dormancy, Kulasegaram (1969 a, b) in Sri Lanka concluded that the roots of tea plants having actively growing terminal buds supplied the top with a stimulus which caused early growth of dormant buds.

Like shoots, roots of the tea plant also grow in phases, but out of step with the growth phases of the top (Barua, 1969b). It is probable that synthesis of the growth factors takes place in the roots when they grow actively and shoots remain dormant. When sufficient concentration of these substances is built up in the roots, they move up to the dormant shoots to promote a new flush of growth. Meanwhile the roots get depleted of these, substances on account of which their supply to the top is interrupted and the shoots become dormant. With the cessation of top growth, more metabolites are diverted to the roots to induce a new flush of root growth and the whole sequence is repeated. The validity of this hypothesis could be put to a test by simultaneous analysis of the root and shoot synthesized growth factors (cytpkinins and gibberellins) in the shoot arid root of the tea plant during phases of growth and dormancy.

Evidence from other sources clearly demonstrates the importance of root factors in regulating the growth of the top. Wareing (1969) thought that root factors might even regulate the overall photosynthetic rates of plants. The necessity of taking a closer look at the root system of tea for a clearer understanding of the phenomenon of growth periodicity is clearly indicated.

FLOWERING HABIT

Barua (1970) investigated the flowering and fruiting of seed trees under conditions of N.E. India. His observations show that on a bush that is pruned but not plucked, some shoots may cease growth after making only one flush but a few may make upto four leafy flushes. In seed trees, which are not pruned, the number of leafy flushes is always less than those on pruned bushes.

The maximum number of shoots on a seed tree produce only one leafy flush during an annual cycle of growth. Barua found an average of 50, 27, 19 and 3 per cent of the shoots making respectively one, two, three and four flushes on seed trees although the percentage varied considerably from tree to tree. Environmental and cultural conditions besides genetic constitution and age affect the number of flushes on shoots of seed trees. Although a shoot remains apparently dormant after making one or two leafy flushes, its terminal bud may continue to be active for varying lengths of time and produce one or two cataphyllary flushes in the later part of the year. Some shoots also produce a third cataphyllary flush during January and February, before the onset of spring growth. The cataphyllary flushes are extremely dwarf, so that shoots terminated by cataphyllary flushes look like dormant shoots. Closer examination can only reveal the presence of the dwarf flushes. The cataphyllary flushes; like leafy flushes, are demarcated by barren scars of shed cataphylls or by leafy appendages resembling a fish leaf. However, a cataphyllary flush is not followed by a leafy flush, although the terminal bud of the same shoot may produce a leafy flush when growth commences in the spring of the following year.

Shoots on mature seed trees usually produce cataphyllary flushes after making one to four leafy flushes although considerable variation is observed between trees in the number and frequency of cataphyllary flushes. In general, younger trees exhibit less tendency to produce cataphyllary flushes than older trees.

Flower buds in tea are produced in the axils of cataphylls. Flowers which appear to be produced in the axil of a leaf actually arise from the axils of cataphylls of the axillary bud subtended by the leaf (Fig. 7). Normally flowers are solitary in the axils of cataphylls of the axillary bud. The axillary bud itself may or may not develop into a leafy lateral shoot (Fig. 8).

At the beginning of a new cycle of growth, flower buds are not seen in the axils of leaves of the first flush, Rudimentary flower buds in the leaf axils of this or any subsequent flush become visible when the terminal bud resumes growth of the next higher flush (Fig. 9), irrespective of whether the flush is leafy or cataphyllary. If the apical bud remains completely dormant after a flush, then no flower is produced in the leaf axils of this ultimate flush although the flowers on the penultimate and lower flushes may develop to reach the stage of anthesis (Fig. 10).

The flushes on axillary shoots, whether leafy or cataphyllary, are synchronous with the flushing of the apical bud. A maximum of two floriferous, dwarf cataphyllary flushes may develop on an axillary shoot.

Each of the cataphylls at the base of a leafy shoot usually carries a single flower bud in its axil. These flower buds become visible as soon as the cataphylls unfold from the growing apex. Flower buds in the axils of cataphylls of axillary buds of the last flush also become visible at the same time. Occasionally some cataphyll axils remain barren without forming any flower (Fig. 11).

If the appendages above the basal cataphylls of a leafy flush is more like a cataphyll than a fish leaf, then a flower appears in its axil simultaneously with the flowers of the cataphylls below. If it is a fish leaf, then flower buds appear

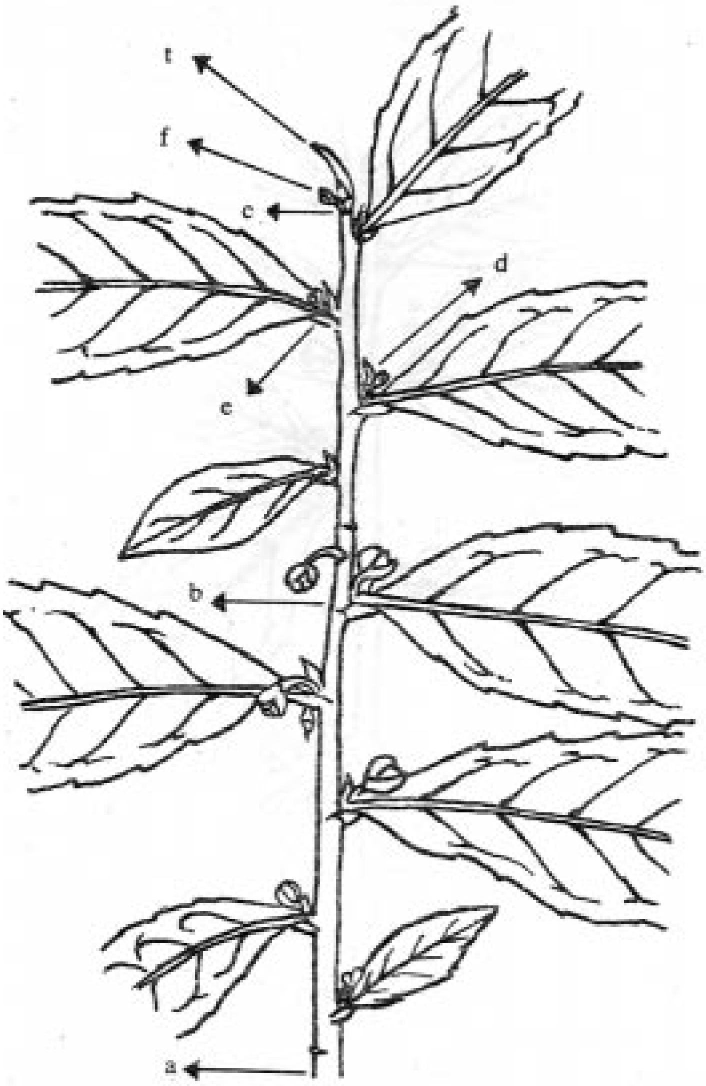

Fig 7. A two flush shoot. **a-b,** first flush; **b-c** second flush. Terminal bud **t** is coming away. Coincident with this flower **f** in its *janam* axil and **d** and **e** in the leaf axils of the last flush become visible.

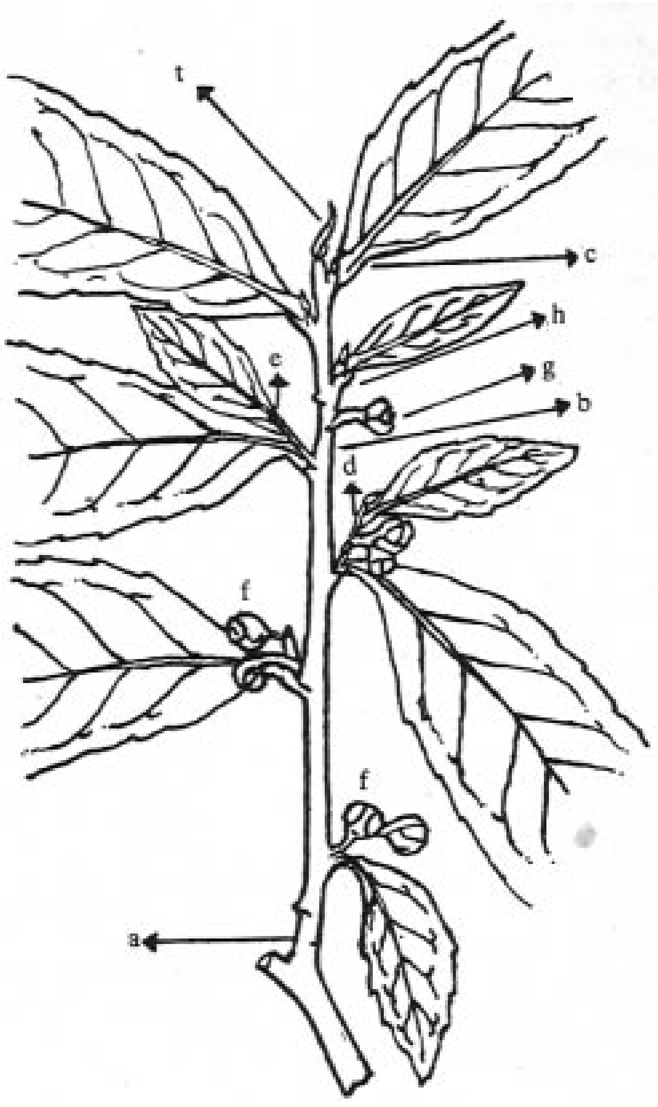

Fig 8. A two flush shoot. **a-b** first flush; **b-c** second flush. Terminal bud **t** in bhanji condition. **g-h** scars of the fallen *janams*; **d, e**, leafy laterals; **f**, floriferous lateral.

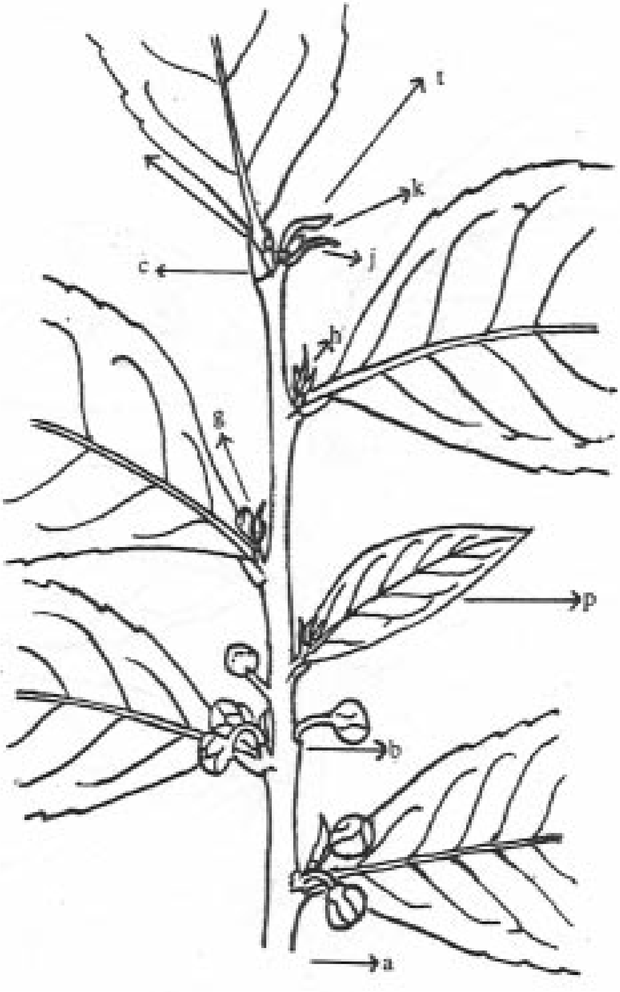

Fig. 9. A two-flush shoot **a-b**, part of the first flush and **b-c** second flush. Terminal bud **t** is just breaking for a new flush. Flower bud **k** is visible with the unfolding of the *janam* **j** Coincident with this, flower buds appear at the cataphyll axils of the dwarf axillary shoots, **g-h** of the last flush. Flower bud in the axil of the fish leaf **p** is appearing at the same time as the flowers on the other leaves on the same flush **b-c.**

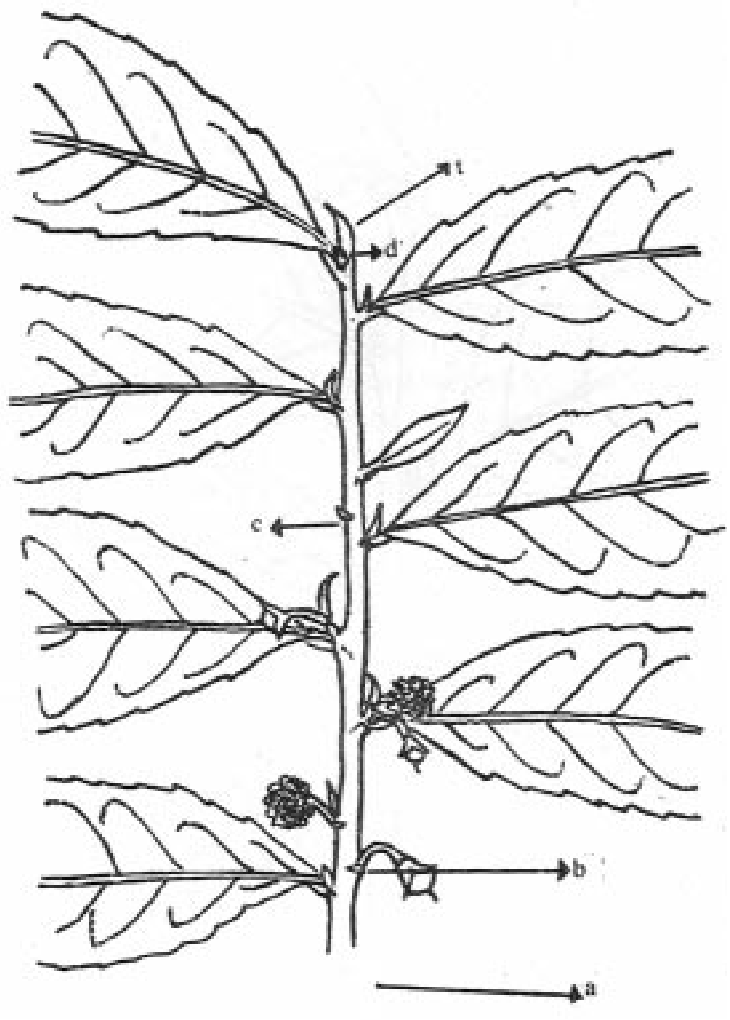

Fig. 10. A three flush shoot. **a-b,** part of the first flush; **b-c,** second flush; **c-d** third flush. Terminal bud **t** in banjhi state . flowers absent on the top flush, **c-d** but flower buds in the lower flushes **a-b** and **b-c** already opened.

in its axil only after the apical bud starts growth for the next flush, as in the case of foilage leaves.

The flowers in the axils of cataphyllary flushes, whether the flushes are terminal or axillary, appear along with the unfolding of the catphylls. Hence a floriferous catpahyllary flush looks like a cluster of flowers, baecuse the catphyllary flush is only a few milimeters in length (Fig. 11).

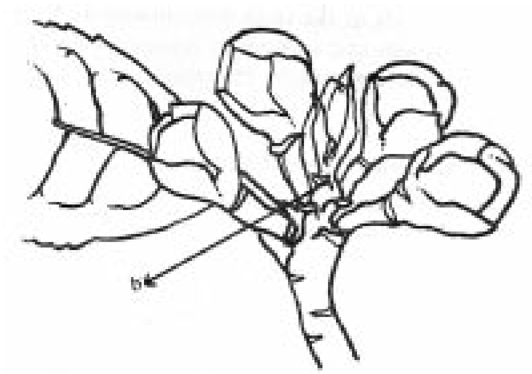

Fig. 11. Cluster flowers. Barren scar **b** seperates the two flushes of flowers.

Fig. 12. A vertical section through an open tea flower. Stemens, carpel and the ovary.

All the flowers formed during a flush come into bloom at the same time. Flowers formed on the first flush when the shoot was growing for the second flush open towards the later part of development of the third flush. Similarly flowers formed during the second flush open towards the end of the fourth flush and so on. The flowers formed in a terminal cataphyllary flush and in the cataphyll axils at the base of a leafy flush open simultaneously with the anthesis of flowers in the leaf axils of the flush immediately below. Thus the initiation, development and anthesis of flowers occur in an orderly sequence which is determined by the phasic growth of the apical bud.

Abscission of Leaves on Unplucked Bushes

Only two consecutive flushes below the terminal bud of a freely growing tea shoot possess leaves. Addition of a new flush causes abscission of leaves from the lowermost of the two flushes, irrespective of whether the new flush is leafy or cataphyllary (Barua, 1970). Thus, the leaves on the first flush of a shoot drop when the terminal bud grows for the third leafy or cataphyllary flush and this order of leaf abscission continues for the remaining flushes. For this reason a shoot becomes completely leafless when two cataphyllary flushes are produced on top of the leafy flushes. A shoot with one or two flushes does not lose any of its leaves if the terminal bud remains completely dormant for the rest of the season. The leaves of the bottom flush of a two flush shoot drop only when it starts growth in the following spring. Depending on the activity of the terminal bud, leaves of any particular flush on different shoots may or may not, therefore, absciss at a particular time of the year. This means that the life span of leaves on freely-growing shoots of tea is independent of chronological time but is determined by the activity of the growing apices.

Although a large majority of shoots on seed trees do not form more than two leafy flushes, most shoots produce cataphyllary flushes until the following spring. Production of cataphyllary flushes causes abscission of the remaining leaves on many shoots. This gives the false impression that the seed trees lose most of their leaves during late winter while, in fact, the shoots on the trees have simply responded to the activity of the growing apices in the normal sequence as explained above.

Abscission of Leaves on Plucked Bushes

In tea bushes under plucking, shoots arising from the pruned bush frame are broken back (tipped) above a certain height and the branches and sub-branches of the tipped shoots are harvested (plucked) repeatedly at a tender age for the manufacture of tea. Decapitation of the shoot apices by tipping and plucking releases the lower portions of the shoots from apical dominance. Absence of apical activity prevents abscission of leaves and stimulates growth of axillary buds. The tipped shoots can retain their leaves for a maximum of 18 months (TES Ann. Rep., 1970-71).

ROOT GROWTH

The youngest roots of the tea plant are white. As they get older the colour of the root changes to cream and finally to reddish-brown, due to suberisation of the endodermis and primary cortex. The primary cortex shrivels and peels off in patches, exposing the reddish-brown bark.

Root hairs are very scanty and poorly developed in tea. The young roots, however, are associated with vesicular-arbuscular (VA) endotrophic mycorrhizas (Tanstall, 1926; 1930). (Fig. 13). Mycorrhizal mycelia are found in the cells of the primary cortex throughout the white and cream portions of the roots; except in the root tip. The mycelia disintegrate as the primary cortex ceases to function.

This fungal symbiont is a member of the primitive family *Endogoneceae*. The fungi associated with tea roots have recently been identified as belonging to the genera *Glomus*, *Gaigospora* and *Acaulospora* (TES Ann. Rep., 1981-82). It is now accepted that both ectotrophic and endotrophic mycorrhizas play a significant role in the nutrition, particularly phosphate nutrition, of a large number of plant species (Harley, 1969), of which many are economically important. The mycorrhizal plant species either do not have root hairs or their occurrence is very scarce (Lamont, 1982) as is the case with tea. In the nutrition of the tea plant, the mycorrhizas obviously must play some important role although this aspect has so far received very scant attention. In preliminary investigations, the author obtained clear indication of increased phosphate uptake by mycorrhizal than by non-mycorrhizal tea roots. For better understanding of nutrition of the tea plant, the mycorrhizas need closer study.

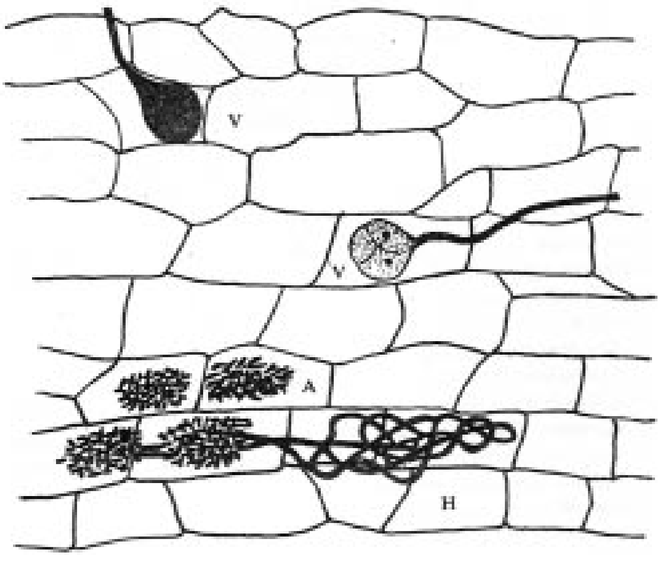

Fig. 13. Camera lucida drawing showing the occurrence of endotrophic mycorrhiza in the cortical cells of white tea root. V vesicles; A arbuscules; H fungal hyphae.

The fibrous roots of tea are thin 0.3 to 3.0 mm in diameter and much branded. Upto four orders of branching have been observed in some of these roots. The white and cream portions of the fibrous roots were designated ‘feeding roots’ and the red portions as ‘extension roots’ (Barua and Dutta, 1961) the terms being used originally by Rogers (1939). Subsequent studies have confirmed that the capacity for absorption of water and nutrients is maximum in the white roots below the root cap. The absorbing capacity diminishes gradually as the root ages and the colour changes from white through cream to red. The red portions have very little capacity for absorption (Chamua, 1975).

The white roots grow in phases similar to those of the shoots (Harada *et al.*, 1957; Barua, 1969b). In young plants grown in root observation boxes, the growth phases of the roots alternated with phases of shoot growth (Barua, *loc. cit.* ; Das, 1977). In young plants, Fordham (1972) observed maximum shoot growth to alternate with minimal root growth and in mature plants root growth was reduced during periods of active shoot growth. Periodicity of root growth was observed also in mature bushes under field conditions. Red roots too exhibited periodic growth, but the growth periods of red roots were opposite in direction to those of white roots i.e. decrement in the length of white roots coincided with increments in the length of red roots (Barua and Dutta, *loc.cit.*).

Reduction in the length of red roots can be ascribed to decay. In closely spaced fields of perennial tea, the fibrous root would, after a time, completely saturate the soil, at least in the zone of maximum root growth. Hence decay must be a regular feature of the fibrous roots to make room for new growth. Rogers (1939) compared the life of rootlets with that of leaves. Once their absorbing function is over most rootlets cease to grow and rot away. On this analogy the fibrous roots of tea can be supposed to remain in a state of dynamic equilibrium, regeneration compensating decay.

The tap root of the tea plant raised from seed diminishes in importance as the plant gets older. Tubbs (1946) concluded from his observations that the value of the tap root was unduly exaggerated. According to Thomas (1944) there is little development of the tap root of tea in Uganda and Sri Lanka. In N.E. India the tap root does not develop to any great extent. In seed-grown bushes, usually a few thick roots develop from the base of the stem and branch off in different directions. The branches of these roots often penetrate to greater depths than the tap root. In Japan, the slender roots of five-year old plants were observed to penetrate to a depth of 90-105 cm in the space between hedge rows while the tap root reached a depth of 45-60 cm only, directly under the collar (Aono *et al.*, 1979).

The adventitious roots of vegetatively propagated cuttings grow at an angle from the vertical. The angle varies from clone to clone. It may be very narrow in some and very wide, almost horizontal, in other clones.

Depth and Spread of Root

Depth of the fibrous root system of tea had been the subject of study in Sri Lanka, East and Central Africa, U.S.S.R., N.E. India and Japan (Eden, 1940; Thomas, 1944; Voroncov, 1956; Barua and Dutta, 1961; Kerfoot, 1962; Fordham, 1972; Aono *et al.*, 1979). These investigations have many points of agreement, notably that the quantity of fibrous roots decreases with depth and that about two thirds of the feeding roots are confined to the top 30 to 40 cm of soil.

Depth of the thicker roots depends largely on local conditions as influenced by physical and chemical properties of the soil, presence of an impervious zone, rainfall and its distribution, depth of the permanent water table etc. Root depth of more than 5 m has been reported from Central Africa (Fordham, 1972) and upto 4-5 m from Tanzania (Carr, 1971). Presence of a high water table restricts root depth in the plains of N.E. India where roots of plucked bushes seldom penetrate beyond a depth of 2.0 metres.

One or two roots reaching down to a great depth does not, however, indicate the efficiency of a root system. The capacity of these deep roots to supply the water and nutrient requirements of the plant would have to be very limited because of their small absorbing surface. On these considerations, the parameter of 'effective depth' has been added to the study of tea root systems (TES Ann. Rep., 1963). Almost the entire volume of root occurs within the effective depth. The mean length of all roots going bellow the effective depth including the one reaching the maximum depth is expressed as the 'average depth'. Effective depth appears to be a more useful concept than average or maximum depth but its determination depends to a certain extent upon the subjective judgement of the investigator. While these parameters assist comparative evaluation of root systems, for proper assessment of the biological efficiency of roots, a knowledge of either the surface area or the length or the weight of the absorbing roots at different depths becomes necessary. Since the thin and succulent roots can hardly make any difference to the total weight of the entire root system, the latter may sometimes be misleading.

There is, however, a close relation between the growth of the top and the roots of any plant although environmental conditions can modify the top: root ratio, Aono *et al*. (*loc. cit.*) in Japan observed a close correlation between the weights of top and roots of tea bushes. In N.E. India the top: root ratio deviated but little from the mean value of 2 among a large number of mature field-grown seed and clonal bushes (Barua, 1966). In contrast, Othieno (1982) in Kenya reported large variations in the shoot: root ratios of different clones. This is not unexpected since partition of dry matter between different organs of the plant, as will be shown later, varies from clone to clone.

The top: root ratio has a direct bearing on planting density. Tea is planted much closer today than in the past. With increase in the number of plants per unit area of ground, the size of the above ground part of every bush becomes smaller. To maintain parity with the top, the size and weight of the root system diminish with increasing plant density (TES Ann. Rep., 1977-78). This aspect of high density planting needs careful consideration, particularly in areas susceptible to water stress.

The spread of the root is always more than that of the top but in a field of closely planted tea, the difference decreases with age of the bush population. This is inevitable since only a restricted area is allotted for the development of each bush. Increase in bush population per unit area causes proportionate reduction in top and root spread.

Effect of Pruning

Pruning of mature seed trees reduced feeder root growth and the effect was seen within a fortnight (Barua, 1969 b). Temporary cessation of root growth following pruning of plucked bushes has also been reported (Fordham, 1972; Esartiya, 1972). Reduction of root growth following pruning is presumably due to mobilisation of metabolites for the growth of new shoots.

Ghosh (1969) compared the depth and spread of roots of 25-30 year old unpruned seed trees and comparable bushes under plucking in flat land with a very high water table and in teela (small hillock, 50 to 100 m high) slopes of Cachar in Assam. A summary of his observations is reproduced in Table 3.

Table 3. Depth and spread of root in cm

Soil type		Depth	Spread	
Flat	Plucked bush	38	250	Waterlogged
Flat	Seed tree	42	630	Waterlogged
Teela	Plucked bush	157	168	Not waterlogged
Teela	Seed tree	256	530	Not waterlogged

Pruned and plucked bushes had smaller root systems than the unpruned seed trees. The striking feature is the extremely shallow roots of both plucked bushes and seed trees on waterlogged flats and their much greater spread, presumably to compensate for the lack of depth. Seed trees have deeper and more spreading roots than the plucked bushes. But even on a high teela, the roots of seed trees did not grow beyond a depth of 2.5 metres. In such situations where a high water table or an impervious pan is not a problem, it seems heavy precipitation keeps the lower profile of certain soils in a saturated condition for a large part of the year. This impedes aeration restricting root growth to the surface layers of soil where air is more freely available. Lack of proper drainage aggravates the problem, which reflects in reduced top growth and yield.

Root Depth of Seed-grown and Vegetatively Propagated Plants

The depth of the root systems of plants raised from seeds and vegetatively propagated cuttings has been debated in many tea forums. The opinion that plants raised from cuttings possess a shallower root system, which make them unsuited for growing in areas susceptible to drought has often been voiced. Initially seedlings possess a deeper root system than plants raised from cuttings but how long the initial advantage persists, depends mainly on the clones selected for commercial planting. In view of the large-scale use of vegetatively propagated clones in commercial estates throughout the world, the few observations comparing the root systems of mature clones and seed populations deserve special mention.

In an experiment at the TES, cuttings were taken from a random number of seedlings of an one year old nursery and propagated vegetatively. Seeds from the same source were planted in another nursery at the same time. The seedlings and the vegetatively propagated plants were transplanted after one year into repeat plots in the same area at 130 cm spacing. The two groups of bushes were brought into bearing in the usual way and treated alike. After 21 years, a number of plants of each group were excavated for observing the root systems. These observations are presented in Table 4 (TES Ann. Rep., 1963).

The seed-grown plants possessed a significantly deeper root system than plants raised by vegetative propagation. There was no difference in the spread of roots between the two groups of plants. The point to note here is that cuttings were originally taken from a random assortment of seedlings and not from any plant proven for vigour and rooting ability.

In another experiment, 12 year old plucked bushes of three biclonal seed progenies and five selected clones growing in adjacent plots were excavated for root observation. Data for only two seed populations and three clones, presented in Table 5, show that clones vary in the depth of their root systems; so do the seed progenies. Between the seed progenies and clones, there is hardly any difference in the depth of roots. In fact, some clones may have deeper root systems than deep-rooting seed populations under the same sets of cultural treatments and environmental conditions. (TES Ann. Rep., 1963).

Table 4. Average length in cm and weight in g per plant

	Seed grown	Vegetatively propagated
No. of bushes sampled	32	29
Radius of plucking surface	71	68
Radius of root spread	99	104
Maximum root depth	134	91 **
Average root depth	102	77 **
Effective root depth	68	57 *
Dry weight of top	5313	4540
Dry weight of root	2621	2271
Top : root ratio	2:04 ± 0.10	2.01 ± 0.08

** ,* : Significant at 0.1 and 1.0 per cent levels, respectively.

These results warrant the conclusion that the depth of root systems of clones selected with proper care will not be less than that of phenotypically similar seed progenies if the growing conditions do not differ. Initially the tap roots of seedlings may explore greater depth of soil than roots produced by vegetatively propagated cuttings of the selected clones, but the advantage does not persist for long.

WINTER DORMANCY

Tea cultivated near the equator produces almost the same yield every month, but farther from the equator winter harvest gradually declines and at latitudes beyond about 16°, there is almost complete winter dormancy. The length of the dormant period increases progressively with increasing distance from the equator (Table 6). Monthly crop distributions of a few tea growing areas are shown in Fig.14.

Table 5. Length in cm and weight in g

In Malawi (16 degrees South) yield drops drastically during winter but complete dormancy is not expierenced.

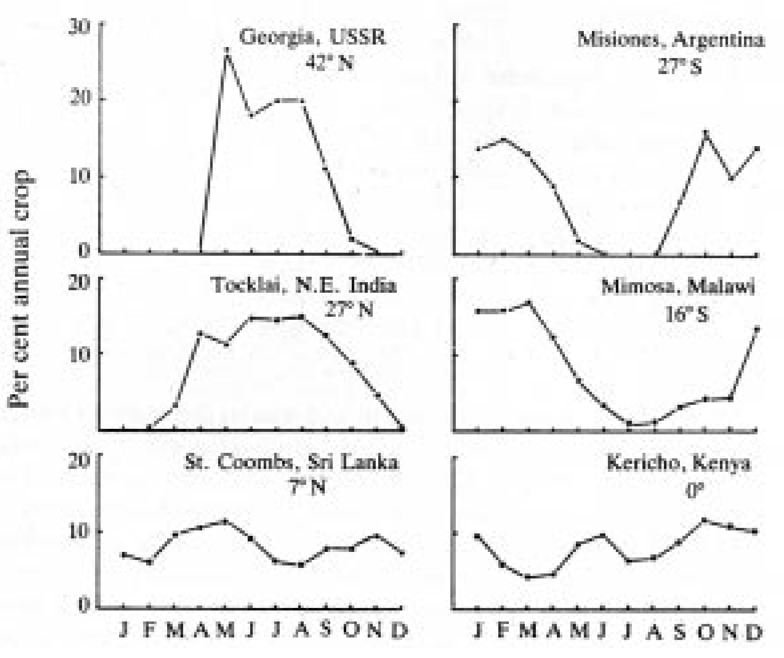

Fig. 14. Monthly average crop distribution at different latitudes.

The phenomenon of winter dormancy is independent of the periodicity of shoot growth and it cannot be explained in terms of Bond's 'bottleneck' hypothesis. Winter dormancy is usually followed by a very heavy cropping summer. Adequate provision of labour and machinery is required to gather and manufacture the crop on peak summer days. The machinery remains idle during winter and is underutilised in the lean months preceding and succeeding the period of winter dormancy. Over capitalisation becomes necessary which places the tea areas experiencing winter dormancy at a disadvantage compared to those where it does not occur.

Table 6. Mean latitude and approximate period of winter dormancy in a few tea-growing regions.

Region	Mean latitude	Months of winter dormancy
Georgia, U.S.S.R.	42°N	6
Turkey	41°N	6
Iran	37°N	5-6
North-East India	26°N	3-4
South India	11°N	0
Sri Lanka	6°N	0
Kenya	0	0
Indonesia	5°S	0
New Guinea	6°S	0
Malawi	16°S	0
Mauritius	20°S	2-3
Argentina	30°S	3-4

Effort, if any, made in the past to understand the cause of winter dormancy was very limited although its adverse effect on estate economy was obvious. Only in recent years the problem has become a subject of serious study in some tea research institutions.

In the past it was generally believed that low temperature was responsible for winter dormancy at higher latitudes. However, temperatures prevailing in certain tea-growing areas suggest that low temperature cannot be its sole cause as can be seen from Table 7.

Table 7. Monthly mean range of maximum and minimum temperatures

	Maximum °C	Minimum °C
Tocklai (Assam), winter	22-26	10-16
Darjeeling, summer	23-25	15-19
Kericho (Kenya), whole year	19-25	8-9

Table 7 shows that the range of maximum and minimum temperatures at Tocklai (26°47′ N) during the winter season is nearly as high as the summer temperature of Darjeeling and higher than the temperatures at Kericho throughout the year.

Soil-water stress and nutrition can also be ruled out as major causes of dormancy because even with ample supply of water and nutrients, tea bushes failed to flush at Tocklai during the winter months (TES Ann. Rep., 1966).

Monthly crop distributions and average day lengths in the tea-growing regions from the equator to 42°N and 34°S latitudes indicate that tea bushes pass through a period of complete dormancy when the winter day is shorter than a critical length of about 11 hr 15 min for at least six weeks. The longer the period of short days, longer is the dormancy (Laycock, 1969).

By exposing irrigated tea bushes at Tocklai to 13 hr photoperiod during the winter season, Barua and Barua (1969) obtained hastening of bud break and drastic reduction of flowering. Shoots developing to harvestable size with a minimum of two leaves during the months of December to February were few but the subsequent harvests during April and May indicated extensive bud break in the preceding months on bushes kept under long-day treatment. In Malawi (16°S), 13 hr photoperiod during winter caused a small but significant increase in yields over 11 hr day length (Fordham, 1970; Herd and Squire, 1976). The rate of shoot extension also increased when day length was raised from 11 to 13 hours. Shoot extension under 13 hr day and 20°C night temperature was as rapid as in the wet, hot summer while at 10°C, the extension rate was markedly reduced. However, even at this low night temperature, 13 hr day had a small but positive effect over 11 hour (Tanton, 1982). These observations clearly show that the tea plant is sensitive to photoperiods.

Photoperiodic induction and termination of vegetative bud dormancy is widespread among woody species (Wareing, 1951; 1954; Doorenbos, 1953), including *Camellia japonica*, a species closely related to tea (Lockhart and Bonner, 1957). Among species showing photoperiodic sensitivity, no exception has been observed to the general rule that dormancy is hastened by short days and delayed by long days (Wareing, 1956). Winter dormancy at high latitudes shows that the tea plant is not an exception to this general rule.

It is now a well-established fact that long and short days regulate plant growth by altering the levels of the endogenous growth regulators (Wareing, 1956; Nitsch, 1957). Among the plant growth regulators, the gibberellins have shown a wide range of activity on various aspects of growth of almost any plant organ (Paleg, 1965). Following their discovery by Miller and his co-workers, the cytokinins have also been tried extensively, particularly as agents for cell multiplication (1955). Barua (1969 a) and Barua and Barua (1969) injected gibberellic acid (GA_3) and kinetin (K) singly and in combination into young, irrigated clonal tea plants during the winter season in Upper Assam when all plants were dormant. GA_3 induced early bud break and growth while kinetin had no effect. In fact, it reduced the effect of GA_3. Indolyl-3-acetic acid (IAA) also had no effect on the dormant plants. The GA_3 treated plants completed a flush of growth before the untreated, control plants started growth for the first flush. Other workers (Torii and Nakagawa, 1960; Ahmed *et al*. 1965; Nakayama 1980) had also reported enhancement of shoot growth following treatment of tea plants with GA_3. Kulasegaram (1969 a) in Sri Lanka found GA_3, K and adenine to be effective in breaking dormancy of tea but, as in N.E. India, IAA was found ineffective. In this study, treatments were applied to banjhi buds (resting buds) at the end of a flush and not to dormant winter buds since winter dormancy does not occur at the latitude of Sri Lanka. It appears from these findings that buds in a state of induced dormancy respond to the kinins whereas GA_3 affects all types of dormant buds.

Considering the effects of daylength and GA_3, Barua (1969 a) suggested winter dormancy of tea to be a matter of short daylength (or long nightlength) acting through the internal plant growth regulators. Short days alter the balance of endogenous growth regulators in favour of dormancy and long days in favour of growth.

To test this hypothesis Das (1977), by using his mustard hypocotyl assay technique, estimated the growth promoting and growth retarding activities in the acidic growth substances extracted from banjhi and growing buds of tea at different times of the year. Growth promoting and growth inhibiting activities were observed in the extracts of both types of bud but growth promotion was higher in the extracts of growing than in the extracts of banjhi buds. However, the maximum growth retardation was not caused by the extracts of dormant buds of the winter season. When the extracts of growing and banjhi buds were separated by paper chromatography and the growth promoting and growth retarding activities at different Rf bands were estimated by bioassay, it was observed that in the extracts of growing buds, the ratio of growth promotion to growth retardation increased gradually reaching a maximum in summer and then started falling with the approach of the cold weather. Although no such clear-cut pattern was discernible in the extracts of the banjhi bud, the data for the two types of bud when pooled, gave a still better picture than observed in the growing buds. The ratio rose to a peak in July-August and dropped gradually to a minimum in the winter. These results which follow the cropping pattern of tea in the latitude of N.E. India are in accord with the hypothesis advanced by Barua.

Kulasegaram (*1oc. cit.*) estimated the levels of endogenous gibberellins in growing and banjhi shoots of tea consisting of the apical bud and two leaves, using the lettuce hypocotyl assay technique. No marked difference in the gibberellin level could be observed in the two types of shoots although growth inhibition was somewhat more in the acidic and neutral fractions of the extract of the banjhi shoots. The lack of a clear-cut difference between the two types of shoots may be due to the dilution of the gibberellin contents of the buds by the leaf tissues which were many times heavier than the buds, and secondly to the fact that the banjhi buds were not in the state of physiological dormancy but that their dormancy was induced.

The tea areas of Malawi are situated around the borderline latitude of 16°S where the winter daylengtlh does not remain below the critical level for a sufficiently long time to induce complete dormancy of the buds as happens at still higher latitudes. Harvesting in Malawi continues throughout the winter although the weight of crop harvested in a winter month is very small, about 3 to 5 per cent of a peak summer month. The harvested crop consists of both growing and banjhi shoots and the proportion of the latter does not change appreciably at any time during the year (Dale, 1971; Tanton, 1982). Shoot size also remain virtually constant throughout the year (Herd and Squire, 1976), while at higher latitudes shoots become progressively smaller towards the end of the growing season (Barua, 196I). These are clear indications that tea in Malawi does not enter the 'main rest' phase of winter dormancy but passes through the 'early rest' phase when the buds retain their capacity for growth. Before the buds reach the main rest phase, conditions in the environment improve and they directly pass over to the 'after rest' or post dormancy phase (Vegis, 1964). This would explain the increased rate of shoot extension under winter conditions in Malawi when the night temperature was raised from 10° to 20°C (Tanton 1982).

Once the buds enter into the main rest phase of winter dormancy, it is difficult to induce growth immediately by manipulating the environmental conditions (Wareing, 1956; Vegis, 1964). This has proved true in the case of tea. In recent growth room experiments at Tocklai, exposure of clonal plants to a constant temperature of 28° ± 2°C from early November to March failed to induce growth of the buds during the mid-winter months of December and January but advanced bud break by about a month, compared to plants grown in the open. A combination of high day (30° ± 0.5°C) and low night (20° ± 0.5°C) temperatures had the same effect (TES Ann. Rep., 1982-83). Exposure to a 13 hr photoperiod from November to March also failed to release buds from mid-winter dormancy but bud break was advanced as in the high temperature treatment. Barua's (1969a) data also show that longer daylength did not prevent winter dormancy but advanced bud break. In view of many reports that even continuous illumination fails to prevent winter dormancy of a number of woody species (Wareing, 1956), the behaviour of the tea plant cannot be considered unusual. It remains to be seen whether formation of winter buds in tea could be arrested by exposing plants to long days well ahead of the dormant season and continuing the long-day treatment throughout the winter.

Gibberellic acid on the other hand stimulated growth of dormant buds at any time during the winter season at Tocklai (Das, 1977). Growth starts within 10 to 15 days of GA_3 application. However, the action of GA_3 does not persist and varies from clone to clone (Das, *loc. cit.*; Rustogi, 1980). A clue to this variation is provided by the bioassay results of Das. Growth promotion of mustard hypocotyl by the extracts from different Rf bands varied between clones and also within a clone at different times of the year. Variation in the formation of other gibberellins or gibberellin like substances between clones and at different stages of growth is indicated. A combination of GA_3 and GA_{4+7} is reported to have induced more growth in certain clones (TES Ann. Rep., 1979-80) than GA_3 alone. Only one Rf band of all clones and at different times of the year displayed growth retarding activity. The substance retained at this Rf band has been tentatively identified as abscisic acid (ABA) (TES Ann. Rep., 1981-82).

The foregoing account will show that the problem of winter dormancy in tea has not yet been fully resolved. Daylength and low temperature apparently interact in inducing dormancy but their respective roles have not been clearly elucidated. Tea plants in the tropical belt not subjected to short days or long nights are observed to continue flushing at temperatures low enough to cause complete stoppage of growth under short photoperiods (cf. Table 7). Whether this is an expression of low temperature adaptation under constant daylength is not known.

The bioassay results indicate the presence of a number of gibberellins or gibberellin-like substances in tea, the proportions of which vary from clone to clone and from season to season. These growth regulating substances need identification and the growth retardant, tentatively identified as abscisic acid, needs confirmation. Only then it may be possible to advance some meaningful explanation of the erratic responses obtained from GA_3 application. An understanding of the differential response of clones to GA_3 is likely to provide a clearer insight into the problem of winter dormancy in tea.

Many tea research institutions have tried GA_3 for increasing the growth of both young and mature plants. Success has been highly variable. The results obtained by Rahman (1971) can be cited as an example of success, although this is not the only instance of successful application of GA_3. He sprayed 25 to 100 ppm GA_3 at monthly intervals on mature bushes of a clone throughout the year. The treatment produced early bud-break and about 50 per cent increase of early season crop harvested till the end of June. Monthly sprays from October to April covering the period of winter dormancy was as effective as spraying throughout the year. This shows that GA_3 spraying was ineffective when the plants were growing actively, presumably because such plants do not suffer from its deficit. However, response to GA_3 has not been consistent from year to year on the same clone.

From .the point of tea growers, it appears that spraying of gibberellic acid under some situations may advance bud-break and increase early season crop at those latitudes where winter dormancy is experienced, provided the ambient temperature in late winter and early spring remains favourable and the tea bushes are not subjected to water stress. However, the present state of our knowledge does not warrant firm recommendation regarding its use under commercial conditions.

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CHAPTER 4

CLIMATE OF THE TEA AREAS

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CLIMATIC BACKGROUND

The original habitat of the tea plant in South-East Asia experiences a warm, wet summer and a dry, cold winter. Atmospheric humidity remains high even during the dry and cold winter months when water vapour condenses into mist and dew. Rainfall normally remains above 2000 mm per year but most of it is caused by the south-west monsoon during the months of June-September. The maximum ambient temperature rarely rises beyond 32°C even in the hottest part of the summer and the winter minimum upto an altitude of about 2000 m remains above freezing. Under these conditions the tea plant grows vigorously during summer and remains dormant during winter.

The climatic conditions prevailing at the natural habitat must have influenced the choice of localities for experimental planting of tea when its cultivation in India was first mooted. A strong body of opinion showed preference for the western sub-Himalayan tracts where the climate is somewhat akin to that of its original home. However, the successful trials conducted by the Dutch in tropical Java during the early years of the last century demonstrated that tea would grow equally well, if not better, under climatic conditions quite different from that of its original habitat. The plant flushed right through the year in Java disproving thereby the belief that it cannot thrive in the absence of a long, dormant season. Incidentally, this started the process of enquiry into the climatic requirements of the tea plant.

At present, commercial cultivation of tea extends from 44°N to 34°S latitudes. In the tropical belt, it is usual to grow tea on slopes of mountains and high plateaus at altitudes varying from about 700 m to 2400 m above sea level. In the Temperate

Zone low hills of less than 700 m elevation are generally chosen for its cultivation. The most prominent exceptions are the large tea tracts of N.E. India and adjoining Bangladesh where tea estates are located on flat valleys at elevations of a few to about 200 m above sea level.

Spread over such a vast land mass of diverse topography, the tea areas differ considerably in their soil-climatic environments. Some indication of temperature and rainfall prevailing in different tea areas has already been given in Chapter 1. An attempt is made in this chapter to give a more complete picture of the range of climatic conditions under which tea is cultivated.

TEMPERATURE

In the equatorial zone, the temperature of a place changes little in the course of a year but as the distance from the equator increases, the seasonal changes in climate come more and more into prominence. The annual mean temperature of a place at any particular elevation falls gradually with increasing distance from the equator. At the high latitudes of the U.S.S.R., Japan, Turkey etc. temperature during winter drops occasionally below the freezing point, sometimes as low as —12°C in certain locations. At the other extreme are some tea areas where temperature rises upto 40°C at certain times of the year. In the plains of N.E. India, the maximum temperature during summer occasionally rises as high as 37°C. During the hot, dry part of the year, the maximum temperature in some parts of Central Africa where tea is grown may go up to 37°C. A summer maximum of 40°C is not uncommon in Argentina. The peculiarity of this latter region is a low minimum temperature all through the year, which contrasts sharply with the temperature profile in Japan situated at about the same latitude of the northern hemisphere.

Without deliberating on the reasons here, it may be mentioned that temperature above 30°C and below 13° are harmful for the growth of the tea bush. Like any other plant, growth of tea is subject to the influence of a number of environmental factors of which temperature is one. Favourable temperature conditions alone cannot ensure its satisfactory growth unless other environmental factors remain congenial. Temperature prevailing in a few tea-growing localities are shown in Table 8 as an illustration of the range under which tea is cultivated.

Constancy of maximum and minimum temperature in the equatorial zone and their widening range of fluctuation at increasing distances from the equator can clearly be seen from the table. Argentina is a special case where the maximum day and minimum night temperatures differ by 20° to 30°C. Such a big drop of temperature at night is not observed in any other tea area, not even in the tea belt of the U.S.S.R. located at still higher latitudes.

The localities mentioned in the table do not necessarily indicate the temperature profiles of the respective regions. Due primarily to difference in elevation, some localities within a region may be warmer or colder than others. Topography and a few other factors of the environment are also partly responsible for influencing temperature changes.

It is noteworthy that at the high altitudes of the equatorial zone, the average minimum temperatures does not rise above 13°C throughout the year while even at the latitudes of the U.S.S.R. and Japan, the minimum stays above the critical level for a few months of the summer season.

LIGHT

The solar radiation reaching the surface of the earth consists mainly of visible radiation in the 400-700 nm wavelength and infrared radiation of longer than 700 nm wavelength. Not more than 2 per cent of the total radiant energy of less than 400 nm wavelength reaches the earth. Plants use light energy in the visible range for carrying out photosynthesis, a process on which life on earth solely depends. The visible part of the solar spectrum contains less than 50 per cent of the total incident energy. The exact proportion of energy in the visible range varies

Table 8. Monthly mean maximum and minimum temperatures of a few tea-growing localities in °C

Month	Poti USSR 42°N Sea Level		Kanaya Japan 35°N 300 m		Tocklai Assam 26.5°N 96 m		St. Coombs Sri Lanka 7°N 1370 m		Kericho Kenya 0° 2178 m		Mufindi Tanzania 8°S 1890 m		Mimosa Malawi 16°S 650 m		Obera, Misiones Argentina 27°S 350 m	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Jan	15.0	-1.7	8.9	1.1	22.4	9.4	21.2	13.1	23.9	9.7	22.8	12.5	29.2	18.6	36.7	11.1
Feb	15.0	-1.7	10.6	1.8	24.0	12.0	24.6	12.5	24.4	9.6	22.2	12.8	28.4	18.8	35.0	8.9
Mar	21.7	-1.1	13.3	3.3	27.5	15.5	25.5	13.0	24.2	10.2	22.4	13.0	28.4	18.3	33.6	12.2
Apr	25.6	5.0	18.3	9.4	28.6	19.1	25.2	14.3	23.1	9.8	21.6	13.0	27.3	16.7	31.1	5.7
May	27.8	10.0	21.7	12.2	29.9	21.9	22.4	15.4	22.9	9.6	20.2	11.5	25.8	12.9	29.0	2.0
Jun	30.0	15.0	23.9	16.7	31.5	24.2	21.4	15.8	22.2	9.2	19.2	9.3	23.3	11.2	27.0	2.0
July	30.0	17.8	27.8	21.1	32.2	24.7	21.1	15.3	21.6	8.9	18.1	8.4	23.3	10.9	28.0	4.0
Aug	31.1	20.0	29.4	21.7	32.1	24.6	21.8	15.1	22.1	8.9	18.7	8.6	26.1	11.6	30.4	1.7
Sep	27.8	12.8	26.1	18.9	31.3	24.0	22.3	14.5	22.8	9.0	21.4	9.9	29.7	13.0	34.7	2.9
Oct	27.2	10.0	21.7	13.3	29.4	21.0	22.7	14.3	23.4	9.3	24.2	10.7	30.9	16.2	32.6	8.4
Nov	22.2	4.4	17.2	8.9	26.4	15.3	23.0	14.0	22.9	9.6	23.6	12.3	30.5	17.7	33.3	7.9
Dec	17.8	0	11.7	2.2	23.4	10.7	23.0	13.4	23.4	10.9	22.6	12.7	29.4	18.6	35.6	12.8

a little under different situations but 44 per cent is generally taken as the global average (Loomis and Williams, 1963). This will be the factor to be used by us for converting total to photosynthetically useful radiation.

The standard unit for the measurement of illuminance or illumination is the lumen. It may be noted that the lumen was redefined in 1948, making the old definition obsolete. The principal units for measuring radiant energy are the calorie, erg and Watt (W). All these units are used according to the choice of the investigator. Langley (ly) is calorie per square centimetre. The conversion factors are:

lux	= 1 lumen m^{-2}
1 cal cm^{-2} min^{-1}	= 6.98 x 15^{5}erg $cm^{-2}sec^{-1}$
1 cal cm^{-2} min^{-1}	= 697.6 W m^{-2}
	= 3210 µmol photons m^{-2} sec^{-1}

Few research stations on tea publish pyranometric measurements of solar radiation but most stations furnish data on hours of sunshine. Sunshine duration records have limited value since they do not give any indication of the radiant energy when the sun is obscured by cloud. Paradoxically, high sunshine values may be recorded even when a part of the sky is occluded. Attempts to convert sunshine duration into energy units have not so far met with much success (Coulson, 1975).

The highest recorded radiation intensity at Tocklai by a Moll-Gorczynsky Pyranometer (Kipp Solarimeter) on a bright clear day in summer is 1.0 cal cm^{-2} min^{-1}. Using a Gunn-Bellani instrument, Squire (1977) reported 900 W m^{-2} (1.29 cal cm^{-2} min^{-1}) irradiance at noon on clear days in Mimosa, Malawi. It is noteworthy that solar energy of such high intensity as reported by Squire has very rarely been observed in any part of the world.

Radiation of very high intensity usually does not last for long. From reports of total radiation received per day and expressed as monthly average, it appears that the total solar energy incident in Malawi increases from a minimum of about

0.55 cal cm^{-2} min^{-1} in June-July to a maximum of approximately 0.8 cal cm^{-2} min^{-1} in September-October (TRFCA Ann. Rep., 1980-81). At Kericho, Kenya, the weather is relatively hot and dry during December-February when the incident energy level rises to a peak of about 0.7 cal cm^{-2} min^{-1} and remains around 0.5 cal during the remaining part of the year (TRFEA Ann. Rep., 1983). At Tocklai (unpublished) where the atmosphere remains very humid throughout the year, the monthly average radiation intensity rarely rises beyond. 0.7 cal cm^{-2} min^{-1} even during the brightest part of the spring and early summer but drops to 0.3—0.4 cal during the rainy months of July-September. At the high altitudes of Southern Tanzania, the mean radiation intensity remains around 0.5 cal cm^{-2} min^{-1}.

The tea districts of Sri Lanka on the west of the central mountain divide receive less sunshine during the months of June-September when the south-west monsoon blows over the island. The situation in the eastern districts which get copious rain from the north-east monsoon during October-December is just the opposite.

Sunny mornings and cloudy afternoons are characteristic features of the tea areas of Indonesia. Cloudiness increases with elevation. The mean radiation intensity is, therefore, generally higher at lower than at higher elevations. The number of sunshine hours is more during the relatively drier months of July, August and September than at other times of the year.

Because of high rainfall almost throughout the whole year, the mean radiation intensity in the tea areas of Sri Lanka and Indonesia is unlikely to exceed 0.5 cal cm^{-2} min^{-1}. Due to cloudy and misty conditions, it is likely to be less at the higher altitudes.

Kanaya, Japan, gets almost the same amount of sunshine as Tocklai in Upper Assam. Days are least sunny in June and September when maximum precipition occurs. Situated about 50 km away from the sea, Kyoto gets more sun throughout the year than Kanaya. In the tea belt of the U.S.S.R. weather remains bright and sunny from April to August but generally dull and rainy for the rest of the year.

Away from the equator the days become short and cold in winter and long and warm in summer. The effect of short and cold days on the tea bush has been discussed in Chapter 3 wherein mention has been made that tea bushes become dormant when short days of less than approximately 11 h 15 min duration last for at least six weeks. Low temperature also contributes towards growth suppression. These conditions occur at latitudes above 16° during the winter months when harvesting completely stops. The length of the dormant period is determined by the number of short days which increases with latitude.

RAINFALL

Tea is a rain-fed crop. In a few areas irrigation has been practised on a limited scale but its impact on total production of tea is yet very small. Being dependent almost wholly on rain, its quantity and distribution are vital considerations in the culture of tea. Rainfall in the tea areas of the world varies from less than 1000 mm to 6000 mm in a year. Irrespective of the total quantity, nowhere is rain distributed evenly throughout the year. However, the distribution is more equitable in some areas where 40-50 mm of rain falls even in the relatively dry months while in some other areas, there may not be any rain for months together. There again are places where rain may occur when other environmental conditions are not congenial for growth. The total amount of rain falling in a place in the course of a year may balance or exceed the quantity of water lost by evaporation and transpiration from the soil and plant, but tea bushes may still suffer from its insufficiency at certain times if the distribution is uneven. Persistent rainless condition causes drought and prolonged drought could be lethal for the tea bush.

The minimum quantity of rain required to sustain healthy growth of tea even when its distribution is fairly balanced, depends on soil and environmental conditions and cultural factors which are directly or indirectly connected with the loss of water from the soil and plant. Since these differ from place to place, a single lower limit of rainfall cannot be specified for all situations. Evaporative loss of water in a year from many tea areas exceeds 1270 mm e.g. Malawi (TRFCA Ann. Rep., 1980-81), which was believed to be the minimum annual requirement of water by the tea crop (Eden, 1976).

Total rainfall and its distribution can vary widely between localities within a region. Topography is the primary cause of such variation. In South India the tea areas situated on the western face of the Western Ghat Mountains e.g. Anamallais, Travancore etc. get about 80 per cent of the total rain from the south-west monsoon while the Nilgiris facing mainly east get more than half the amount of rain from the north-east monsoon. In Sri Lanka, the tea district of Uva which falls on the east of the central rain divide, gets more rain from the north-east monsoon but areas like St. Coombs, Ratnapura, Nuwara Eliya etc. located on the west are fed mostly by the south-west monsoon. Rainfall in the Kandy area is more evenly distributed since it is exposed to both the monsoon currents.

Large year to year variation of rainfall is not uncommon in many tea areas. Sometimes the departure from the long-term average may be as high as 40 per cent. Wide fluctuations of annual rainfall cause serious problems of water management.

It would be clear from the foregoing that the mean rainfall of a few localities cannot adequately depict the capricious rainfall patterns prevailing in many parts of the tea-growing world. However, such data are useful in bringing out some of the major points of difference between regions. The information given in Table 9 may be viewed in that light.

In a large part of the tea-growing world, rainfall exceeds evaporative losses in the course of a year but its uneven distribution leads to deficit of water in the soil during periods of scanty rain. This does not happen in the tea areas of Indonesia where rainfall is balanced. Sri Lanka is another country where draught is not common but in the tea areas of adjoining South India dry conditions occur quite frequently. November to April is a dry period in N.E. India. Even a little rain during this part of the year is a great help. Light rain usually comes as post-monsoon and spring showers but either one or both may fail in some years. When this happens tea suffers from drought, its severity increasing with the length of the rainless period. Parts of Central Assam, Cachar, Dooars and Terai are more susceptible to drought than Upper Assam which normally gets a few showers during the dry part of the year.

In the tea belt of the U.S.S.R. rainfall decreases from west to east and north-east. Batum on the Black Sea coast receives about 2500 mm but the rainfall at the eastern end of the tea tract is hardly 1000 mm per year. Throughout this area more than 60 per cent of rain falls during autumn and winter, causing scarcity of water in summer when tea bushes flush. The distribution of rain in the tea areas of Turkey is similar to that of Georgia with the difference that precipitation decreases from about 2300 mm at Rize on the east to 1500 mm at Ordu at a distance of approximately 250 kilometres to the west.

The major tea districts of Japan receive 1800 to 2500 mm of rain in a year. The rainfall is distributed fairly evenly. In South-east China, the main tea belt of the country, rainfall and its pattern of distribution are similar to those in the Assam valley. Canton on the Pacific coast gets 1700-1900 mm of rain annually but the quantity decreases inland as the distance from the sea increases. Only 1000-1200 mm rain falls in a year at a distance of 700-800 km from the sea. Yangtze Kiang valley of Central China also does not receive more than 1300 mm of rain annually.

Shortage of rain and its unbalanced distribution are major problems for a large section of the African tea industry. Not that rainfall is inadequate everywhere; its distribution is the major constraint almost throughout the tea-growing areas. For instance, rainfall in the tea areas of Mozambique, parts of Tanzania and Nkhata Bay district of Malawi is much in excess of the total evaporative demand but most of it comes during the months of December to May. This pattern of rainfall distribution is characteristic of all African tea areas south of approximately 5°S latitude. During the dry half of the year, soil water deficit builds up. In areas of low rainfall the deficit may be so large as to damage the tea bushes permanently.

Table 9. Rainfall in a few localities in mm

Month	N.E.India			South India			Sri Lanka			Indonesia			East Africa		Central Africa	South Africa	Japan	U.S.S.R.	Argentina
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Jan	21	16	13	66	23	61	91	25	135	627	353	282	89	36	261	190	71	205	137
Feb	32	50	24	23	11	56	60	76	112	284	318	183	96	58	215	168	140	160	158
Mar	77	112	44	16	28	48	115	109	218	384	335	226	157	132	297	122	188	141	139
Aprl	193	305	145	172	125	104	162	190	317	409	277	221	263	221	159	62	279	81	161
May	278	409	358	371	176	152	286	118	447	264	168	305	290	162	56	16	229	74	159
June	329	586	851	787	979	104	333	58	508	165	112	175	198	89	69	13	305	126	177
July	382	513	1026	1028	1444	119	298	51	328	99	61	170	198	71	47	12	208	139	103
Aug	344	416	726	714	942	109	239	81	302	96	66	244	218	124	10	10	312	165	118
Sep	255	334	561	409	427	168	213	86	381	102	107	348	187	160	16	24	386	246	151
Oct	117	183	211	318	249	366	246	251	477	231	196	424	156	211	47	47	198	270	249
Nov	28	34	24	142	78	259	188	264	363	350	272	224	138	137	137	116	180	201	169
Dec	12	10	7	101	69	109	133	312	223	416	338	249	93	74	279	158	76	206	127
Tot	2068	2968	3990	4147	4551	1655	2364	1621	3811	3427	2603	3051	2083	1475	1593	938	2572	2014	1848

(a) Tocklai, Upper Assam (b) Silcoorie, Cachar (c) Nagrakata, Dooars (d) Cinchona, Anamallai (e) Munnar, High Range (f) Nilgiris (g) St. Coombs (h) Badulla, Uva (i) Ratnapura (j) Soekaboemi, Java (k) Pengalengan plateau, Java (1) Siantar, Sumatra (m) Kericho, Kenya (n) Toro, Uganda (o) Mimosa, Malawi (p) Tzaneen, South Africa (q) Kanaya (r) Anaseoula, Georgia (s) Obera, Misiones.

A different pattern of rainfall distribution can be seen near the equator. Here December to March is a relatively dry period. In these equatorial tea areas of East Africa, annual precipitation stays around 1500 mm except in a few sites where it may be as low as 1100-1200 mm or as high as 2000-2200 mm.

A chronic deficit of rainfall characterises the tea areas of Zimbabwe and South Africa.

Hail

In N.E. India spring showers are often accompanied by hail until the middle of June. Hail storms are unpredictable but fortunately, they usually are of a localised nature. Damage caused to tea bushes depends on the severity of the storm, its time of occurrence and state of growth of the tea bushes. Unpruned and light skiffed tea suffers less damage from hail than young tea and bushes in the process of recovery from pruning. Presence of shade trees afford some protection to tea bushes. Severe hail causes complete defoliation, breakage of young stems and striping of bark. Some tea estates in Assam insure against loss of crop from hail damage.

East African tea areas, notably those to the west of the Rift valley, are prone to severe hailstorms throughout the year. It is on record that Kericho and Nandi Hills areas experience an average of 100 hail storms in a year (Mwakha, 1983). Loss of crop caused by hail is extremely heavy. At one time rockets used to be fired into certain cloud formations in the area for combating hail. Recently seeding of potential hail clouds with silver iodide has been tried on an experimental scale but so far without success.

Bushes damaged by hail become more susceptible to attack by fungal diseases. Loss of foliage debilitates the bushes. Prophylactic spraying of fungicides immediately after hail and resting of bushes for the production of new leaf are the usual recommendations for sections of hail damaged tea.

WIND

Wind may not be as important an ecological factor in the growth of plants as temperature, sunlight and rain, but by interacting with all these, it exerts considerable influence on plant growth. Wind affects plants directly by increasing transpiration and causing various kinds of mechanical damage. Among the many indirect effects, special mention may be made of transportation of hot and cold masses of air thereby causing fluctuation of temperature, movement of clouds and fog that affects water relations and alter illumination intensity, and evaporation of water from soil and water reservoirs, both natural and artificial.

The rate of movement of air is expressed as velocity over an interval of time. Wind velocity is usually recorded per day and often expressed as monthly averages. The velocity of wind is affected by topographical configuration, height above sea level, presence or absence of vegetation, distance from sea or a large body of water e.g. a big lake etc.

Wind velocity increases with elevation. Valleys and mountain slopes facing the sea experience more rapid movement of air than sheltered localities. In the tropical zone, air movement does not vary to any great extent throughout the year but in the temperate zone, both direction and velocity of wind are affected by the apparent movement of the sun to the north or south of the equator. Wind velocities recorded at several sites in the N.E. Indian tea areas illustrate the above points.

Wind velocity is least in the most sheltered part of the flat Brahmaputra valley in Upper Assam. Maximum air velocity is recorded at the Darjeeling site at an elevation of 1150 m while the recording sites in North Bengal at less than 250 m elevation but exposed to the flat plains of Bengal, register much higher velocities than in the Assam valley but considerably lower velocities than in Darjeeling. In the entire region, wind velocity starts increasing with the movement of the sun from the Tropic of Capricorn towards the equator and reaches the peak in April at the time of the vernal equinox. Thereafter the velocity declines steadily until reaching the minimum in November (TES Ann. Rep., 1983-84).

The evaporative power of the air is increased by high temperature and wind. Due to increase in the vapour pressure gradient between the atmosphere and the moist surfaces of soil and plant, more water can escape into the atmosphere when its relative humidity is low. All the three factors influence the evaporative power of the air simultaneously or by any one of them when the other two are constant. Evaporation by wind is not directly proportional to its velocity. Loss of water vapour from a plain surface is proportional to the square root of wind velocity. However, more water evaporates from a wet soil than from an open surface of water since the minute irregularities on the surface of a soil present a bigger evaporating surface. It is worth mentioning in this connection that evaporation by wind or other atmospheric agencies cannot dry up a soil beyond the depth of 20-30 cm. If rain or irrigation water is insufficient to sink beyond this depth of surface desiccation, it gets quickly evaporated into a dry atmosphere.

Wind also affects the rate of transpiration by removing layers of moist air surrounding the leaves but unlike evaporation, transpiration is not a passive process. The plant exercises control over transpiration by closing the stomata of the leaf when loss of water becomes very rapid.

A small quantity of water, generally less than 5 per cent of the total transpirational loss, escapes from the plant through the cuticle. The plant has very little control over this loss so that cuticular transpiration continues even after complete closure of the stomata. Cuticular transpiration in tea has not been measured but as in most other plants, it is unlikely to exceed 5 per cent.

Apart from serving other vital functions, transpiration keeps the leaves cool. At times it becomes a factor of very great importance when a few degrees may mean the difference between efficient and inefficient functioning or even between life and death of the leaves.

Temperature of tea leaves exposed to the sun may rise

10°-12°C above the ambient temperature (Hadfield, 1968). During the warm, humid summer of N.E. India when the air remains virtually still, temperature of exposed tea leaves occasionally rises upto 48°C on hot days. Such high temperature damages the leaf tissues, often irrevocably. This is a situation where a light wind can assist in keeping the leaf temperature down by increasing the rate of transpiration. Excessive transpiration under conditions of high temperature forces the stomata to close but cuticular transpiration is not affected. In fact, high temperature is known to increase cuticular transpiration in certain plants (Martin, 1943). The effect of cuticular transpiration will obviously be small but it may still have a significant effect in arresting the rise of leaf temperature.

Tea bushes in many parts of the world have to combat with strong winds either throughout the year or at certain seasons. The scope for mitigating the harmful effects of wind is, however, very limited. In parts of East and Central Africa where rainfall is marginal and unbalanced, attempts to conserve water in tea fields during dry weather by providing windbreaks have so far met with little success. Under droughty conditions, competition for water between tea bushes and windbreaks becomes so acute that even distant rows of tea get affected. Trees like *Hakea saligna, Pinus patula, Grevillea robusta* have so long been used for planting windbreaks.

Composition of the species of vegetation, their planting density, distance from the crop to be protected are known to have important bearing on the efficacy of windbreaks. On these considerations, the experiments so far carried out in Africa do not eliminate the possibility of obtaining better success from windbreaks and shelter belts planted with more carefully selected plant species.

ATMOSPHERIC HUMIDITY

The air around us is a huge reservoir of water, which it holds in the form of invisible water vapour. The atmosphere as a whole is nearly always dry enough to allow evaporation of water from soil, plant and bodies of water. The invisible water content of the air is expressed variously as Relative Humidity (RH), Saturation Vapour Pressure Deficit (SVPD) or Dew Point. Relative humidity is the moisture content of a volume of air expressed as a percentage of the maximum quantity that the air can hold at the prevailing temperature. It is essential to mention the temperature since the water holding capacity of the air and the partial pressure of water vapour increase with temperature. A 10°C rise of temperature doubles the water holding capacity. When moist air is cooled the RH increases. If cooling is continued, the Dew Point is reached and the excess water vapor is condensed into liquid. SVPD, as the term implies, is the difference in the pressure of water vapour in a volume of air from the pressure that water vapour can exert when it fully saturates the air at that temperature. Thus the three methods of expressing the moisture content of air are interlinked. Knowing one the other two can be worked out without difficulty.

The notion that tea requires a humid climate for its growth found unquestioned acceptance in the old tea-growing countries. Since tea bushes grown in these countries do not get exposed to a very dry atmosphere at any time, the necessity to verify this age-old belief did not arise. In South India, Indonesia, Sri Lanka and other countries of South-East Asia vapour pressure of the atmosphere shows the typical diurnal and seasonal pattern of variation as anywhere else but due to heavy and fairly well-distributed rainfall in most of these countries, mean relative humidity rarely drops below 60 per cent at any time of the year. Despite unbalanced distribution of rain, nowhere in N.E. India mean relative humidity drops below 60 per cent even during the driest part of the year in March although in the early afternoon hours, it may sometime fall as low as 30 per cent. In the northern latitudes of the U.S.S.R. and Japan atmospheric humidity remains fairly high.

The situation is, however, different in many parts of Africa where the vapour pressure of the atmosphere drops so low during the hot and dry part of the year that yield of tea is reduced drastically, At this time of the year, the transpirational loss of water and the soil water deficit are at their maximum. In Malawi, the cumulative deficit sometimes exceeds 500 mm in the hot dry part of the year (Ellis, 1971). It was thought that yield depression could be reduced, if not completely avoided, by preventing build up of moisture deficit through properly planned irrigation (Laycock, 1964). A series of irrigation experiments were conducted in Central and East Africa with varying degrees of success. In Malawi, despite intensive irrigation, yields during the hot and dry months of August-November did not rise to the level of the main rainy season yields of December-May (Dale, 1971), although response to irrigation was better in southern Tanzania (Carr, 1971) and Kenya (Othieno, 1978).

Faced with this situation, the Tea Research Institutes of East and Central Africa undertook a series of experiments to study the relationship between plant, soil and water. These are the first investigations to provide direct evidence on the role of water vapour of the atmosphere on growth and yield of tea.

During the hottest part of the year in Malawi, the air remains very dry when SVPD may rise upto 45 m bar (Ellis, *loc.cit*). Under such hot and dry conditions, transpiration proceeds at a rate faster than the uptake of water from a saturated soil even by well-developed root systems of mature tea bushes. Internal stress develops in the plants, the cells lose turgidity, stomatal aperture decreases, gaseous exchange with the atmosphere is reduced and photosynthetic rate falls. Respiration is also affected due to inadequate supply of oxygen. Extreme stress causes wilting and total closure of stomata. Stomatal closure deprives the plants of the cooling effects of transpiration resulting in scorching and abscission of leaves. Williams (1971) considers dryness of the atmosphere and high temperature to be the major causes of yield depression during the hot, dry part of the year in Malawi. Squire (1979) too arrived at the same conclusion.

The internal water stress is reduced by irrigation but it does not have any lasting effect on temperature and vapour pressure of the atmosphere except for short periods when water is being actually applied overhead (Fordham, 1969-70). In contrast, intermittent sprinkling of water each day was reported to reduce temperature and increase humidity around tea bushes in Russia (Lebedev, 1962). However, neither temperature is as high nor humidity as low in the tea areas of Russia as in Malawi where irrigation or misting will presumably have to be more frequent to keep leaf temperature low and humidity high during the hot and dry part of the year.

Williams (*loc. cit*) observed a direct correlation between shoot water potential and vapour pressure deficit of the atmosphere. Squire (*loc. cit*) found shoot water potential to be more closely related to vapour pressure deficit of the atmosphere than to water status of the soil. Working within the temperature range of 16° to 24°C, he further observed that weekly rate of shoot extension of the single clone used by him was inversely related to saturation deficit although a deficit of 20 m bar (approximately 15% RH at 20°C) had no adverse effect on growth. It is, however, unlikely that all tea plants will maintain growth at such a high level of saturation deficit since tolerance to dry conditions differs from plant to plant.

The foregoing account will show that tea bushes cannot grow below a critical level of atmospheric humidity and that this level is not the same for all bushes. Since bushes are not adversely affected in an atmosphere fully saturated with water vapour, an upper limit of humidity does not seem to exist for the tea plant at any stage of its growth.

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CHAPTER 5

TEA SOILS

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FORMATION AND CHARACTERISTICS OF TEA SOILS

Commercial cultivation of tea has met with success on soils of very diverse geological origin, which may give the impression that the plant will grow on almost any soil. This, however, is not true. Any particular soil type where tea is grown is required to fulfil certain conditions for the plant to flourish and make its cultivation commercially viable. Mann (1935) had described the tea soils of different countries and analysed the characteristics of soils which can support healthy growth of tea. The large volume of information gathered on tea soils during the last fifty years has not materially affected his analysis.

The parent rocks giving rise to the soils where tea is now cultivated are widely different. Extensive areas of tea in Assam lie on almost flat alluvial land of fairly recent geological origin, washed down from the Himalayas and the other mountain ranges of this region by the Brahmaputra and its tributaries. Alluvial soils of the Cachar district of Assam are derived from sandstones of the neighbouring hills. Two special types of soil found in Cachar are the *teelas* which are small hillocks of sandstone and the *bheels* which are drained peats very rich in organic matter. Except for the old alluvial 'Red Bank' soil, other alluvial soils of North Bengal are also of more recent geological origin. Alluvial deposits occur also in the tea areas of Malawi. In Darjeeling, South India, Sri Lanka, Tanzania, Uganda and parts of Japan tea has been grown successfully on sedentary soils derived mostly from gneiss or granite. The sedentary tea soils of Russia and Turkey are based primarily on andesite. Tea soils of Indonesia, Kenya, parts of Japan and Tanzania are derived mainly from volcanic ash.

Since tea areas of the tropics and sub-tropics are located only in the high rainfall belts, all these soils have been subjected to heavy precipitation which varies between regions from less than 1000 mm and more than 6000 mm in a year. The total rainfall received in the tea belts during the course of a year, with a few minor exceptions, exceeds evaporation but due to its uneven distribution many tea areas suffer from a deficit of water in the soil at certain times. The ambient temperature in the tropical tea belts varies but little throughout the year but wide seasonal fluctuations are experienced in the sub-tropical tea areas. At the higher latitudes of Russia, Turkey, Persia and Japan temperature in the winter drops below freezing.

Climate profoundly influences the characteristics of a soil. Being subjected to heavy rainfall, tea soils are intensively leached. When leaching continues under warmer conditions, as obtained in most tea areas, then besides bases like lime and magnesia, silica is also washed by the percolating water. Where this happens, the proportion of iron and aluminium increases in the soil and the soil assumes the red colour of the sesquioxide of iron (Fe_2O_3). The process is known as laterisation and the soils so formed are described as lateritic or *latasols*. A true laterite is nothing but a mass composed almost exclusively of iron and aluminium oxides. Lateritic soils are found in the tea districts of South India, Sri Lanka, Indonesia, East and Central Africa. The soils of N.E. India also are in various stages of laterisation. Under cooler conditions, iron and aluminium oxides are also washed away along with the bases and the soil that is eventually produced is described as a *podzol*. Podzols are found in certain tea areas of Japan and the U.S.S.R. Naturally, the intensity of leaching depends on the state of aggregation of the soil particles, presence of organic matter and the quantity and distribution of rain.

As may be expected, soils formed at different geological epochs from such a vast range of parent materials and under very dissimilar climatic conditions differ widely in their structural and textural characteristics. Some soils in South India and Sri Lanka may contain upto 40 per cent stones and pebbles while, at the other extreme, the extremely fine-grained soils of Kenya contain upto 80 per cent clay. The fact that tea has been grown successfully on such widely divergent soils is an indication of the limited value of mechanical analysis for judging the suitability of a soil for tea, although it may give a general idea of the soils of different regions and of their variation within the same region.

Soil Fertility

The water present in a soil containing dissolved solids, liquids and gases is known as soil solution. Plants require 14 to 18 elements for their growth. Of these all but oxygen and carbon are taken up by plant roots exclusively from the soil solution. If a soil is lacking in any of the elements essential for growth or the amount present is too small, then plants cannot grow normally in that soil. The mere presence of an element in the soil does not ensure that it will be available for absorption by roots. Its combination in the soil minerals may be too complex for absorption. Plants cannot live normally also when the soil solution contains excess of acids, bases, salts and harmful organic toxins. A soil can be considered fertile when it contains neither too little nor too much of any solute. However, a soil considered fertile for one plant may not be so for another since plants differ in their solute requirements.

The inorganic particles form the main framework of soil but, in addition, it contains humus, which is the product of degradation of organic matter. The organic matter may be of plant or animal origin. Dead roots, deposition of leaves, twigs, wood etc. on the surface, death and decay of soil-borne organisms like earthworms, insects, protozoa, nematodes, algae, fungie, bacteria etc., contribute towards the organic matter content of a soil. The organic matter is broken down in successive steps by various organisms inhabiting the soil into humus, which is a dark colloidal substance that gets incorporated into the mineral soil. The humus itself is eventually converted completely into carbon dioxide, water and minerals, a process known as mineralisation. Elements locked up in the organic material are released by this process in a condition suitable for absorption by plant roots. Of these, nitrogen is the most important which almost exclusively is a product of breakdown of organic matter. In a balanced native vegetation, plants get all the essential elements required for their growth from the mineral complex of the soil. The mineralised organic matter supplies nitrogen as well as some of the active elements. In cropped soils some minerals get depleted faster than their release from the soil mineral complex. The nutrient elements of which the soil has the smallest reserve in relation to the requirement of the crop are the ones to get deficient first. Replenishment of the deficient nutrients becomes necessary to meet the nutritional requirement of the crop. As time passes, other elements become deficient one after another depending on the reserves present in the soil and these too have to be added to the soil in the form of organic or chemical fertilisers.

The aggregation of the small, elementary particles of soil into larger granules gives to the soil some of the unique properties that favour plant growth. The growing conditions improve with the extent of soil aggregation. Aggregated soil becomes more permeable to water, air and plant roots and the aggregates possess high water holding and cation exchange capacity. Such soils are more resistant to erosion by rain and wind.

Humus produced by the decomposition of organic matter binds the soil particles like glue into granules or aggregates. In addition, the meshwork of fungal hyphae which develop in a soil rich in organic matter mechanically binds the particles into cohesive lumps. Earthworms too play a significant role in granulating soil. Some soil bacteria are also known to help in the formation of aggregates. Hence, aggregation of soil is chiefly a biological process for which organic matter is essential.

The coarse-grained or light soils and the fine-grained or heavy soils each have a wide range of intergrades which makes division into light and heavy soils purely subjective. Each of light and heavy soils has certain advantages as well as disadvantages. Water, air and plant roots can more easily penetrate a light than a heavy soil where interstitial spaces are very minute but the total surface area of the smaller particles of a heavy soil can retain more water. Aggregation of particles improves the water and nutrient retaining capacity of light soils and makes heavy soils more permeable. This way humus plays a vital role in the improvement of both light and heavy soils.

The virgin soils owe their fertility primarily to the presence of large amounts of humus. Under virgin forest or grassland conditions, deposition of organic matter, its humification and mineralisation proceed continuously in a closed cycle but as soon as the land is cleared, the cycle is broken. Humification and mineralisation continue without deposition of fresh organic matter in amounts equal to its rate of breakdown. As a result the soil gets depleted of humus causing loss of aggregation and reduction in the level of nitrogen and other minerals useful for plant growth. In other words, fertility of the soil goes down.

An idea of the rapid loss of soil structure following removal of the vegetation cover and the prunings from areas planted with tea can be had from Table 10 which is based on observations made at Tocklai on adjacent plots of a sandy loam soil (D.H.L. *et al.*, 1966).

There being no virgin forest in the neighbourhood, the bamboo bari was taken as an approximation to a virgin forest.

The rate of decomposition of organic matter in a moist soil is dependent on temperature. High temperature accelerates the rate. For this reason virgin soils of the sub-tropical belts where the temperature is lower, contain more organic matter than tropical soils formed under similar vegetal cover. Even in the tropics, the soil organic matter increases with altitude because of fall of ambient temperature. Thus, it can be said that, within limits, a soil owes its fertility rather to the effects of climate and vegetal cover than to the nature of the parental rocks.

This brief account should suffice to show the importance of organic matter in improving the fertility status of all types of soil.

Table 10. Per cent soil aggregates in the top 30 cm profile

	Per cent aggregates of 0.25 to 5.00 mm size
Bamboo bari over 25 years old	70
Guatemala grass over 10 years old	66
Eragrostis curvula grass, nearly one year old	46
Mimosa invisa, 2 years old	35
Crotalaria anagyroides, grown for four years following uprooting of old tea	48
40 years old unshaded tea	
Prunings left	29
Prunings removed for the first time after last operation about a year ago	19
Unshaded tea; replanted, 3 years old	16
Bare soil, previously grazing land	20

In the climatic conditions under which tea is necessarily cultivated, organic matter and nitrogen are lost rapidly when a soil is cleared, irrespective of whether it was previously under forest or grass. The loss is extremely rapid in the initial years of clearing and establishment of young tea, which is further, aggravated by frequent cultivation. Information collected at Tocklai on changes in the physical and chemical characteristics of virgin soils of N.E. India after clearing and cultivation of tea for 10, 20 and 40 years or more, clearly demonstrates the rapid degradation of all types of soil during the initial years of cropping. The rate of degradation slows down considerably with increasing age of the plantation. An idea of the loss of carbon and nitrogen at successive periods of cropping can be had from Table 11 (Dey *et al.*, 1968-70).

Table 11. Nitrogen and organic carbon contents of virgin and cropped tea soil in the top 90 cm profile in tons ha.

Locality	Cropping period					
	O (Virgin soil)		10 years		40 years or more	
	Nitrogen	Organic Carbon	Nitrogen	Organic Carbon	Nitrogen	Organic Carbon
Darjeeling district	24.0	329.8	14.9	168.0	13.6	149.7
Cachar district	15.8	144.3	11.6	108.1	9.7	87.3
Tocklai (Mid Assam)	7.5	67.0	5.0	52.5	6.8	56.9

The table representing three distinct types of soil of high, medium and low organic matter status is extracted from the huge mass of analytical data of soils from all the tea districts of N.E. India. The Cachar district average does not include *bheel* soil. It is of interest that Tocklai soil of initially low organic matter content showed a net gain of nitrogen and organic carbon between 10 and 40 years of cropping. However, the original virgin status has not been regained in either these or any other soil even after 40 years.

The table also indicates the effect of high and low temperature on the build up of soil organic matter. The maximum quantity of nitrogen and organic carbon is found in the soils of the Darjeeling district where the mean temperature is about 10°C lower than at the other two sites.

It follows from the foregoing that while opening virgin land or uprooting old tea for replanting, the aim should be to provide a cover to the soil soon after clearing by establishing some quick-growing grasses or green crops. Soil disturbance is to be kept to the minimum necessary for planting tea. The kind of tea bushes their density of planting and other cultural operations should be such that the bushes can cover the ground within the shortest possible time. A cover crop should be kept on during this period. If climatic factors preclude the use of bush crops in young tea, the land should be kept covered by mulching. Where necessary, shade trees should be established at the same time as tea.

A long-duration crop like tea has the advantage that it remains on the same piece of soil for many decades. By following the modern improved methods of husbandry, soil under a stand of tea can be left virtually undisturbed during the entire life span of the plantation. The tea bushes and shade trees, where present, continue to add organic litter to the soil. Under these conditions, the organic matter status of the soils under tea should remain fairly high although the original status of virgin forest or grassland soil will be almost impossible to regain.

Tea is grown only on soils from which free lime and calcium carbonate have been leached out to a very large extent. However, the leaching action does not spare other bases like potash and magnesia. These and other bases too are washed away along with lime and calcium carbonate. The resulting soil is much depleted in potassium, calcium, magnesium and other bases, all of which are essential for the growth of tea and other plants. Leaching from the soil continues all the time and further loss of minerals occurs through their removal along with the harvested crop and the prunings, if these are allowed to be taken away. In order to maintain the productivity of a tea field, the loss of essential minerals has to be replenished from outside sources.

Along with the loss of organic matter, the physical condition of a soil deteriorates rapidly after clearing of virgin land. The waterstable aggregates in the soil decrease and the soil loses in ‘tilth’. This means that the soil becomes closely packed, air spaces and permeability are reduced and its capacity to absorb and retain water and minerals is impaired. Thus, deterioration of the physical properties is the major factor responsible for the loss of fertility of a soil. Within limits the deficiency of nitrogen and other minerals can be made good by applying fertilisers but there is no short cut method for improving the physical properties of a soil except by maintaining the organic matter status at a high level.

Soil Acidity

The tea plant thrives only on a soil which is acidic in reaction. Acidity or alkalinity of a solution is measured on a scale of pH values ranging from 0 to 14 with 7 in the middle. A pH of 7 indicates neutrality, from 7 to 14 indicate increasing alkalinity while pH values from 7 downward show increasing acidity. The normal range of pH encountered in the tea soils of the world is from 6.2 to 4.0, but higher and lower values have also been reported. Some plants of the China type are known to survive in soils which are almost neutral in reaction but for healthy growth, a pH around 6.2 appears to be the upper limit. The lower limit of acidity is not well-defined although it is generally accepted that the pH should remain above 4.0 for healthy growth of tea. Vigorous growth of tea has been reported even at a pH of 3.2,but such highly acidic condition of the soil is not only undesirable but presumably harmful.

Leaching of bases like calcium, potassium, magnesium and sodium makes a soil acid. Although presence of free lime or calcium carbonate has proved harmful for tea yet like other plants, tea cannot grow without calcium. Potassium and calcium are the most abundant basic elements present in tea. These facts do not support the belief once entertained by some that tea is a calcifuge i.e. avoider of calcium. Why then tea needs an acid soil largely devoid of free lime? This question has not yet been satisfactorily settled.

Chenery (1955) reported accumulation of unusually large quantities of aluminium, from 5,000 to 16,000 parts per million (ppm), in old tea leaves while young leaves contained much less. Sivasubramaniam and Talibudeen (1972) observed upto 20,000 ppm of aluminium in old leaves of tea. Very young leaves normally had 50 to 100 ppm which increased to 5,000-16,000 ppm in leaves about to fall. In comparison, the aluminium content of most other plants does not exceed 200 ppm. In the acidic soils where tea is grown, large amounts of aluminium occur in the exchangeable form. Availability of aluminium decreases as the pH of the soil rises and at pH 7 and above none or very little aluminium is found in the exchangeable form. These findings have raised the issue whether it is the need for aluminium that necessitates an acid soil for tea.

Instead of water if the solution of a neutral salt like potassium nitrate is used for extracting the acidic soils where tea is grown, then the pH of the neutral salt extract is generally lower than that of the water extract. This happens because some of the hydrogen and aluminium ions of the clay complex are displaced by potassium ions and the dispelled ions form nitric acid and aluminium nitrate, the latter also being acidic in reaction. The term ‘reserve acidity’ has been used to designate the excess acidity that develops in the potassium nitrate extract of soils (Harrison, 1930). If the hydrogen ions of the soil have already been replaced by bases like calcium and magnesium, then nitric acid or aluminium nitrate is not formed and the pH of the salt solution does not change. When excess lime is present in the soil, it comes into solution in the potassium nitrate extract rendering it alkaline or, at any rate, less acid than the water extract.

Some soils of N.E. India were observed to carry good stands of tea even at a pH of 6.0 or 6.2 when their reserve acidity was high but tea did not grow well even at pH 5.6 when the reserve acidity was low. Workers at Tocklai have, therefore, placed considerable value on the pH of potassium nitrate extract of soils.

From estimations of aluminium in the neutral salt extracts Harrison (*loc. cit.*) deduced that, “The percentage of soluble alumina is then in some measure an indication of the degree of soil acidity”. This statement implies that the availability of exchangeable aluminium indicates the suitability of a soil for tea which is substantiated by the findings of the latter workers.

There is another type of acidity encountered in the *bheel* soils of Assam. These are pockets of peaty soil of remarkable depth, sometimes as much as 7 m deep. The soils are highly acid, usually within the pH range of 3.5 to 4.5 and contain upto

50 per cent organic matter. The acid condition of these soils can be attributed primarily to the presence of organic acids in the soil humus.

Application of sulphur, aluminium sulphate and pyrites (Ferrous sulphate) is advocated for increasing acidity of sub-acid soils. The effect of these chemicals in altering acidity varies with the type of soil. Table 12 shows the effect of sulphur on five different types of N.E. Indian tea soils.

Table 12. Quantity of sulphur required to raise acidity to pH 5.5 (After Harrison, 1932a)

Soil texture	Original pH	Quantity of sulphur applied in kg ha^{-1}
Stiff clay	6.7	1300
Sandy loam	7.0	888
Sandy	6.2	157
Flood silt	6.2	942
Alkaline sandy loam	8.0	888

More sulphur was needed to increase acidity of a stiff, clayey soil while sandy soil required much less. The effect of the other two chemicals can be seen from Table 13 (TES Ann. Rep.,1980-81).

Table 13. Effect of aluminium sulphate and pyrites on soil acidity

Chemical	Rate of application tons ha^{-1}	Soil pH			
		Before application		Nine months after application	
		Top soil	Sub soil	Top soil	Sub soil
Control	No application	5.84	5.97	5.79	5.83
Aluminium	4	5.99	6.20	5.28	5.45
sulphate	8	5.72	6.05	4.96	5.05
Pyrites	4	5.86	6.01	4.41	4.88
	8	5.88	6.12	4.24	4.49

In this loamy soil, pyrites was more effective in reducing acidity than aluminum sulphate. Stiffer soils will require more chemicals to effect the same change. However, these are costly chemicals and their application may not be paying if the area to be treated happens to be large and the acidity very low. Acidic fertilisers like ammonium sulphate also increase acidity but at a much slower rate than the acid forming chemicals of the above tables. Table 14 is an example of the effect of ammonium sulphate on the acidity of a sandy loam soil of Assam.

Table 14. Effect of ammonium sulphate on soil acidity (After Harrison, 1932 b)

Quantity added kg ha^{-1} $year^{-1}$	Original pH	pH after 1 year	pH after 2 years
600	4.37	4.23	4.18
600	5.37	4.87	4.49

In Sri Lanka, application of ammonium sulphate at the rate of 168 kg and 336 kg per hectare for 15 years reduced soil pH from 4.80 to 4.04 and 3.79, respectively (Bhavanandan and Sunderalingam, 1971).

In general all acid forming fertilisers displace from the soil mineral complex equivalent amounts of bases like potassium, calcium and magnesium, making the soil more acid. Some displaced bases may be absorbed by plants but the major portion gets leached out by rain. Leaching of bases continues even in the absence of fertiliser application, but the quantity lost is small in comparison with the loss that follows the application of acidic fertilisers. Gokhale and Bhattacharyya (1958) estimated the loss of calcium from the sandy loam soils of Upper Assam following application of ammonium sulphate for 10 to 15 years. They observed significant reduction in soil calcium which varied linearly with the quantity of applied fertiliser. The losses worked out at 10 to 15 kg calcium carbonate for every 100 kg of applied ammonium sulphate. Considering that 100 kg ammonium sulphate is customarily assumed to displace base equivalent of 110 kg calcium carbonate, these estimates are much too low even allowing for the fact that other bases are also displaced. The authors attributed this to the extremely low base saturation of these soils. Greater leaching of divalent calcium and magnesium than monovalent potassium took place from the red-yellow podzolic soils of Sri Lanka following application of ammonium sulphate (Golden *et al*., 1981). The tea industry which uses large quantities of fertilisers like ammonium sulphate, urea, ammonium nitrate etc. has to keep a constant watch on the base status of soils. Magnesium and zinc have already become deficient in many tea soils necessitating their application as fertilisers. Deficiency of other elements can also develop in the course of time.

Lime is used for reducing acidity of soils but here again the effect varies with the texture of the soil as shown by Table 15.

Table 15. Change of soil acidity following application of 4483 kg ha^{-1} of limestone (After Harrison, 1932a)

Soil texture	pH Original	pH After lime application
Light sand	5.1	6.5
Sandy teela	5.2	6.8
Stiff red soil	5.1	6.0
Peat bheel	3.8	4.3

SPECIAL CHARACTERISTICS OF TEA SOILS

Mann (1935) agreed with Vageler (1933) that for successful culture of tea, the soil should not be less than 1.52 m (5 feet) in depth. Although there are situations in many parts of the world where tea is cultivated on soils of lesser depth, general experience supports the above views. The economic viability of tea grown on shallow soils is highly questionable.

Not only the surface soil but also the subsoil should also be fairly porous because the young, much-branched tea roots lack the power of penetrating stiff layers of soil. Presence of a hard, impervious layer in the subsoil, such as an iron pan, is equally undesirable. However, a thin pan that occurs at a shallow depth can be broken up by deep ploughing when the land is prepared for planting tea, provided the terrain is amenable to such an operation. A well-designed network of drains, trench planting and deep-rooting shade trees also help in breaking up shallow pans. The presence of a thick pan within the root zone makes the soil unsuitable for tea. Fortunately, pan formation is uncommon under conditions of heavy rainfall and tea areas of the world are located only in the high rainfall belts of the producing countries.

Tea bushes cannot grow well in soils where the ground watertable remains so high as to submerge a portion of the root system as well as in soggy soils where the soil pores are clogged with water to the exclusion of air. In an experiment at Tocklai where the ground watertable was maintained at a fixed depth of 45 cm, tea plants failed to thrive. Maximum yield was obtained from bushes when the ground watertable was held at 90 cm depth. A further drop of the watertable to 135 cm reduced growth and yield. At the watertable depth of 45 cm, the top soil was completely soaked with water while at 135 cm, the surface 30 cm soil layer had 2.5 cm less water during the dry part of the year than at 90 cm depth (TES Ann. Rep., 1975-76). These results, obtained on a sandy loam soil, indicate the adverse effect of very high or very low watertable on the growth of tea. The optimum watertable depth, however, is likely to differ between soil types since the capillary rise of water is affected by size and arrangement of the soil particles. The optimum depth is also linked with the depth of penetration of the root system.

Under field conditions, the watertable does not remain stationary at a particular depth. It rises and falls depending on the presence or absence of rain. The fluctuation of the ground watertable is minimal in regions where rainfall is distributed fairly evenly throughout the year, but where heavy rain during a part of the year is followed by prolonged spells of dry weather, as in N.E. India, the range of variation of the watertable depth is very wide. In some parts of N.E. Indian plains, the watertable occasionally rises nearly to the surface in the summer season during periods of heavy rain and drops far beyond the root zone of tea bushes during winter and early spring. In such situations bushes get waterlogged during summer and suffer from drought during winter. Due to the death of a portion of the absorbing roots, particularly those at lower depths, which remain submerged for long periods, the waterlogged bushes are the ones to be affected first and ultimately suffer more when the ground watertable recedes to lower depths during the dry season. Hence it is extremely important to drain out the excess water quickly from the soil during periods of heavy rain in order to restrict rise of the watertable above a certain critical height which appears to be around 90 cm in the case of sandy loam soils of N.E. India and for tea bushes having shallow root systems. If the soil is not drainable, then it cannot be considered suitable for tea.

Presence of a layer of dry sand or other non-waterholding material in the subsoil may be fatal for tea. Mann observed that in certain parts of Africa (Tanganika) tea failed for no other apparent reason than the presence of a layer of coarse sand and pumice stone in the subsoil which tea roots find great difficulty in penetrating.

In short, tea requires a soil, which should not normally be less than 1.5-2.5 m deep. Within this depth, the soil should not contain such developments as iron pan or layers of sand or pumice. Both the top and the subsoil should be fairly porous to enable the delicate tea roots to penetrate. The soil upto a depth of about 90 cm should be free from excess of water at all times of the year.

Plant and Soil Indicators

The scope for expansion of tea cultivation is getting extremely limited in most countries though it may still be possible in some countries of tropical Africa, South-East Asia and Latin

America. In the choice of a new site for tea, the existing vegetation can provide some guidance. According to Mann, Albizzias are reliable indicators of land suitable for tea and the plant thrives in all those areas where Albizzia species form a part of the natural vegetation. *Melastoma malabathricum,* a shrub bearing bright pink-coloured flowers, was a common feature of the shrub lands in a large part of the Brahmaputra valley. The plant was considered to be a reliable indicator of land suitable for tea and the areas once occupied by this shrub were successfully utilised for tea cultivation. The plant has now become a rarity in these parts. Some members of the genus *Dissotis* of the some family *Melastomaceae* are also known to be good indicators of tea land. These plants, like tea, accumulate aluminum.

Chenery (1955) classified the aluminium accumulating species and used some of them for successfully identifying land for tea cultivation. Some members of the family *Rubiaceae* accumulate aluminium. One species of the family *(Craterisperum laurinum*) is reported to have been a decisive factor in the choice of a site in Uganda for the cultivation of tea (Eden, 1976).

Bracken has long been recognised as an indicator plant in Sri Lanka and South India. The fern *Gleichenia* is also regarded as an indicator.

Tea has been grown successfully on land previously occupied by forest, shrub jungle or grass, but in the course of preliminary visual inspection of land for growing tea, a forest cover should be preferred since deep rooting trees indicate a deep and well-aerated soil. Soil under shrub or grass may not be deep enough for tea although the surface soil may be very fertile.

Red soil as found in Java, Sri Lanka, parts of China and N.E. India were considered to be highly suitable for tea but tea has been grown successfully also on soils of many different colours. The *bheel* soils of Cachar and Sylhet are almost black while grey is the predominant colour of many sandy soils of N.E. India. The tea soils of Kenya are chocolate red. Hence a soil should not be accepted or rejected on the basis of colour alone.

The indications given by plant species, vegetable cover or colour of the soil narrow down the number of sites during preliminary selection. This helps since the few selected sites can be subjected to closer scrutiny at lesser cost. However, equally, if not more important than soil, is the availability of water to sustain a healthy stand of tea. Tea everywhere is almost wholly a rain-fed crop; irrigation has yet to make significant impact on its production. Hence the total quantity of rain and its distribution at the selected site must be favourable. If irrigation is intended, a suitable source of water will have to be located at this stage. In areas where the watertable remains high and rainfall is also heavy, the drainage potential of the site needs checking. Examination of the soil profile to a depth of about 2 m is the next operation. If the profile is found satisfactory then representative samples of soil have to be examined for physical and chemical characteristics. Should the selected site prove satisfactory on all these counts, then a part of the area may be cleared first for test planting to be followed in due course by planting of tea on a commercial scale.

SOILS OF THE MAJOR TEA-GROWING REGIONS

A full account of the tea soils of different countries is beyond the scope of this book. Attempt is made in the following pages to give a brief introduction to the soils of the main tea-growing regions.

Some information on the geographical location of areas used for the cultivation of tea and their climate is included in the survey of the historical development of the tea industry in various parts of the world (Chapter 1). To avoid repetition, description of the localities is excluded, as far as possible, from the following account.

North-East India

In North-East India tea is cultivated in four separate tracts of which the valley of the Brahmaputra is the largest. Tea is grown on both banks of the river over an area of 200,000 ha which is two thirds of the total tea area of North India. The other tea tract of Assam is in Cachar, south of the Shillong plateau in the valley of the river Barak. The third tea tract known as the Dooars and Teiai is a long, narrow strip immediately to the south of the Himalayan foothills in the state of West Bengal. The fourth zone consists of the mountainous tea district of Darjeeling also in West Bengal.

The bulk of the tea soils of N.E. India are alluvial in origin. Besides the Brahmaputra, a large number of rivers and their tributaries flow through this region and the alluvial deposits laid down by these rivers during recent geological times now form the tea soils (Mann and Gokhale, 1960). The alluvial deposits in different parts of this region vary in their physical and chemical characteristics due to differences in the nature of the detritus brought down, their mode and time of deposition and geological and climatic factors. Tea is planted on flat or gently sloping valley beds previously occupied by forests or tall grasses at elevations of less than 300 m above sea level. In the Darjeeling district planting is done on sedentary soils upto an elevation of 2000 metres. In the Cachar district of Assam and the adjoining Sylhet district of Bangladesh, a large proportion of tea is planted on teelas or low hillocks of sandstone and flat land surrounding the teelas and a smaller proportion on the *bheels* as earlier mentioned.

The history of formation of the Brahmaputra valley through a long series of geological upheavals was described by Carpenter and Harler (1924). The floor of the valley probably consists of gneiss the like of which is currently found in the Shillong plateau and peninsular India. The alluvial deposits laid on top of it in successive epochs are thousands of metres thick in the middle of the flat valley. The valley slopes so gently that from its easternmost point at Sadiya at an elevation of 134 m until it merges with the plains of Bengal, the drop is merely 88 m over a distance of 630 kilometres.

Except on the west, the valley is surrounded by hills on the other three sides. Owing to the variation in height and character of these hills and to the sinking of the valley in recent geological times, several types of alluvia are observed. The older alluvium is now seen as a red loam, specially on the northern bank of the river, which occasionally crops up in other areas through the new alluvium. The soils of the Brahmaputra valley can be classified into three broad groups.

a) The soils which owe their origin mainly to the Brahmaputra river. These soils are usually very sandy and poor in plant food. They are often subacid for tea.
b) The soils deposited from the adjacent hills by the tributaries of the Brahmaputra. They are usually rich loams suitable for tea, and
c) The older red soils (Red Bank) occurring largely in the north bank of the Brahmaputra. They are usually rich in nutrients and good for tea. .

Soils of class (a) are rarely used for tea cultivation. Some estates of the Biswanath district on the north bank are located on this type of soil. Soils of class (b), extensively used for tea cultivation, vary widely in texture. In Dibrugarh, Lakhimpur and Nagaon districts, these soils are generally loamy, tending to become heavy in places. In Jorhat and Sibsagar districts, sandy and heavier loams occur side by side. The red soils of class (c), which are very suitable for tea, are small in area and confined largely to the north bank of the river.

The Surma Valley included Cachar and Sylhet, of which the latter is now in Bangladesh. The hills on the eastern and southern boundary of this valley are sandstones of the tertiary period and the alluvium in the flats surrounding the teelas is derived almost wholly from this material. The flats vary in texture from sands to heavy clays. The ‘plateau’ soil of Cachar on the north of the Barak river appears to be an old, weathered soil pushed up by geological activity. Mention has already been made of the *bheel* soils.

In the Dooars and Terai, tea tracts slope upwards towards the mountains but does not at any place rise to more than 300 m above sea level. A large number of rivers flow swiftly through this region and the deposits left by these rivers in the past form the tea soils. The deposits are, therefore, characteristic of the geological nature of the hills through which the rivers flow.

A large part of the Dooars tea district is made up of the old red soils known as the Red Bank which bears close affinity to the Red Bank of Assam. These are well-weathered, rich, loamy soils of great depth and are very acid. At the other extreme are the grey, sandy loam of eastern Dooars which have undergone very little weathering and are rich in lime, magnesia and phosphoric acid but low in organic matter and nitrogen. Soils of very different types and ages are found within these classes. One is ‘Mal sand’ which consists of fine quartz and accompanied by a large percentage of talc and potash mica. Dolomite rocks are found to the north of central and eastern Dooars and some limestone deposits also lie scattered in the foothills of this region. The ‘plateau’ soils of western Dooars are fairly old deposits, probably a stage in the formation of the Red Bank series. At the western end of this strip in Terai, there is no distinctive outcrop of Red Bank soils. The soils throughout this area are coarse and sandy, getting stiffer farther away from the hills.

In the mountainous tea district of Darjeeling in Bengal, tea is planted in an area of approximately 20,000 ha between 600 m and 2000 m above sea level. The whole of the central and western portion, constituting the major part of the Darjeeling tea district, is on soils derived *in situ* from gneiss. It is a chocolate loam with high nitrogen and phosphoric acid contents. The eastern portion is on micaceous schists. At lower elevations, some soils resemble the Red Bank while others are situated on shales and sandstones.

Analyses of a few typical tea soils of N.E. India are reproduced in Table 16.

Note: Mechanical analysis by the method of Hall.
Coarse sand, 1.0-0.2 mm; Fine sand, 0.2-0.04 mm; Silt 0.04-0.01 mm; Fine silt, 0.01-0.002 mm; Clay, < 0.002 mm.

A. Upper Assam loam.	B. Mid Assam sand.
C. Lower Assam sand.	D. Tezpur Red Bank.
E. Dooars Red Bank.	F. MaI sand, Dooars.
G. Grey sandy loam, Dooars.	H. Mountainous soil, Darjeeling.
I. Teela, Cachar.	J. Clay flat, Cachar.
K. Plateau, Cachar	L. Bheel, Cachar.

The table shows that the tea soils of N.E. India are low in the oxides of iron and aluminium and contain a very high proportion of sand and silicates. Only the older Red Bank soils of the Dooars contain upto 20 per cent of the oxides. The organic matter and nitrogen contents, of the Brahmaputra valley soils are generally lower than those of North Bengal and Cachar. The bheel soils of Cachar are exceptionally rich in organic matter and nitrogen. The North Bengal soils in general contain a higher amount of potash than the soils of Assam.

South India

The tea areas of South India extend over a distance of nearly 500 km, from Karnataka on the north through western Tamil Nadu to Kerala on the south, along the Western Ghat mountains. The mountain ranges of the Ghats have different names. The Nilgiri ranges of Tamil Nadu slope southwards from an elevation of 2500 m to 300 m in a 60 km wide gap at Palghat, through which the railway passes from the eastern to the western coast. The Cardamom ranges south of the Palghat Gap, which include the Anamallai hills, rise gradually to the Anaimudi peak (2695 m) in the tea district of High Range in the State of Kerala, this being the highest point south of the Himalayas. From here the altitude drops gradually towards the south through the tea districts of Central Travancore including Mundakayams and South Travancore. Much of the tea to the north of the Palghat Gap is grown on the slopes of the Nilgiris at a mean elevation of approximately 1500 m and also in the adjoining plateau of Wynaad abutting on the western flank of the Nilgiris

Table 16. Per cent on oven-dry soil (After Mann and Gokhale, 1960)

	A	B	C	D	E	F	G	H	I	J	K	L
Coarse sand	23	1	52	23	10	55	7	13	23	0	13	5
Fine sand	26	57	25	24	9	19	28	10	38	9	30	5
Silt	22	21	13	13	20	8	29	15	14	15	27	9
Fine silt	8	13	4	16	20	10	26	23	8	35	8	22
Clay	15	4	3	18	32	4	7	30	10	28	16	10
Loss on ignition	5.8	3.1	3.0	5.2	9.8	4.0	3.5	9.0	5.5	11.0	5.1	46.0
Organic matter (Grandeau)	1.55	1.35	1.20	2.20	3.10	2.40	1.50	3.50	2.20	4.00	1.60	25.00
Nitrogen	0.106	0.085	0.071	0.096	0.135	0.130	0.085	0.180	0.120	0.220	0.130	0.600
Total phosphoric acid	0.075	0.051	0.060	0.046	0.130	0.090	0.160	0.095	0,300	0.072	0.100	0.200
Available phosphoric acid	0.011	0.009	0.012	0.003	0.012	0.021	0.055	0.020	0.140	0.005	0.025	0.050
Available potash	0.009	0.008	0.004	0.007	0.018	0.008	0.015	0.043	0.120	0.015	0.005	0.040
Available lime	0.020	0.013	0.033	0.030	0.025	0.021	0.150	0.050	0.050	0:080	0.020	0.030
pH water extract (15:50)	5.7	5.6	5.6	5.2	5.4	5.3	5.8	5.2	5.6	5.2		4.8
pH KNO_3 extract	4.6	4.5	4.6	4.4	4.2	4.5	4.8	4.6	4.6	4.5		4.0
Insoluble silicious matter	84	92	90	80	68	86	85	71	92	78	84	53

at about 1000 m altitude. The elevation of the large Anamallai tea district is about 1000 m while the highest grown tea at an average elevation of 1500 m occurs in the High Range. The elevation of the tea areas of central Travancore is around 1000 m beyond which the altitude drops to less than 300 m in South Travancore. In addition to these, some tea is grown in the district of Coorg in Karnataka and in the Madurai and Kanniya Kumari districts of Tamil Nadu.

The tea soils of this area are derived from gneissic rocks containing a large amount of mica. The weathering of the soils has been very considerable as is shown by the very low proportion of lime. Though the soils of different parts of South India vary considerably, all are sedentary soils, except in the Wynaad where the detritus from the Nilgiris and other hills has got mixed up with the soils formed *in situ*.

In South India, tea was planted almost entirely on clearings of virgin forest. The soils are described as red and lateritic loams enriched by forest humus. Analyses of typical soils from a few important tea tracts of this region, reproduced in Table 17, show that these soils are richer in nitrogen, organic matter and potash than the soils of N.E. India, with the exception of the *bheel* soils.

The Nilgiri and Wynaad soils contain a much higher percentage of clay but the soils of the other, regions are distinctly open in texture. The acidity generally ranges from pH 5.0 to 5.8 but less acid soils occur in the High Range.

Sri Lanka

Tea is grown on the mountainous south-west part of the island from a few metres upto an elevation of 2100 m above sea level. Planting is done on mountain slopes, sometimes at very steep gradients and occasionally on rocky soils of shallow depth. Like the tea soils of South India, Sri Lanka tea soils are formed *in situ* from gneissic and granite rocks. Most soils are reddish brown in colour but occasionally with highly coloured patches of quartz. The soils generally contain a high percentage of iron and aluminium oxides and correspondingly low percentage of silicious matter, indicating their partial laterisation and very old age. However, mechanical analysis does not reveal the ages of these soils as clearly as of the older soils of N.E. India (Harler, 1924 b).

The land used here for planting tea falls into three categories. Forest soils either planted directly with tea or planted first with coffee and afterwards with tea. Next comes the patanas which are grassy downs common in the province of Uva. The third variety is *chena* which is land cleared by burning for growing other crops before being used for tea cultivation: The forest soils are the best but planting has been extended to the other two categories of land due to scarcity of forest soil.

Soil erosion has been a serious problem in the tea areas of Sri Lanka which was aggravated in the past by faulty planting practices, thorough cultivation and clean weeding of the sloping terrain. Considerable damage was done to the soils until the problem started receiving serious attention after publication of the report of the Committee of Soil Erosion (1931). Because of erosion, the soil now seen in many Sri Lanka tea estates is not what it used to be when tea was first planted. Perhaps on account of this, Harler quoted analytical data of some forest soils of Sri Lanka to compare them with the tea soils of N.E. India. Some of his data are reproduced in Table 18.

A relatively high percentage of the oxides of iron and aluminium and low percentage of insoluble sand and silicious matter compared to the soils of N.E. India are the characteristic features of these soils. Only the Red Bank soils of the Dooars show some resemblance to these soils. Being formed from the same type of rocks under climatic conditions, which are closely similar, Sri Lanka tea soils have close affinity to those of South India. The soils are rich in nitrogen and organic matter although the loss on ignition values, being inclusive of combined water, are overestimates of the organic matter status of these soils. The effect of low temperature (high elevation) on organic matter build up is clearly seen in the samples from Nuwara Eliya.

Table 17. Per cent on oven-dry soil (After Mann and Gokhale, 1960)

	High Range	Anamallais	Nilgiris	Central Travancore	South Travancore	Wynaad
Coarse Sand	38	35	25	28	43	26
Fine Sand	27	32	23	36	19	18
Silt	20	15	18	13	9	20
Clay	15	18	34	23	25	35
Loss on ignition	17.0	15.2	14.8	15	11.7	12.0
Nitrogen	0.350	0.280	0.240	0.220	0.150	0.170
Total phosphoric acid	0.130	0.140	0.110	0.130	0.090	0.064
Available phosphoric Acid	0.010	0.009	0.004	0.008	0.005	0.003
Total potash	0.580	0.430	0.290	0.370	0.300	0.280
Available potash	0.040	0.030	0.023	0.024	0.025	0.022
Coarse gravel & stones	30	35	20	30	15	15

Figures quoted by Hope (1916) show that the Sri Lanka soils in general retained large quantities of nitrogen even after carrying tea for two-three decades. Many estates located between 900 and 1800 m elevations had 0.11 to 0.34 per cent nitrogen in the top soil while those below 900 m had 0.09 to 0.16 per cent.

Although the average acidity of the tea soils of Sri Lanka is not as low as the virgin soils indicate, yet they are much less than that of the N.E. Indian soil. The reserve acidity of the soils seem to be fairly high to permit healthy growth of tea.

Indonesia

Java and Sumatra are the two islands of the Indonesian archipelago where tea is cultivated. Hope (1916) has given a full account of the geology, formation and characteristics of the tea soils of the two islands.

A chain of volcanoes stretch along the entire length of Java from east to west and the surface soils of nearly 75 per cent of the island consist of weathered products of the eruptive rocks. Granites and shales which make up the foundation of the island are rarely seen on the surface because they were covered up during the tertiary period by volcanic material. The eruptive rocks, andesite and basalt, are of the basic type containing less than 60 per cent silicic acid in combination with basic oxides of lime, magnesia, soda, iron and aluminium. However, the volcanoes in Java with few exceptions have thrown out chiefly ash, sand and dust and not lava. Most of the tea soils are sedentary and are formed *in situ* by the weathering of eruptive rocks or volcanic ash, sand and dust.

The basic rocks from which the tea soils of Java are mainly derived differ from the acid rocks such as those found on a large part of the Himalayas in that the former is richer in substances of direct use to plants. This is an advantage, which has been reinforced from time to time by fresh volcanic eruptions throwing up materials of the same type in the surrounding areas and renewing the fertility of the land. Most of the tea estates of Java are situated in the tract of land where this has happened.

Table 18. Forest soils of Sri Lanka from different tea districts. Per cent on oven dry soils excluding gravel (After Harler 1924 b)

	Sabaragamua		Central Provinces		Uva	
	Permadulla	Ratnapura	Kandy	Nuwara Eliya	Paliagoda	
Galhada						
Coarse sand	34	39	39	20	34	30
Fine sand	16	29	22	19	33	30
Silt	13	15	10	13	8	10
Fine silt	17	14	22	23	15	14
Clay	20	9	8	25	10	15
Loss on ignition	15.2	16.8	9.1	21.4	5.5	5.5
Oxides of iron and aluminium	26.8	24.3	23.7	30.2	15.4	19.6
Sand & silicates	51.1	53.9	60.8	41.3	75.3	69.1
Lime	0.28	0.20	0.38	0.22	0.18	0.20
Nitrogen	0.252	0.207	0.140	0.431	0.112	
0.140	Available potash		0.018	0.007	0.019	
0.014	0.034	0.016	Available phosphoric			
acid	0.0006	0.094	0.006	0.010	0.003	
0.005						
Acidity (pH)	6.9	7.1	6.7	6.4	7.2	7.4
Coarse & fine gravel	82	46	37	34	11	37

Tea is planted on mountain slopes upto an altitude of 2000 metres. Estates on the higher slopes of mountains are on soils derived from recent volcanoes. These soils are stoney, greyish in colour and more basic while at lower elevations soils are more completely weathered, less basic, reddish and devoid of stones.

The tea soils of Java are classed as laterites (Hope, 1916). However, as mentioned earlier, the process of laterisation is controlled by climatic factors and vegetal cover. Since temperature changes with altitude and rainfall varies widely in Java, laterisation has not proceeded everywhere to the same extent. At lower elevations where rainfall is persistent, temperature high and water moves downward through the soil all the time, the red lateritic soil is formed. At higher elevations where temperatures are low, the laterisation process is slowed down. The process is reversed at still higher latitudes where the climate is much cooler and a thick carpet of organic matter covers the decomposing layer of rock. The layer is bleached by the humic acids as they are washed down by water and the acidic water percolating through the layer washes down the salts of iron and aluminium to lower depths. In other parts of Java where percolation of water through and evaporation of water from the soil occur alternatingly due to uneven distribution of rainfall at different seasons; black and brownish soils are formed.

Soils in Java were classified into four major types, the mechanical analysis of which are given in Table 19. Harler (1928) recalculated the original data (Deuss, 1971) to conform as nearly as possible to Hall's limits for the various fractions.

The last type represents the geologically old soils with very high proportion of clay. Pengalengan soils resemble some of the young volcanic soils containing high proportions of sand. These soils are rich in organic matter and nitrogen as can be seen from Table 20.

The soils are generally low in phosphoric acid although it tends to increase at higher elevations. Potash content is usually low but the soils are richer in lime and magnesia.

Table l9. Mechanical analysis of Java soils. Per cent on dry weight

Soil type	Gravel	Coarse	Fine sand	Silt sand	Fine	Clay silt
Very young volcanic	47	37	2	2	5	4
Young volcanic	7	32	31	11	14	5
Pengalengan	2	24	39	16	13	6
Old soils	0	1	3	3	16	73

The soils are acidic but like the soils of Sri Lanka, the pH is on the high side. The best tea soils have a pH around 5.5 though tea has been successfully grown at a pH of 6.5 and above. On less acid soils tea bushes are said to be more prone to the attack of the root disease *Rosellinea arculata*.

Despite many favourable points, these soils are very prone to erosion. The Dutch, who started the tea industry in Java, were fully conscious of this problem and took effective measures for soil conservation.

Of the two districts of Sumatra where tea is grown, one is on the Padang highlands near the south-west coast and the other is on the Siantar plateau near lake Toba on the north-east coast. The average elevation of tea on the south is 1000 m, about 300 m higher than on the north.

The soils of the Siantar district is of volcanic origin but very different from those of Java since the eruptive rock is highly acidic. The surface soil is dark, loose, friable and of good tilth. Large, glistening patches of minerals appear on the soil after heavy rain, indicating that finer particles get washed away. The subsoil is clayey and yellowish white in colour, which is impervious to water. The soil on the whole is shallow and easily erodable. Tea grows well in this district because the surface soil is rich in humus and mineral nutrients.

The soils on the South coast are black on the surface and full of humus while underneath is a porous red brown mixture of clay and sand through which water can easily move. Below this is an impervious layer of white clay. Tea does not grow well if this layer occurs near the surface.

In the south, tea is planted on steeper slopes than in the north. Steepness of the land aggravates erosion of soils in the southern districts although soils here are less erodable than those on the north. Richness of the soil and lower elevation of the estates make tea bushes grow somewhat faster in the Siantar district than in the Padang highlands.

Table 20. Chemical analysis of volcanic tea soils of Java. Per cent on dry weight (After Mann, 1935)

	A	B	C	D	E	F
Humus	4.3	8.1	6.5	6.7	11.9	4.7
Combined Water	11.7	13.8	13.0	10.2	5.9	11.5
Nitrogen	0.20	0.39	0.29	0.25	0.46	0.23
Total phosphoric acid	0.07-0.22	0.22	0.14	0.04	0.14	0.07
Total potash	0.05-0.22	0.03	0.05	0.07	0.08	0.04
Total lime	0.04-0.46	0.04	0.07	0.66	0.93	0.35
Total magnesia	0.10-0.31	0.06	0.03	0.37	0.76	0.40

A. Young estate in the Preangers
B. Good estate in the Buitonzorg district
C. Particularly productive estate.
D. Very productive estate
E. Grassland of the same kind as D.
F. Fertile estate on black soil.

The analysis of soil samples from a tea estate in the Siantar district (Table 21) is extracted from a report by Hope (1916). The chemical analysis of Table 21 is based on two separate samples from the same estate.

A porous subsoil and comparative richness of the soil in phosphate make Padang highlands more suited to tea cultivation than the Siantar plateau. The soil and a more congenial climate indicate better scope for expansion of tea cultivation along the southern coast.

Table 21. Analysis of soils from Sumatra

	Percentage
Stone and gravel > 3 mm	10.0
Coarse sand	26.8
Fine sand	16.2
Silt	21.1
Fine silt	10.3
Clay	16.6
Moisture	4.4- 5.0
Organic matter and combined water	13.0-13.6
Oxides of iron and manganese	3.6- 4.4
Oxides of aluminium	11.3-11.6
Sand, silicates etc.	64.4-65.9
Nitrogen	0.21
Total phosphoric acid	0.038-0.040
Total potash	0.408-0.426
Total lime	0.220-0.450
Total magnesia	0.590-0.634
Acidity	Fair to neutral

China, Japan and Taiwan

In China tea is a village industry confined largely to the south-eastern provinces where climatic conditions are more favourable for the crop. Planting being done in small patches, the tea areas spread over vast territories where many different types of soil are found. Tea is planted usually on slopes of low hills alongside other crops.

The commonest type of tea land in this region is somewhat heavy and acidic in reaction with a pH around 5.0 and contains little, or no free lime. The soil is deeply weathered.

The surface horizon to a depth of about 150 cm is brown to reddish brown in colour and medium to markedly heavy in texture. A brownish and clayey layer is usually found below a depth of about 180 cm. The soil is often a loam or a clay loam and is well-drained (Mann, 1935).

The heart of the tea districts of Japan is Kanaya in the Shizuoka prefecture of the mainland, Honshu. As in China, tea is grown by peasants in small patches on any available piece of land. They prefer to grow other crops like rice in their best plots. Most of the tea is planted on exposed hill slopes where other crops would not grow or fare well. Among the exceptions, mention may be made of a fairly large area near Uji where tea is planted on land at a low elevation.

The tea belts of Japan are located mostly on the eastern coast where temperature during summer remains higher than in the west. Kanaya is situated on the Pacific coast between the rivers Oi and Tarrya. Tea plantations start from the coast and extend inland to the mountain slopes bordering the Oi valley. Some of the best teas of Japan are produced in the Kyoto district, approximately 50 km west of Kanaya.

A wide range of soils is encountered in the tea districts of Japan. At least some of these are podzols derived from granites and some from volcanic ash. Soils generally are well-weathered and sedentary although exceptions are not rare. Some tea is found on alluvial soils. The pH of the soils is nearer to 6 than to 5 and hence lower than the average of the N.E. Indian tea soils. Harler's (1924 a) analysis of a sample of soil from the Uji district is given in Table 22.

The available phosphate of the tea soils of Japan appears to be on the high and potash on the low side. Total nitrogen of most soils is high compared to .the ordinary run of tea soils of other countries. Application of large quantities of organic manure and heavy mulching may account for the high nitrogen status.

Tea soils of Japan are usually very deep and it is remarkable that the subsoil is nearly as fertile as the top soil. It is also worthy of note that in Japan the soil is believed to exert considerable influence on the quality of made tea although no clear-cut effect of soi1 on tea quality has so far been observed in any other country.

Hutchinson (1904) had described two kinds of soil on which tea is grown in Taiwan. The first of of them is a red or reddish brown loam, more or less friable and the second is a clayey, yellowish soil. The former type is found on the hilly, undulating uplands, old volcano slopes and on the plateau areas. The soil rests on a coarse substratum of sand and gravel. The other type is less common and found only in pockets. However, the famous Oolong tea of Taiwan is produced on lighter, loamy soils farther away from the central mountain range. These soils are richer than the other types in potash and phosphate.

Most soils are clearly acidic and lateritic in character.

Table 22. Analysis of a soil sample from the Uji district. Per cent on dry weight (After Harler, 1924 a)

Moisture	5.9
Soluble in dilute acid	1.0
Coarse sand	14.0
Fine sand	16.0
Silt	11.0
Fine silt	21.0
Clay	18.0
Loss on ignition	12.9
Nitrogen	0.24
Total potash	0.23
Total phosphate	0.041
Total lime	0.089
Available potash	0.043
Available phosphate	0.010
Organic matter	6.18

U.S.S.R. and Iran

The main tea tract of the U.S.S.R. is in the Republic of Georgia. It is a triangular piece of territory near the eastern shore of the Black Sea, bounded on three sides by mountain ranges except on the west. The rainfall in this area is about the highest in the U.S.S.R. Autumn and winter are the wettest seasons when tea bushes remain dormant. Tea here and elsewhere in the U.S.S.R. is planted on slopes of low hills and on level plateau land. The soils get easily eroded as the soils of Java. This has been a pressing problem for the tea industry, which has largely been overcome by adopting suitable soil conservation measures.

The principal soil types met with in the tea areas are the red-yellow earths and the podzols (Gokhale, 1958). The subsoil of the former type is heavier than the red topsoil. At intervals among this type occurs a soil which is sandier at the surface with gravel underneath. According to Mann (1935) soils on the southern part of the tea tract appear to be formed from very deeply weathered andesite but the deep subsoil has often been left in a raw condition. The stiff and underrated condition of the deep subsoil proves difficult for tea and other roots to penetrate. All these soils contain very little free lime and a pH of 5:0 to 5.5 is the normal range of acidity.

In the northern tea belts of Russia where the rainfall is less and temperature is lower than in the south, the surface soil is acidic but the layers may contain calcium carbonate in fairly large quantity. There is a great tendency here for the formation of an iron pan in the subsoil and this tendency is more prominent in grassland soils (Mann *loc. cit*). Thus, the northern parts of the Russian tea area appear less suitable for tea, both from soil and climatic considerations.

In Iran, tea is planted on the northern slopes of the Elburz mountains and on low plateaus at the base. The mountains consist of granite, gneiss, schists and some recent volcanic materials. The soils on which tea is chiefly grown are rich, red loam containing a very large proportion of silt. This is seen from Table 23.

Table 23. Tea soils of Iran (After Hope, 1941)

	Sample 1	Sample 2
Moisture	1.9	1.9
Coarse sand	2.2	8.1
Fine sand	18.1	11.9
Silt	50.5	45.5
Fine silt	7.6	10.5
Clay	18.6	21.1
Loss on ignition	6.3	7.2

Africa

Writing about the soils of the Kericho district, the main tea tract of Kenya, Bates (1975) has observed that the original volcanic lava had eroded and decomposed *in situ* to varying depths giving rise to a dark, red soil. Most of the Kenyan tea soils are of the same kind. All are well-drained, deep to extremely deep, friable clay with an acid humic topsoil. The normal range of acidity is 4.2 to 5.2 with a few minor exceptions. The clay content of the surface soil is around 40 per cent but it increases upto 80 per cent at lower depths. The soil has the capacity to absorb large quantities of water but it gets slippery under pressure, which makes it very prone to erosion. In spite of the very high clay content, these soils behave like loam but their proneness to erosion poses a major problem to the tea growers.

Isolated pockets of soil washed down from the mountains can be found within this major type. These pockets of soil are coarser and less acid. All these soils are very rich in organic matter and nitrogen but their lime content is very low. Analysis of a typical soil of the Kericho district is given in Table 24.

The soils of the seven tea districts of Uganda differ to some extent in their physical and chemical compositions but all are highly weathered deep soils. These soils are very rich in organic matter and other plant food but are more open and less acid than the tea soils of Kenya.

Table 24. Soil from the Kericho district. Per cent on dry weight (After Njihia, 1969)

	Sampling depth in cm		
	0-8	26-41	69-93
Sand	22	6	7
Silt	39	30	18
Clay	39	64	75
Carbon	13.1		
Nitrogen	0.9		
pH	5.4*		

*pH of calcium chloride extract, 1 : 2.5

Mufindi and Rungwe are the two important tea growing tracts of southern Tanzania. According to Mann (*loc. cit.*) the forest belt of Mufindi where tea is cultivated at an altitude of 1700 to 2000 m is highly weathered granite and gneiss. Despite its high clay content, the soil is described as a loam. The acidity of the surface soil is high with a pH around 5.0, the subsoil being still more acid.

Two major soil types are found in the Rungwe district. On the higher slopes of the Rungwe mountain above 1500 m, the volcanic soil is black and clayey with a subsoil interspersed with beds of pumice. The soil, particularly the subsoil, is sparsely acid with a pH around 6.0 but the pumice layers are still less acid. The pumice tends to dry up quickly impeding root penetration. At lower elevation, the soil is a red loam derived mostly from volcanic material. The subsoil is porous and has a pH of about 5.0 but the top soil is less acid.

In the Usambara mountains on the north-east, conditions are tropical. The soil produced on the spot from gneissic rocks is very deep and is chocolate to dark red in colour, tending to become lighter at lower depths. To a depth of about 180 cm, top soil is loamy which gets stiffer at greater depths. The topsoil is acid, a pH of 5.5 to 6.0 is the normal range. However, the soils erode easily although the very dense forest puts a check on erosion. Proper anti-erosion measures are necessary at the time of clearing land and during the early years of planting tea.

In Malawi the first tea was planted on the south-west face of the Mlanje mountain at an elevation of 700 to 1000 metres. The mountain is composed of gneissic rocks and the washings from the mountain constitute the soils on which tea is grown. These are deep, freely draining alluvial soils classed as sandy clays or sandy clay loams. The other tea district Cholo is at the base of the Cholo mountain on the opposite side of the same valley. The bulk of the soil of this area is sedentary. These soils are described as varying from red loams to laterites. Pockets of black soil occur at each location. These soils are less clayey and more sandy.

Tea soils in Malawi suffer from the deficiency or non-availability of sulphur and this is manifest by a disease of the tea bush called Yellows (Storey and Leach, 1933). Certain soils of Tanzania and Mozambique have also been found deficient in sulphur. Application of sulphur or ammonium sulphate eliminates the diseased symptoms. In certain highly organic soils of the Mlanje district, tea shoots do not oxidise (ferment) properly after rolling. This was traced to the deficiency of copper in the leaf, which is an important constituent of the enzyme, polyphenol oxides, responsible for bringing about oxidation of the catechins present in the tea 1eaf. Spraying of dilute solutions of copper salts improves fermentation. (TRFCA Ann. Rep.,1968-69).

Analysis of a few soils from Mlanje and Cholo districts are given in Table 25.

Table 25. Soils from Mlanje and Cholo districts of Malawi. Per cent on dry weight (TRFCA Ann.Rep,1961-62)

	Mlanje		Cholo	
	Red Soil	Black Soil	Red Soil	Black Soil
Coarse sand	23	32	28	32
Fine sand	16	31	22	25
Silt	8	10	6	10
Clay	45	23	37	24
C:N	12.3	10.2	12.4	15.1
pH	5.3	5.1	5.4	5.1

MINERAL DEFICIENCY

Before closing this chapter, the present state of mineral deficiency of tea soils is worth recording.

Deficiency of potash in some tea soils was recorded more than half a century earlier. Use of potash as a fertiliser for tea is increasing steadily since the war. It is now used throughout the world and the rate of application is increasing. Deficiencies of other elements have since been reported from time to time. de Haan (1941) first noticed magnesium deficiency in certain tea soils of Java. Tolhurst (1954) reported the appearance of magnesium deficiency symptoms on tea bushes of Sri Lanka. Since then magnesium deficiency has appeared on tea bushes in many parts of the world and application of magnesium salts, usually dolomite, has become a regular practice in Sri Lanka, South India, Indonesia and many of the African countries. Magnesium deficiency symptoms have sporadically been observed on certain tea bushes of N.E. India during the dry part of the year. The symptoms disappear with the coming of the rains and response in terms of yield to the application of magnesium salts has not so far been reported. Deficiency of zinc was also first reported from Sri Lanka (Tolhuist, 1962). Judging from yield response, the deficiency of this element appears to be more wide-spread than that of magnesium. At present a very large part of the tea-growing world applies zinc to tea bushes mainly in foliar sprays. Along with magnesium, Tolhurst also reported the appearance of manganese deficiency symptoms on some tea bushes of Sri Lanka. However, deficiency of this element appears to be sporadic and its occurrence has not so far been reported from many places: Reference has already been made to the deficiency of sulphur and copper in certain soils of Central Africa. Boron deficiency in tea and *Grevillea* has also been reported.

Yield of tea per unit area of cropping surface is increasing steadily in all countries. It has approximately doubled during the last 25 years. With the use of high-yielding planting material and improvement in field management practices, yield can be expected to increase faster in the coming years. The quantity of minerals removed from the soil is also increasing along with the harvested crop. In the past when plenty of firewood was available, tea prunings were left alone to decompose *in situ*. Now-a-days hardly any pruning remains in the tea fields. These are taken away to be burnt as firewood. Along with the pruning litter, large quantities of minerals, more than the amounts removed by crop, go out of the tea soil permanently.

An idea of the amount of nutrients removed with the prunings can be had from the balance sheet of supply and utilisation of nutrients prepared by Willson (1969) in East Africa. Prunings at the end of a three-year cycle weighing 24000 kg per hectare, contained 785 kg nitrogen (N), 135 kg phosphate (P_2O_5) and 570 kg potash (K_2O). The corresponding quantities of nutrients removed by the tea crop of 5050 kg per hectare during the same three-year period were 252, 40.5 and 108 kg of N, P_2O_5 and K_2O, respectively. Estimates made elsewhere tell the same story although the quantities may vary to some extent due to differences in pruning, plucking and manuring practices and the quantities of matter removed. Use of acid forming fertilisers like ammonium sulphate has increased manifold during the last 50 years, aggravating the leaching loss of the basic soil minerals. With the exception of a few countries like Japan, organic manures like oil cakes, animal meals and farmyard manures are now rarely used on account of their scarcity and high cost. A combination of all these factors is draining the tea soils of the essential minerals at accelerating rates. The quantities of trace elements released by the soils are proving inadequate to meet the requirements of the tea crop. More wide-spread deficiencies of these elements can be expected with the passage of time and other elements like molybdenum may also get deficient unless corrective measures are initiated without further loss of time.

Renewal of interest in recent years on the use of lime is an indication of the concern of the scientists at the development of excessive acidity in tea soils. While efforts to control acidity should be pursued with vigour, no pain should be spared in maintaining the organic matter status of the soils at a high level. This will go a long way in preventing micro-nutrient deficiency, arresting rise of soil acidity, checking soil erosion and conserving moisture during periods of drought.

Mulching with grasses, leaves or any form of organic matter is the only alternative to the application of bulk manures for building up organic matter status of tea soils. Annual mulching of young tea should be a regular feature in all tea estates. Mature tea should also be mulched, particularly during the pruned year, if the pruning litter cannot be retained in the field. It might be more convenient and less costly to chop up the pruned branches and scatter them as mulch. Getting the material required for mulching can be a serious and costly problem for many tea estates. It is, therefore, necessary to make provision for raising, mulch crops. This matter should receive no less priority than application of chemical fertilisers unless mulch material can be procured cheaply from outside sources.

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CHAPTER 6

PLANT IMPROVEMENT

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OBJECTIVES AND BASIC CONSIDERATIONS

Discovery of a simple method for vegetative propagation of the tea plant paved the way for breeding of tea on scientific lines. The method was discovered in the early thirties but its standardisation for large-scale use in tea estates took nearly 15 years. Vegetative propagations commenced on a commercial scale only after the Second World War.

Improvement of yield and cup characters of made tea, the two major objectives of tea breeding, are common to all tea-growing regions. High yield per unit area is of primary importance not only for tea but for all crops but quality of the product cannot be subordinated to yield. A combination of both should be the aim. The tea drinking public is conscious of quality. To cater to the taste of the consuming public, the world tea market in the course of time has evolved fairly critical standards for teas from different parts of the world and market standards that the products conform to the set standards. Other objectives of breeding vary according to the requirements of different regions. Cold tolerance is a primary objective of the tea breeders of countries like Japan and the U.S.S.R. where low temperature injury is of common occurrence. Development of clones and seed varieties resistant to blister blight (*Exobasidium vexans*) will immensely benefit the tea growers of Sri Lanka, South India and Indonesia. If left uncontrolled, this disease causes heavy loss of crop and its control is costly. Production of drought-tolerant cultivars will be a relief to growers in many parts of the world. Increasing the length of the harvesting season through the development of suitable cultivars will benefit tea growers at higher latitudes to a very great extent. Likewise many other objectives of tea breeding will be of regional nature.

Simultaneous achievement of all the economically desirable objectives will not be practicable but some of these can be realised at a time through the selection of outstanding plants and their multiplication as vegetative clones or by breeding improved strains of seed. Elite clones and improved strains of seed superior to the existing seed populations can both be used for commercial cultivation. There is no valid reason for the exclusive use of one in preference to the other. Bushes for vegetative multiplication as clones can be selected from the commercial populations of mature, hybrid tea or from progenies produced specially for the purpose by crossing different plants. Selection from the existing fields of mature tea is necessary for meeting the immediate need of the tea industry for improved planting material but its acceptance as the ultimate goal rules out further improvement of the crop. Besides, the sources of selection will get exhausted after a time, ending up in a few clones.

Any seed progeny may be the source material for selection of vegetative clones but to qualify as a seed variety for commercial cultivation, a progeny must have high yield, good cup quality and an acceptable degree of morphological uniformity, because a highly heterogeneous population creates problems of management, both in the field and in the factory. The seed yield of the parental clones should also be sufficiently high to make the seed producing units economically viable and to keep the cost of seed down at a reasonable level. Production of clonal seed varieties fulfilling all the requirements is an arduous task but it should not be used as an argument against the merit of seed varieties which possess certain distinct advantages over vegetative clones.

Seed vs Clone

Barua (1963) has observed that the basic difference between clone and seed progeny is one of adaptability. A seed population composed of a large number of genetically distinct units, is elastic and can be fitted into a wide range of cultural and environmental conditions without much change in its overall performance. On the other hand, thousands of bushes of a clone widely separated in space and time behave, in most ways, as a single bush. Consequently a clone lacks elasticity which makes it more selective of environment and cultural treatments. The problems connected with the use of clone stem from this basic difference. It follows that a clone will be more sensitive to any change in soil and climate than a seed population.

Being genetically different, all bushes in a seed population are unlikely to suffer equally from the incidence of a disease or a pest but all bushes of a clone will be equally susceptible. Teas made from different bushes of a seed population differ in taste but the tastes of individual bushes are merged when leaf from all the bushes are manufactured in bulk, as it happens in practice. The resulting tea from bulk manufacture is an integration of different tastes. It is an advantage from the point of marketing. On the other hand, leaf manufactured from a clonal field retains the distinctive characteristic taste of the mother bush, which is one among many bushes of a seed population. Teas manufactured from a single clone of good quality may not be acceptable to the buyers unless they are assured of a regular supply of the same product in sufficient quantity to meet the requirement of a particular blend. Teas made from the mixed leaves of a number of clones also suffer from the same disadvantage. Besides mixing of leaves from different clones before or after manufacture poses a number of problems which will be discussed later.

Against these drawbacks, clones have certain advantages not found in seed progenies. Being extension of a single bush, all members of a clone are morphologically alike. As clones are selected for high yield and good cup characters, every bush in a clonal field can be expected to produce high yield under a given set of conditions and good cup quality. Cultural treatments like pruning, plucking, manuring and control of pests and diseases can be standardised for a section of clonal tea. Besides, better control can be exercised over the manufacturing operations with shoots harvested from a single clone. However, to guard against epidemic out-break of a disease or a pest, it is inadvisable to plant large areas of an estate with a single clone. On empirical considerations, Wight (1956) suggested the use of three to five clones for planting one fifth of an estate.

Longevity of Clones

Clonal progenies raised by vegetative propagation of nodal cuttings are in cultivation in many countries for the last 25-30 years. A small plot of clonal tea has been growing at Tocklai for over 50 years with less than 10 per cent mortality. This is a clone raised from an Assam type bush which was one among many bushes randomly selected by Tunstall (1931 a) for his early experiments on vegetative propagation from nodal cuttings. The clonal plot has throughout been treated in the same way as other seed-grown tea in its neighbourhood without any extra care. These are clear indications that under any given set of conditions clones may live as long as seed populations.

However, it will be wrong to assume that all clones will live long under diverse soil-climatic conditions. There is an instance from N.E. India where a clone (TV2) had died for no apparent reason after growing vigorously in a locality for 8-10 years, although the same clone has not shown any sign of debility in other areas even after 30 years (Rustogi and Bezbaruah,1979). Even in the locality where this particular clone has failed, other clones have shown no sign of suffering. These facts emphasise the sensitivity of clones to soil and environmental conditions and stress the need for testing the performance of each clone in different soil-climatic environment for a sufficiently long time before releasing them for large-scale cultivation. Once the adaptability of a clone to a particular set of conditions has been established then, under those conditions, the clone can be expected to thrive as well as any seed progeny. In the absence of proper tests or knowledge about the performance of a clone in a particular locality, its durability in that locality becomes a matter of speculation.

Clone and Seed Complementary

The question often asked is — what will happen to clones when clonal seed becomes available on a commercial scale. By the time such seeds become available, a part of the area of a tea estate in many regions would have been planted with elite clones. When improved varieties of seed become available, it is possible that growers would prefer to make use of seed as seed is less troublesome than cutting initially and is more adaptable. The seed phase will continue for some time until better clones are selected from the seed progenies. The choice then is expected to shift to clones. If the breeders remain active they will eventually produce seed varieties to match with the new generation of clones. The emphasis will then change again to seed (Barua, 1963). The race between seed and clone is expected to continue, one complementing the other, and clones stimulating development of better and better strains of seed. This is represented schematically in Fig. 15.

While screening bushes for vegetative clones in mature seed-grown fields of commercial tea or in clonal progenies specially bred for the purpose, plants having distinctive features should also be retained. Such plants may not have any value as vegetative clones, but may prove to be important breeding material. The terms ‘generative clone’ is used to distinguish such clones from the ‘vegetative clones’. Vegetative clones can also be used for the purpose of breeding seed varieties as indicated in Fig. 15.

It is possible to bypass either the phase of seed propagation or vegetative propagation but to effect genetic improvement of the tea crop, breeding of improved strains of seed cannot be avoided. Recombination of the desirable traits e.g. yield, quality, resistance to disease, drought etc. of different clones through appropriate breeding procedure should be the aim. Among the progenies of clonal crosses, some plants may combine a few desirable traits. Such genetically improved plants will get selected as vegetative or generative clones. The new generation of clones, both vegetative and generative, will be the progenitors of the next generation and so the process will continue. If

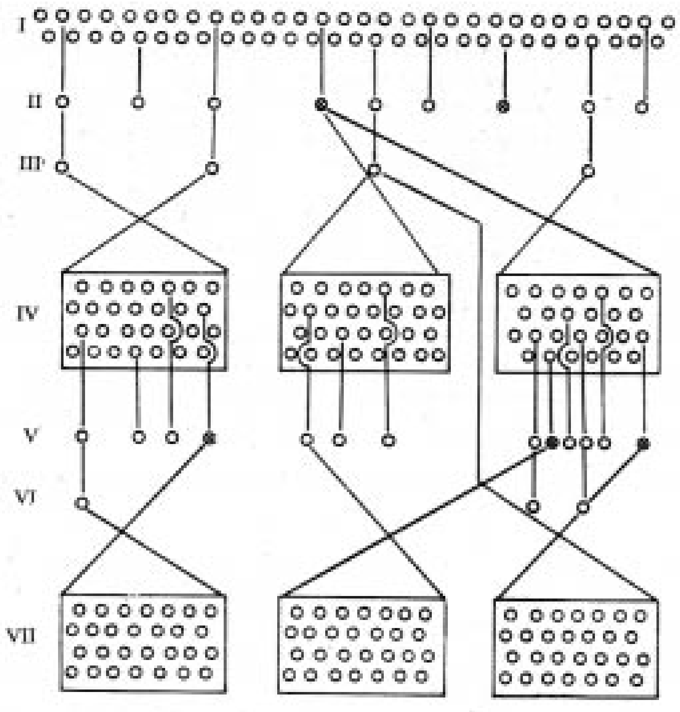

Fig. 15. Schematic representation of the procedures indicated in the text for the selection of vegetative clones and breeding of clonal seed varieties in tea.

I Seed-grown bushes from which mother bushes are selected.

II Mother bushes retained after preliminary selection, including bushes with special characters (marked with a cross), which may prove useful as generative clones.

III Mother bushes retained as vegetative clones after final selection.

IV Performing crosses between pairs of clones. Clones selected for vegetative multiplication may also be included in these crosses. The clonal progenies are tested for their suitability as seed varieties for commercial cultivation.

V Preliminary selection of mother bushes from the progenies of biclonal crosses.

VI Final selection of second generation of vegetative clones.

VII The breeding cycle is repeated as above for the production of third and subsequent generations of clones.

If a clonal progeny is found suitable for commercial propagation, then the two parental clones are multiplied vegetatively for establishing seed orchards.

vegetative propagation on a commercial scale is not desired then improved seed varieties can be developed for large-scale use as suggested in Fig. 15.

Visser (1969) recognises the limitation of clonal selection from existing tea fields and stresses the importance of breeding for overall genetic improvement of tea. But considering that good clones can be developed more quickly and easily than seed varieties, he seems to prefer vegetative clones for commercial propagation. According to his calculation, it takes 8-10 years to develop a batch of clones and 21-26 years to develop seed varieties.

However, these time schedules are not universally applicable. In Japan, it takes about 15 years to develop a clone (Amma, 1975) which perhaps applies to other cold countries. Using recent experience of Tocklai as a guide, a seed variety can be developed in approximately 15 years and a clone in about 10 years. Although production of seed varieties takes more time, breeding for seed varieties and selection of clones from progenies of clonal crosses can proceed simultaneously as shown in Fig. 15. When a potential pair of generative clones is located by preliminary examination of its progeny within the first 2-3 years from seed, a micro-seed bari could be established for seed production with vegetatively propagated plants of the two clones. Production of seed can be advanced by about two years by grafting the clones on mature root stocks. Hence nursery selection of plants for trial as clones and planting of micro-seed bari can be carried out almost simultaneously. Furthermore, a clone requires more rigorous trials and adaptability tests than a seed progeny. Secondly, some tea growing regions which experience severe cold or drought prefer seed varieties to clones on practical grounds.

From these considerations and judging from current developments, total displacement of seed from the tea industry of the world by vegetative clones can possibly be ruled out. It is more likely that development of seed varieties and selection of clones from old tea areas as well as from specially bred progenies will proceed simultaneously. The growers would then have the option of using either clones or seed varieties superior in merit to the existing planting material. The choice of the growers for one or the other will depend primarily on the performance of the material and soil-climatic environment of the locality. Other considerations such as the presence of a serious disease or a pest in the locality, economic soundness of the tea estate, availability of labour etc. will also influence the choice. If the present trend in N.E. India is any guide, then given seed and clone of similar merit, most growers will prefer seed.

SELECTION OF VEGETATIVE CLONES

Variability in Tea Populations

The wide bush to bush variation that exists in any field of seed-grown tea will be apparent to any casual observer but the extent of variability was perhaps not fully realised until yields of a large number of bushes were recorded separately (Tunstall 1931 b; 1933; Wellensiek, 1934; Tubbs, 1938; Kehl, 1951). Some of these records show that a few bushes may yield four to five times or even more than the average yield of a population, while some other bushes may yield only a small fraction of the average. The range of yield variation differs with the nature of the seed population. A population of highly mixed ancestry exhibits a wider range of variability than a more uniform *jat* of tea. But variation exists in all seed populations whatever may be its range. This makes selection of bushes superior in yield to the average yield of a population a possibility in any seed progeny. Besides yield, the bushes differ in other desirable characters like cup quality, disease, pest and drought resistance etc. A bush must combine some, if not all, the desirable characters to be eligible for selection as a superior bush fit for vegetative multiplication as clone. Such bushes are scarce so that very large number of bushes have to be screened in order to get a single, suitable clone. According to estimate made by Wight (1956), on an average, one out of 40,000 bushes in a seed progeny will be outstanding in yield and cup characters. Visser (1969) and his co-workers in Sri Lanka also arrived at the same figure. Inclusion of other attributes like drought and disease resistance in addition to yield and quality will make the size of the selection unit even bigger.

The yield variation observed between bushes in a field of seed-grown tea is attributable partly to genetic diversity and partly to the location of the bushes. Although the exact contribution of the genetical and environmental factors to total variability is not known, the effect of environment seems to be quite profound. Visser (1969) observes that soil heterogeneity may account for a yield difference of 100 per cent or more of the same bush at two separate locations in a tea field.

Notwithstanding the serious limitation imposed by environmental factors in determining the yield potential of a bush, quick estimation of bush vigour as an indicator of yield is the first step in the screening of seed-grown tea bushes for the selection of vegetative clones. During screening, a certain proportion of the bushes retained as high-yielding or rejected as low-yielding are, in reality, artifices of environment. This situation is obviously unsatisfactory but will persist so long as reliable criteria for detecting genetically superior bushes are not evolved.

Many tea research institutions have formulated detailed schemes for quick elimination of a large number of supposedly low-yielding bushes by eye judgement in the field. Procedures for more thorough examination of the bushes retained after field selection until final selection of a few of them as clones have also been worked out. All these selection schemes fall into the same basic pattern although emphasis on individual selection criterion varies from region to region on account of differences in soil-climatic conditions, type of plant, cropping pattern and the kind of tea made. For instance, size of leaf can be a useful selection criterion in areas where only the small-leaf China bushes are cultivated. Early and late flushing bushes will carry a premium in regions with a short cropping season. Frost resistance is an important selection criterion in regions where below-freezing temperatures are encountered during the winter season. Pubescence becomes an important criterion for the production of tippy, orthodox teas. However, certain criteria like density of plucking points and weight of pruning are equally important for all regions. These and other criteria recommended for the selection of bushes for high yield and good cup quality will be examined in some detail.

SELECTION CRITERIA FOR MATURE BUSH YIELD

Size or Surface area of a bush in a mature tea field is one of the criteria recommended for estimating yield (Visser, 1961). Cohen Stuart (1929; 1930) observed correlations (0.38 to 0.68) between pruned or plucked surface area and yield of individual bushes. Similar correlations (0.52 to 0.72) were found by Visser (1969) and his co-workers working in groups of clones. Such correlations can be expected when the bushes get ample room for spread but in closely planted tea fields, the spread of a bush is limited to the space allotted to it. In the past, tea bushes used to be planted wider apart than at present. The closest spacing was around 120 cm and the number of bushes did not normally exceed 8000 per hectare. Now-a-days upto 20,000 and sometimes more bushes are planted per hectare, usually in hedge-rows, at a spacing of 60 to 80 cm between plants within the row. This system of planting leaves much less room for spread than in the past. Secondly, a large bush does not necessarily have a high density of plucking points; the reverse is generally the case. Hence, many plants selected for large size are likely to prove disappointing on account of lower return per unit area. It is, however, desirable to discard bushes with very small frames even if they carry a large number of plucking points. If selected, such clones may require very close spacing and hence a much larger number of plants to fill up a given area than clones of average size. Besides, small size may well be an expression of the lack of inherent vigour.

Leafiness or total leaf area on a bush is sometimes used as a criterion of yielding capacity. A positive correlation between yield and area of mature leaf on a bush can be expected since young shoots harvested as crop develop mainly at the expense of food manufactured by the maintenance foliage and reduction of maintenance foliage causes a proportional loss of crop (Barua, 1961a). Visser (1969) obtained significant correlations of 0.73 and 0.68 between total leaf area per bush and yield of shoots plucked from two groups of 22 and 26 clones, respectively. Toyao (1965) also reported correlation between leafiness and yield. However, caution should be exercised in selecting for leafiness, which, like the shrubby growth habit, is more pronounced in bushes of the China type. In a mixed population where Chinery bushes also exist, selections for leafiness will tend to be biased in favour of the shrubby China type. In general, such bushes will be less productive in areas where large-leaf Assam type bushes can be grown.

Leaf size which is related to size and weight of shoot, has also been used as a yield criterion. Mamedov (1961) reported positive correlation between size of leaf and yield of tea in the U.S.S.R. Correlations between leaf size, leaf number and yield were observed also in Japan (Toyao, 1966). Amma (1975) obtained good correlation between length of the growing shoots and yield. These correlations were observed in small-leaf China and China-hybrid populations where bushes with relatively bigger shoots have an advantage. No such correlation was observed in other countries where large leaf bushes predominate. (Bezbaruah, 1968 b; Visser, 1969). Selection for leaf size can, therefore, be advocated in sections of small-leaf tea. However, a bush with large leaf and big shoot has another advantage apart from yield; its plucking cost is less. On this account weightage may be given to large leaf-size provided other requirements permit.

Density of plucking point is the most important criterion for quick selection (or rejection) of mother bushes by eye. This is an estimate of the number of shoots actually plucked from a bush. The maximum concentration of plucking points occurs in the central zone of a tea bush and shoots get progressively thinner towards the periphery. This is true for all bushes irrespective of their vigour (Barua and Dutta, 1971) although in some bushes the plucking points do not decline as sharply from the centre to the periphery as in others. In eye selection, those bushes where plucking points spread upto the periphery of the bush giving a high density per unit area of the plucking surface, should only be retained.

The following morphological characters of the tea bush are supposed to contribute towards high density of plucking points (D.N.B., 1965).

Thickness and distribution of pruned sticks: The branches on a bush should not be very thick at the centre and thin towards the periphery but should be relatively of even thickness. Their number should also be large. This character can be conveniently observed after a light prune.

Bud break per stick: The number of buds to ‘break’ per pruned stick determines the number of primaries (maiden shoots). The primaries are the basic units, which sustain the crop harvested during the following years until the bush is pruned again. This selection criteria is in conformity with the observation made by Portsmouth (1957) that the number of active axillary buds on unplucked shoots is correlated with the relative yields of different clones. The correlation disappears on terminal bud removal.

Evenness of flush: All the buds on a pruned bush should ‘come away’ at the same time and grow vigorously without going banjhi at a low Ievel.

Frequency occurrence of banjhi shoots and leaf periods i.e. time taken for unfolding of successive leaves, have also been considered as criteria for yield. However, their correlation with yield of bushes in the same field has not been established. Besides, both the characters are influenced by soil-climatic environment.

The above analysis of the several criteria used for rapid eye selection of high-yielding bushes in mature fields of tea exposes their limitations. Density of plucking point is the only criterion, which gives some indication of the shoot-yielding capacity of a bush. Other criteria are essentially supplementary. Even plucking point density is not a measure of comparative yield of different bushes. Yield is the product of shoot number and weight per shoot. If shoot weight differs between bushes, which happens in any heterogenous tea population, then shoot density cannot be a true reflection of yield. This is clearly shown by Table 26.

Table 26. Correlation of yield with different growth parameters (TES Ann. Rep., 1966)

Parameter	Correlation coefficient	Predictability index
Visual estimate of plucking points	0.66	25.3
Actual number of plucking points	0.81	41.5
Fresh weight of pruning	0.85	47.0
Number of pruning sticks	0.70	28.5
Weight of tipping	0.68	27.2
Number of tipped primaries	0.61	20.9

A mature plot of 28 different clones of varying growth habit and shoot weight was taken for these observations. Yield was recorded for one growing season from April to November. Visual estimate of plucking point density was made by a trained observer followed by a count of the actual number of plucking points in November. The bushes were pruned in December, 5 cm above the previous pruning mark for recording pruning weight and the number of pruned sticks. The new crop of shoots was tipped in April of the following year when the last two records were taken. All the correlations are highly significant.

The table reveals a few important facts. The correlation between yield and the actual number of plucking points is not as high as one would expect. The low correlation is due to variation of the average shoot weight of different clones. Pruning weight is as good, if not a somewhat better, index of yield as the number of shoots plucked. The correlation between tipping weight and yield is not as close. This is understandable since tipping weight determined during the early part of the growing season does not reveal the true growth potential of all clones, some of which are early and some late starters. The number of pruned sticks and tipped shoots are not as closely related to yield as their respective weights. Visser (1969) also observed similar correlations between pruning weight and yield of the previous pruning cycle (0.89 and 0.92) and tipping weight and yield (0.57 to 0.76), of clonal bushes.

Pruning weight can, therefore, be used as a fairly reliable criterion for bush yield and tipping weight can serve to eliminate late starters i.e. bushes which recover slowly from pruning. Recording of pruning weight involving a single weighment is much less laborious than weighments of pluckings at every round for at least 8-10 rounds (Visser and Kehl, 1958; Visser, 1969). Even then the number of bushes has to be reduced to a manageable proportion through visual inspection to make pruning weight recording a practicable proposition. Table 26 shows that eye estimation of plucking point density is not a futile exercise if done properly. Its value could be enhanced substantially if shoots are categorised into a convenient number of size grades at the time of selecting bushes for high, shoot density. Given appropriate weightage for shoot size, plucking point density per unit area of bush surface will be a more realistic appraisal of bush yield than shoot density alone. If by using these eye selection criteria the number of bushes in the selection unit is reduced to a sizeable proportion, then further elimination can be done on the basis of pruning and tipping weights.

SELECTION OF SEEDLINGS FOR YIELD

Harada *et al.* (1961) found height, stem diameter and leaf area of seedlings to be reliable indices of bush vigour. Green (1971) obtained positive correlations between each of height, girth, root weight and branch angle of nursery seedlings and size and yield of the same plants at maturity. On the other hand, Amma (1973) did not find any correlation between each of girth, height, total number of leaf, leaf per stem, leaf area and two other characters of one year old seedlings and yield at maturity (8 years) of the same seedlings. Multiple regression co-efficient of the seven characters also did not reach the level of significance. Grice (1969) too did not find seedling vigour to be a reliable character for predicting yield at maturity. The cause of these conflicting reports could be the age at which nursery seedlings were taken for observation by various workers. Amma's results suggest that one year old seedlings are much too young for such correlative studies. In this connection it is worth noting that the difference in the weight of seedlings diminishes with age (Barua, I961 b). Two year old or older seedlings are likely to provide better information regarding their yield at maturity than seedlings of lesser age.

In view of the close correlatiom (0.78-0.89) reported by Othieno (1982) between yields and shoot-root ratios of four year old plants of five different clones, this ratio deserves testing as a nursery selection criterion. However, the ratio based on one year old nursery seedlings will not be reliable since the ratios of one and four year old clonal plants did not show significant correlation while those between four and 15 year old plants were highly correlated (0.98). Older seedlings will have to be used if the criterion proves to be of value.

YIELD OF A BUSH AND ITS CLONAL PROGENY

In the selection of clones, the problem does not end with the identification of high-yielding bushes. As mentioned earlier, high yield may be an inherent character of the bush or may be due to its favourable location in the field. Visser (1969) did not observe significant correlation between yields of selected mother bushes and their vegetative offsprings in any of the six groups of clones examined by him. He attributed high yield of a fair number of mother bushes to favourable soil conditions. Green (1971) did not find any relation between pruning weights, sizes and yields of mature plants grown from seed and yields of the clones derived from them, both in the early years as well as at maturity. Matsushita (1969) on the contrary reported a positive correlation (0.70) between yields of nine year old mother bushes and their four year old clonal progenies. A closer correlation like this is possible when among the selected mother bushes, the proportion of genetically superior bushes happens to be high. Since this is a matter of chance clones derived from the selected mother bushes will have to be tested independently for yield without relying on such a correlation, even when it is observed.

The foregoing account shows that suitable criteria for the selection of mature bushes and nursery seedlings for yield have not yet been found. Furthermore, there is no certainty that a high-yielding mother bush will produce a vegetative progeny which also will give high yield. This unsatisfactory situation led Green (1970) to observe that currently recommended selection methods were of little or no value and were time consuming. Visser (1969) was also of the opinion that test plucking of the mother bushes to improve upon the selection based on morphological criteria would be of little use. Since morphological criteria have failed to give reliable indication of yield, both of mature bushes and young seedlings, it is of prime importance to test anatomical, physiological and chemical parameters for the assessment of yield.

Attempts made in Africa to select mother bushes with the aid of computer have not, so far, met with success (Magambo, 1982).

WHAT IS QUALITY

Quality of black tea has not been clearly defined. In a broad sense, quality is the overall value of a tea. In other words, it is a summation of its desirable attributes. But it also has another narrow meaning. Professional tea tasters determine the value of a tea from its infusion and appearance of the dry leaf particles and of the infused leaf. The infusion is evaluated for colour, brightness, quality, strength, briskness and flavour. As an attribute of black tea infusion, quality has a narrow, specific meaning like that of colour and strength. Colour and brightness have the usual meaning. According to Wight and Gilchrist (1961 a) strength by itself imparts a bitter taste. “Bottled beer acquires briskness. The taste of malt is part of the character of beer but hops could give it a special flavour”. Flavour in tea is made up of numerous aromas that contribute to its general taste and character. Flavour differs between different kinds of tea. These authors (1961 b) define quality as “a dulcet freshness like that of a recently caught fish in contrast with one that has been too long in cold store. Without such quality the aroma of tea loses most of its value”. They conclude that “quality of tea is something that stimulates the taste-buds of the tongue and has the effect of enhancing the value of aroma”.

Quality differs from one kind of tea to another The China kind of tea has a quality different from that of the Assam kind. A tea taster accustomed to the Assam kind of tea may underestimate the quality of tea made from bushes of the China type. Quality relative to strength is higher in the China plant, conversely high strength relative to quality characterises the Assam plant (Wight and Gilchrist, 1961 b). Different kinds of tea are made in different parts of the world from more or less morphologically distinct populations. For example, Darjeeling tea is made from Chinery bushes. Plants of the Southern form do not make good Assam tea but open-pollinated seeds of these plants produce good quality teas in Sri Lanka. According to the same authors the regional kinds of tea differ greatly in the balance of attributes such as strength and quality and in the aroma which contribute to their regional character.

On the definition of quality opinion may differ but it cannot be gainsaid that the concept of quality alters with the kind of tea and its place of cultivation. A tea may be considered to be of good quality when it is produced in a particular region but coming from a different region, the same tea may not be rated high. In clonal selection the characteristics of the teas produced in a particular region have to be kept in view. This calls for change of emphasis on one or other of the liquor characters and on dry leaf appearance. However, good liquor quality, in whatever way it is interpreted, is desirable everywhere.

Selection Criteria for Quality

Simple criteria for rapid identification of tea bushes for superior quality are scarce. Wight and Barua (1954) obtained a positive correlation between *pubescence* i.e. hair on the undersurface of young tea leaves and quality of black tea infusion. Pubescence varies from bush to bush. In glabrous plants hairs occur only on the mid-rib but in highly pubescent plants, it forms a dense indumentum on the undersurface of the entire leaf lamina. These workers categorised a large number of bushes into five grades of pubescence and manufactured leaf from each one of the graded bushes. The teas were tasted by professional tasters. The correlation between their marks for quality and the five grades of pubescence was weak (0.26) but significant. The correlation improved (0.76) when assessments of average hair density and liquor quality were done on repeat samples of a number of seed populations. However, these results are based on bushes of the Assam type and the teas were made by the orthodox or whole-leaf system of manufacture.

Venkataramani and Padmanabhan (1964) could make teas of better quality from pubescent than from glabious bushes. Wu *et al.* (1958) and Wu (1964) also obtained a weak correlation between pubescence and quality. Kanthamani (1971) obtained enhancement of quality by mixing very small quantities of hair from quality clones with leaf from clones of poor quality. She concluded that chemicals present in hair contributed towards quality. Without going into the merit of these investigations, her interpretation is not convincing since all densely pubescent clones do not produce quality tea. This, in fact, is a major argument against the value of pubescence as an indicator of quality. Wight and Gilchrist (1961 a) are also of the view that hairs themselves do not seem to have a causal connection with quality.

Using the cut-leaf (C.T.C.) system of manufacture, no correlation could be observed between pubescence and quality (TES Ann, Rep., 1964). The C.T.C. roller used in cut-leaf manufacture does more mechanical damage to the leaf tissues than the conventional reciprocating roller of the orthodox system. Wight and Gilchrist (1961 a) noted that the C.T.C. process was associated with lower quality because undesirable aromas might be made more obvious by severe mechanical damage to the leaf. That would lower a taster’s impression of quality though the quality staff would be there all the time.

Apart from quality, pubescence contributes to the appearance of teas made by the orthodox method. It produces 'tips' and tippiness has an aesthetic appeal that enhances the value of orthodox teas. A high degree of pubescence, on the other hand, detracts from the appearance of teas made by the cut-leaf method as the teas take a greyish hue due to the presence of cut fragments of hair. It is possible that the presence of tip exerts a positive influence on the judgement of the taster in his assessment of quality of orthodox teas, while the greyish appearance of C.T.C. teas resulting from the presence of cut pieces of hair influences his judgement of quality negatively.

Wight and Gilchrist (1961 a) were of the view that association of hair with quality could be due, in part at least, to its association with some desirable aromas not located in the hair. In *assamica* populations they observed a positive correlation between grades of pubescence and the density of vessel and fibre cells in unit cross-sectional area of the petiolar xylem. This led them to the conclusion that hairs have special importance as indicators of lignified tissues which is likely to be the seat of aromas and some of these aromas probably contribute to the sensation of quality. If pubescence is regarded as a xeromorphic character, then a connection between hair density and xylem elements could possibly be inferred. Assuming that such a connection exists, it still remains to be demonstrated that aromas are located in the woody tissues.

From the foregoing exposition the relationship between pubescence and liquor quality appears to be loose and indirect. Pubescence cannot be used for predicting quality, but as a selection criterion, it is likely to increase the proportion of bushes of good quality. Pubescence has a definite value in the selection of bushes for the orthodox or whole-leaf systems of manufacture where tippiness counts.

Occurrence of *red anthocyanin pigment* in the leaf petiole is a characteristic of the Southern form of tea. Plants of this type are glabrous and lack quality but are usually more vigorous than those of the pubescent Assam type. The Southern form is rarely cultivated as such but appearance of petiole pigmentation in some pubescent cultivated plants shows that the pigmented and non-pigmented races must have hybridised in the past, imparting vigour to the progenies. Wight and Barua (1954) consider that upto some low optimum, pigmentation of the leaf petiole is beneficial and above this low optimum it is detrimental to quality. If pigmentation is used as a criterion for screening bushes for quality, then the danger of retaining bushes having more than the optimum amount of pigment cannot be minimized. Retention of such bushes will reduce rather than enhance quality.

The relationship between colour of the mature leaf and quality of black tea has always been a hotly debated issue among planters and researchers alike. The belief that teas of better quality can be produced from light-leaf rather than from dark-leaf Assam bushes is fairly wide-spread. Venkataramani and Padmanabhan (1964) had lent some support to this belief. Harler (l964) too had stated that bushes with yellow-green shoots are associated with quality, To set this controversy at rest, Wight *et al*. (1963) determined the depth of colour of .the mature leaves of 375 bushes taken from 51 seed sources, by matching them with standard colour charts. The bushes were then divided into five colour groups ranging from very light box-green to dark English-green and shoots from every bush were manufactured. Tasters' assessment of quality of the teas was observed to vary between bushes within each colour group but the maximum average quality was found in bushes having intermediate shades of 'greenness' and the minimum, in the lightest-coloured bushes. Quality associated with the darkest bushes was low but not significantly lower than those of intermediate colours were. The results clearly show that leaf colour is not an indicator of quality. Selection of bushes for very light colour may, in fact, tantamount to selection for poor quality.

An association between quality and the number of *calcium oxalate crystals* in the phloem parenchyma of a transverse section of the petiole, designated phloem index, has also been suggested (Wight and Gilchrist, 1961 a). However, it was pointed out earlier (cf. Chapter 2) that large errors are involved in the determination of phloem index. Any relation that it may have with liquor quality is vitiated by the error of its estimation.

Chloroform Test

This test for fermentation is claimed to give good indication of the quality of black tea manufactured in Japan (Toyao *et.al.*, 1971). It is recommended in many countries (Ellis, 1964; Richards, 1967; Toyao and Katsuo, 1972) for screening bushes for fermentation ability.

The chloroform test for assessing fermentation was developed by Sanderson (1963). When young tea leaves are exposed to chloroform vapour, the colour of the leaf changes from green to brown. The rapidity of colour change indicates the rate of fermentation and the intensity of brown colouration measures the extent of fermentation. The change of colour is caused by the oxidation of catechins present in the cell vacuoles. The vacuoles are enclosed by lipid membranes, which are denatured by chloroform, allowing the vacuolar contents to come into contact with the oxidising enzymes located outside the vacuoles. Oxidation of the catechins takes place with the formation of compounds having the familiar brown colour of fermented tea leaf. Young leaves are used for this test because the change of colour shows up better in young than in old leaf.

Selection for Frost Hardiness

Simple tests have also been devised for detecting frost hardiness of plants at the young stage. Two tests have been described by Toyao *et al*. (1974). In the first test, shoots bearing mature leaves were kept in a freezer at about 0°C for 30 min. The temperature was then lowered and maintained at —9°C for two hours. After this freezing treatment, the shoots were cultured in the laboratory for two to three days and the degree of freezing injury graded visually.

In the second method, approximately 3 g of frozen mature leaf were infused in 150 ml water at 20°C for 20 hours and electrical conductivity ‘A’ of the solution was measured. The values of ‘A’ corresponded to degrees of freezing injury. For more accurate estimation, electrical conductivity ‘B’ of a similar infusion of unfrozen leaf was determined. A third sample of leaf was infused in boiling water and its conductivity ‘C’ was also measured. The degree of freezing injury X was calculated from the equation:

$$X = \frac{A—B}{C—B} \times 100$$

Winter hardiness of mature plants can be predicted by performing this test on young plants since this property does not change with age.

PRACTICAL SELECTION PROCEDURE

The limited value of various field selection criteria for yeild and quality will be evident from the foregoing account. These are more appropriately ‘rejection criteria’ for eliminating a large proportion of the poor bushes. Because of limitations inherent in these criteria, some good bushes get rejected in the process while retaining some poor bushes. The urgent need for more suitable selection criteria has already been stressed.

It is not possible to outline a rigid selection procedure for all regions because of differences in the kinds of tea made, the type of bushes grown and soil-climatic environments. Requirements for the production of orthodox teas will be somewhat different from those of cut-leaf manufacture. Selection for green tea quality will be entirely of a different nature. Flavour will be a very important consideration in some regions. Selection for disease and pest resistance has also been suggested in some countries (Richards, 1966). The procedures suggested below for selection in mature fields and seedling progenies should, therefore, be taken as guidelines which may need modification to suit local requirements.

Selection in Mature Fields

It is basically unsound to confine selection to the popular commercial *jats* of tea where the bushes are morphologically more uniform than in the heterogenous progenies of obscure *jats*.

The chances of getting outstanding clones are more among the latter *jats*. There is another sound reason for carrying out selection in hybrid populations. More light can reach the lower leaves in the canopy of tea bushes having erect or semi-erect leaves than of bushes with flat leaves. Since the heavily shaded lower leaves do not get enough light for maximum photosynthesis, any increase in the intensity of light reaching those leaves can be expected to raise dry matter production and yield (Hadfield, 1974). The hybrid progenies usually contain a larger proportion of bushes with erect and semi-erect leaves and hence the chances of selecting high-yielding bushes increase in such progenies. However, selection of bushes with erect or semi-erect leaves is unlikely to have any additional benefit on yield in regions like N.E. India where yield increases under overhead canopies of shade trees. Even erect and semi-erect bushes at Tocklai produced more dry matter and yield when grown under leguminous shade trees than in the open (Barua and Sarma, 1982).

The selection unit should contain approximately 40,000 bushes, which can be sub-divided into smaller units if necessary for the sake of convenience. The unit will have to be much bigger if, in addition to yield and quality, selection for disease and pest resistance is also envisaged.

Ideally the section should neither be too young nor too old. Young bushes cannot provide sufficient leaf for mother bush manufacture or cuttings for rooting trials. The adaptability of a young section of tea to the locality is also not known. There can be no objection to selection in an old section except that infills of lesser age than the section itself may be included among the selected bushes.

Field selection is best carried out in stages using one rejection criterion at a time. Selection can be started at any time of the year using the criteria appropriate for that particular state of growth of the bushes. However, it is preferable to start screening for density of plucking points. In areas where longer pruning cycle is followed, selection for plucking point density should better be postponed till the second or third year from pruning to allow time for the plucking table to fill up. Where bushes are pruned annually, selection for plucking point should be carried out towards the end of the plucking season.

The various criteria suggested below have already been described:

a) Reject all bushes of very small size and those suffering from branch canker.

Bushes bordering roads, paths and drains generally have larger frames as they get more room for spread. Such bushes should be left out from screening as they do not bear comparison with other bushes of the selection unit.

b) Select for density of plucking points.

It is expected that 5 per cent or approximately 2000 bushes of the selection unit will be retained after this phase of selection. Mark the bushes at site with proper levels as well as on a ground plan of the selection unit.

c) Selection for pubescence can be carried out at this stage. Depending on the type of tea, the number retained after this phase of selection will be about 1000 to 500 bushes.

d) Prune bushes and record the weight of prunings of each bush. Reject bushes giving less pruning weight than the average of all pruned bushes. The number retained reduces to about 400 to 200 bushes.

e) Estimate pruned surface area of the selected bushes with a light grid or by measuring bush diameter and work out pruning weight per unit area. Reject all bushes having less than the average weight.

The number comes down to about 200-100 bushes.

f) Allow majority of the shoots arising from the pruned bush-frame to grow above the usual tipping height. Tip and weigh tippings. Reject bushes whose recovery from pruning is below average.

Number retained is about 100-50 bushes. Selection for leaf-size can be carried out at this stage, if necessary.

g) Cut across the primary shoots and use the leaves for making cuttings in repeat plots and estimate rooting success.

Some clones produce roots at a very wide angle from the vertical. Such clones are likely to be shallow rooters. To eliminate them, it is necessary to carry out the initial rooting trial in nursery beds instead of in sleeves. Sleeve-grown plants do not reveal the true nature of the root system.

Number of good rooters would be about 40-20 bushes.

h) Bring the selected bushes into bearing. Pluck and use the shoots for mother-bush manufacture in miniature rollers. Taste for cup-characters at least on eight occasions spread over a large part of the growing season.

Retain bushes with above average quality, which will leave about 20-10 bushes. Plucking weight can be recorded at the same time but as Visser (1969) has observed, it is not going to provide any more information on the yielding capacity of a bush than has already been obtained from pruning weight.

i) Prune mother bushes for the production of cuttings. Propagate cuttings and record rooting success again. Sufficient number of plants should be available for planting clonal trials from the planted cuttings. If not, repeat propagation when the plants make sufficient growth.

j) Continue to take cuttings from the mother bushes. Plant observation plots in different soil-climatic localities.

Note: The chloroform test for fermentation has not been mentioned in the above scheme. It can be carried out at any stage after (c) to eliminate the sluggish fermenters.

Frost hardiness can be assessed after phase (d).

Occurrence of diseases and pests and their severity of infestation vary from region to region. Hence selection for disease and pest resistance does not fit into a general scheme. Where selection of bushes resistant to a particular disease like blister blight or a pest like shot-hole borer (*Xyleborus* sp.) is considered necessary, it should be done during the initial stages of selection viz. (a) and (b).

Clonal Trial

Special emphasis attaches to the clonal proving trials since a clone can be judged only from its performance. The trial is designed statistically and laid out with the plants obtained from the rooting beds. There should be a minimum of three repeats in the trial with adequate number of plants of every clone in each repeat. At least one known clone and a seed *jat* which grows well in the locality should be used as controls.

The standard procedure for young tea in respect of all cultural treatments such as cultivation, pruning, plucking, manuring, drainage etc. should be followed in the trial area. Plucking weight of each plot is recorded separately at every plucking round. Pruning weight is also recorded when the bushes are pruned.

When sufficient leaf is available, plucked shoots from each clone are manufactured in bigger (1, 2 kg or bigger) rollers and the teas graded before tasting for liquor characters. For this purpose pluckings from all the repeats of a clone can be mixed. It is useful to assess the performance of a clone under both the systems of manufacture (Orthodox and Cut-leaf) although greater weightage will have to be given to that system which will be used for the manufacture of the clone under commercial conditions. Manufacture and tasting should continue for two years.

The final selection of a clone is based on its yield, cup-characters, response to cultural treatments like pruning, plucking, manuring, resistance to diseases, pests, drought, frost, water-logging etc and adaptability to different soil-climatic situations.

In warm climate, the clonal proving trials and the observation plots are expected to provide sufficient information in about 5-6 years but in cold climate where growth is slow, the trial takes longer; about 8-10 years. From the start of the selection programme until final selection of clones, it takes about 10 years which may extend upto 15 years in colder climate.

Selection of Clones in Nursery

The nurseries should be raised in beds and not in sleeves so that root growth is not restricted and each seedling grows in competition with its neighbours. Conditions in the nursery should be congenital for vigorous growth of the seedlings. The seedlings should be allowed to grow at least for two years from seed before starting selection.

Seedlings are first screened by eye for girth above the collar region and height. Plants retained are examined for pubescence. The chloroform test can be performed at this stage. After this phase, all seedlings in the nursery are pruned and pruning weight of the selected plants recorded. Seedlings which recover well from pruning are retained and examined for frost-hardiness and leaf-size, if necessary. Cuttings taken from the selected and pruned seedlings are propagated and rooting success recorded. The plants finally retained on the basis of rooting ability are used for the production of cuttings to raise plants for clonal proving trial and observation plots. The rest of the selection procedure is the same as the one described under selection of mature bushes.

BREEDING OF SEED VARIETIES

Flowering and Fruit-set

Selection of plants for vegetative multiplication as clones is a comparatively easy and straight-forward matter which does not require any knowledge of their genetic make up. On the contrary, the genetic constitution of the plants used as parents becomes the most important consideration in breeding improved strains of seed. Tea is a long-duration and highly heterozygous crop which takes 5 to 10 years from one seed generation to another depending on climate, method of propagation of the seed bearer and, to a certain extent, the kind of plant. Existence of homozygous strains of tea has not been reported from anywhere. Even dwarf plants having very small leaves and generally considered to be ‘pure’ China when selfed, threw up segregates some of which looked like prostrate herbs (TES, unpublished). Production of improved strains of tea seed has to be viewed against this background.

Before considering the methods and progress of tea breeding in different countries, the factors involved in the flowering and fruit-set in tea are briefly reviewed.

Time of Flowering

Geographical location determines the time of flowering of the tea plant. In N.E. India flowering starts in October and continues till February with the peak in November-December. The dependence of flower bud initiation on phasic growth of the tea plant has already been described. It takes l20-l50 days from initial appearance of flower buds to their anthesis. Maximum fertilisation occurs during the peak flowering period. Although the peak flowering time does not usually extend beyond December, there is considerable variation between different seed trees of each race of tea in flowering time and occurrence of the peak period. In general, flowering commences early and continues for a longer period in the Southern race of tea. The Assam race has a shorter flowering season and the China race occupies an intermediate position (Bezbaruah, 1975 a). A few flowers can be seen on some trees during spring. These flowers are borne on the fourth flush of the previous year made late in the season and the flower buds on this flush open when the tree completes the first flush growth of the current year. Bakhtadze (1931) observed similar flowering habit of the tea plant under Chakva (U.S.S.R.) conditions. In Taiwan (25°N), the peak flowering period of December-January coincides almost with that of N.E. India (Wu, 1967). Under sub-tropical conditions of the U.S.S.R. (42°N), tea commences flowering from mid-September and continues upto December until frost sets in. The China plant shows a tendency to flower earlier than the Assam plant. The same pattern of flowering is seen also in Japan (36°N). In the equatorial regions, tea flowers all the year round but maximum flowering and fertilisation are confined to a few months of the year. In Kenya (0°) May to September is the main flowering period (Othieno, 1983). During the months of heavy rain, seed set is poor under conditions of Sri Lanka (6°N), December to March being the most suitable period for fertilisation (Elliot and Whitehead 1926). Cohen Stuart (1916) did not observe flowering and fertilisation peaks in Java (6°S). Further South in Malawi (16°S), tea flowers from February to June (Ellis, 1983).

Thus, in the tropics tea flowers under a constant day length of about 12 hours. It also flowers under short-day conditions of the winter season at the higher latitudes of the U.S.S.R., Japan and N.E. India. This shows that flowering of tea is not controlled by photoperiod. As regards temperature at flowering time, the range is from near freezing at high latitudes to about 30°C in the equatorial regions, indicating that within this wide range flowering of tea is not thermosensitive.

Irrespective of location, if the main flowering time of the parental clones in a clonal seed bari does not coincide, seed yield of the bari remains low. This applies particularly to a bari where only two clones are used as parents. Hence time of flowering needs special attention in selecting clones for establishing clonal seed baries.

Pollination

Pollen grains of the three races of tea are morphologically similar. The grains of diploid plant's are triangular, tricolporate and binucleate. Wellensiek (1938) and Visser *et al.* (1958) observed that tea pollen germinated well in distilled water. Germination of pollen grains in sugar solutions upto a concentration of 25 per cent proved to be slightly more satisfactory than in distilled water. Sugar solution of 10 per cent strength was found to be the best; at 25 per cent the growth of the pollen tube was retarded (Bezbaruah, 1971). At 12°-25°C ambient temperature, all freshly collected pollen grains started germinating within two hours and germination was complete within eight hours. The germination rate was slow at lower temperature.

Tea pollen loses viability rapidly when stored at high temperature. When stored at 12°-25°C in cotton-plugged glass vials, the germination percentage of the pollen grains dropped from 96 to 83 after 24 hours and to 30 after 120 hours, while at 4°-6°C and 0°C, 30 per cent of the grains remained viable for 30 and 45 days, respectively. Pollen grains of Assam plants had a relatively shorter life than those of China and Cambod plants under the same set of conditions (Bezbaruah, 1971). Humidity was not controlled in these studies, which was presumably around 80-100 per cent relative humidity. From experiments of Visser (1955) and Visser *et al*. (1958), it appears that a humidity of 40 per cent is optimum for storage of tea pollen at 0°C. Under these conditions, 50-60 per cent of the grains remained viable for 120 days: Tomo *et al*. (1955) in Japan could partially preserve tea pollen for one month at 5°-7°C and 60 per cent relative humidity. Recently Amma and Watanabe (1983) reported successful preservation of tea pollen at —80°C for more than five years but storage at —40°C reduced germination after five years. At the storage temperature of 1°C, the pollen grains failed to germinate after four years.

The tea plant flowers profusely but seed yield is comparatively very low. Bakhtadze (1932), Wight (1938) and Wu (1967) found appreciable degree of self-sterility in tea, which invariably set a better crop of seed when cross-pollinated. Efficient cross-transfer of pollen from one tree to another in a tea seed bari is, therefore, a prerequisite for obtaining a good set of fruit. Harler (1964) mentions only 2 per cent fruit set in tea under natural conditions and about 14 per cent when pollen is transferred by hand. Bezbaruah (1975 a), who studied the problem in depth, observes that because of its large size and sticky nature, the pollen grains of tea aggregate into lumps. Such pollen grains are not suitable for carriage by wind and this was proved by trapping pollen at various distances from flowering trees. Earlier Amma and Harada, (1955) in Japan observed that only dried up, non-viable tea pollen was carried by wind.

The number of insects visiting tea seed trees at the flowering time is very low, despite the fact that the flowers secrete large amounts of honey on the disc. In N.E. India bees and wasps (*Hymenoptera*) are not very frequent and small flies (*Diptera*) are the most common insects on and around flowering trees (Bezbaruah, 1975 a). Beehives were maintained in a few seed baries of Assam as an experimental measure but their presence did not make any difference to the yield of seed. The small quantity of honey collected from the hives was dark-brown in colour and possessed an unpleasant taste. It is possible that the honey secreted by tea flowers is contaminated with the polyphenols present in the plant. This may also be the reason for not attracting bees.

The small flies, when trapped, are found to carry a large amount of pollen on their bodies but these insects have a very narrow flying range. Bakhtadze (1932) observed a similar situation in the tea seed baries of Georgia and considered insect population to be too inadequate to effect efficient transfer of pollen.

These observations clearly show that pollination of tea flowers is inadequate under natural conditions and that production of seed could be improved considerably if more efficient pollination could be ensured. Since the frequency of visits by insects like bees and wasps with long flying range is very limited, seed baries need not be sited too far away from the neighbouring tea bushes to prevent contamination by foreign pollen.

Artificial Pollination Procedure

In crossing selected plants artificially, flowers have to be protected from chance pollination by natural agents. Flowering branches chosen for pollination are enclosed in fine muslin or polythene bags after removing all open flowers, immature fruits, and very small flower buds which may take a long time to reach the stage of anthesis. Although fruit-set from selfing is generally very low yet, in some clones, it may be as high as l0 per cent. This necessitates the need for emasculation while making crosses. Emasculation is done by cutting off the stamens below the anther lobes with a scalpel or any convenient tool. Fertilisation and fruit-set are not affected if, along with the stamens, a portion of the petals is also removed during emasculation. Visser (1951) observed that complete removal of stamens and petals had only a minor effect on fruit set. Flowers which have just opened and whose anthers have not yet burst and flower buds in advanced state of development are most suitable for pollination. Emasculation is more convenient in the late-bud stage.

Pollen should be collected from bagged flowers to eliminate chances of contamination. Flowers that open inside the bag are collected and kept in a covered container. Pollination can be carried out by bringing the burst anthers into contact with the stigmatic surface of the flower or by applying the pollen grains with a soft brush. In the latter case, pollen grains are shaken off into suitable containers. Pollination of the bagged flowers is continued by removing the bag at the time of pollination and then replacing it until it is finally removed approximately 48 hours after pollinating the last flower.

A branch should not be kept enclosed in a bag for too long a period because repeated opening and closing of the bag for the purpose of pollination damage the leaves, buds and pollinated flowers. Muslin bags are preferable to polythene bags as air inside a polythene bag gets warmer than the surrounding air. Polythene bags are particularly unsatisfactory in places where the temperature at the time of flowering remains high.

Fertilisation and Fruit-set

There is no fixed hour for anthesis of tea flower; it can open at any time during day or night. Within 24 to 48 hours after opening, the corolla withers and, together with the filaments, drops from the pedicel leaving the ovary and the stigma exposed. The stigma becomes receptive of pollen about 24 hours before anthesis and remains so until the corolla shows signs of withering. Some flowers drop off the trees two-three days after detachment of the corolla lobes while in others the persistent calyx lobes close in over the ovary, leaving the style exposed. The style and the stigma gradually wither off.

Syngamy and triple fusion are reported to occur simultaneously after fertilisation. The embryogeny conforms to the solanad type. The endosperm remains nuclear in the beginning which changes to cellular afterwards (Wu, 1960; Bala Sethi, 1965).

Development of the ovary during the first three-four months after fertitisation is very slow. Under conditions of N.E. India, the external signs of development of the fruit become evident by about March-April when the tree starts growth of the new season. After the initial phase, the rate of development of the fruit becomes rapid and by the end of May it reaches almost one half the final size. The fruit attains its full size by August. The fruit usually contains one round seed, sometimes two round or half seeds and occasionally, three or more seeds.

In the mature embryo, two large cotyledons are enclosed by a hard, brown testa formed by the outer integument. The pericarp encloses one to three and rarely more seeds and is made of thick parencymatous tissue when young, becoming sclerotic on maturity (Bezbaruah, 1971). The ripening of the fruit continues till the next flowering season. Dehiscence starts in October and continues till late November. Thus, from the time of flowering till dehiscence of the mature fruits, it takes about a year and this happens in all tea growing regions of the world. However, the timing of the various phases of development of the embryo varies from place to place due to difference in the time of flowering.

Abscission of Fruits

In tea, as in most other fruit crops, fruits continue to drop off the trees from the time of blossoming till dehiscence of the mature fruits. Abscission of tea fruits occurs in perceptible waves at different stages of development. This happens everywhere but more prominently in seasonal climate. Observations made by Bezbaruah (1971) in N.E.India, show that the first and the maximum drop consisting mostly of unfertilized ovaries occurs during the main flowering period of November-January. The second drop of slightly developed fruits occurs in February-April and the third crop of nearly mature fruits, in May-July. After this, a few mature fruits drop until the time of dehiscence but these are generally empty or damaged. There was some variation between the three kinds of tea in the retention of open-pollinated fruits. The first drop accounted for 70 to 80 per cent, the second 11 to 16 per cent and the third drop amounted to 1 to 6 per cent. The final harvests for Assam, China and the Southern form of tea were 1.8, 2.3 and 5.0 per cent, respectively.

Examination of the dropped fruits during the second and third phases showed normal development of the pericarp and testa, often with mucilagenous endosperm inside. Bezbaruah was of the view

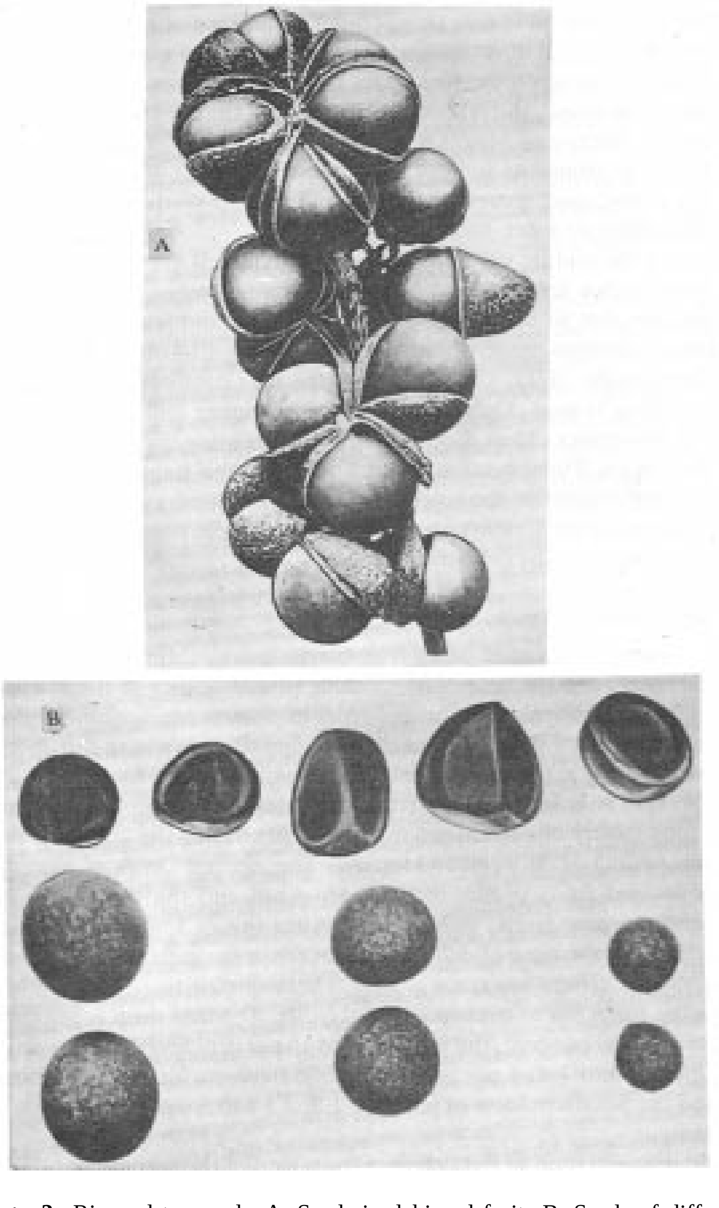

Plate 3. Ripened tea seeds. A. Seeds in dehisced fruits B. Seeds of different sizes and shapes.

that the abscissed fruits were parthenocarpic and that abscission was caused by lack of pollination leading to failure of syngamy or triple fusion. Both Wu (1967) and Bezbaruah (1971) reported least drop of fruits formed during the peak flowering season.

Biennial Bearing

Like many important fruit crops e.g. apple, pear, plum, mango, orange etc. the tea plant also fruits heavily in one year and lightly in the following year (Barua, 1961 b). Confirmation of the biennial fruiting tendency in tea came later from the studies conducted by Bezbaruah (1975 b) on polyclonal seed baries established in different parts of N.E. India with the same clonal combination. Seed yield of all the baries fluctuated from one year to another without any relation to temperature, rainfall or soil water potential. Whether such a biennial pattern of seed yield is universal or not is not known but this is a factor to be watched in the production of improved seed.

SELF AND CROSS COMPATIBILITY

Although tea is regarded as a plant which does not set fruit with its own pollen, the extent of self-fertility is not as insignificant as is commonly believed. Wu (1967) obtained a mean fruit-set of 0.71 per cent from a large number of selfed clones but it doubled in their F_1 progenies. Analysis of the results of more than two hundred thousand pollinations carried out at Tocklai during the last 40 years gives a clear picture of the extent of self-and cross-fertilization in tea. The survey includes plants of the three races of tea as well as their cross-pollinated progenies.

The extent of self fertilisation can be seen from Table 27. Some clones of each of the three races were completely self-sterile while self fertility of some other clones of the Assam and Cambod races were as high as 9-10 per cent. The average fruit-set from selfing was the highest in the Cambod and lowest in the China clones with a mean of 1.7 per cent for all the three races of tea. Due possibly to the presence of Cambod plants, this figure is higher than the mean (0.71) obtained by Wu for the Assam and the China races. On an average, plants of selfed F_1 progenies gave a better self-set than their parents as observed earlier by Wu (1967). Fairly high set of selfed fruits in tea was reported also by Sebastiampillai (1961). Toyao (1966) obtained upto 10 per cent selfed fruits from a Japanese tea variety.

In one interfertility trial conducted earlier at Tocklai, plants were observed to vary widely in their cross-compatibility (Wight, 1938). Some plants were good females, others were good males and a range of integrades existed between these two extremes. The success of crosses within and between clones belonging to the three races of tea and also between parents and progenies is illustrated in Table 28.

Table 27. Self-compatibility among tea clones and their F_1 generation (After Bezbaruah and Saikia, 1977)

Types of tea	No. of clones selfed	No. of flowers pollinated	Per cent fruit-set Average	Range
China	9	14,783	0.98	0–3.35
Assam	16	19,534	1.35	0–8.70
Cambod	12	8,729	2.70	0–9.88
F_1 China	4	449	3.13	0–5.01
F_1 Assam	23	15,897	1.23	0–13.40
F_1 Cambod	21	8,079	2.86	0–9.42

A number of crosses made within the Assam and China races failed to produce any fruit but none of the crosses made within the Cambod race completely failed. The average fruit-set was the least in the China and highest in the Cambod race.

Among the inter-racial crosses, Assam clones were the worst females. Some of the crosses with Assam clones as females did not set any fruit, particularly when China clones were the pollinators. Most of the three-way crosses where the parents were used as females, did not succeed but failure was less and fruit-set was generally high when progeny plants were the females.

Table 28. Cross-compatibility of tea clones and their hybrid progenies (After Bezbaruah and Saikia, 1977)

Nature of cross	Plant types Female ♀ Male ♂	No. of combinations	No. of flowers pollinated	Per cent fruit-set Range	Average
Single cross	China x China	54	41,877	0-34.5	8.9
	Assam x Assam	108	67,275	0-53.0	11.5
	Cambod x Cambod	3	3,320	0.8-34.6	17.4
	China x Assam	11	10,429	2.2-59.6	34.3
	China x Cambod	7	5,475	0.9-41.2	14.3
	Assam x China	19	4,459	0-45.0	2.8
	Assam x Cambod	18	9,541	0-32.8	10.0
	Cambod x China	5	1,895	3.1-30.9	8.6
	Cambod x Assam	12	9,435	1.3-50.6	18.5
Three way cross	China x F_1 (Assam x China)	19	2,442	0-11.3	3.0
	China x F_1 (China x Cambod)	16	2,248	0.7-3.1	1.6
	Assam x F_1 (Assam x China)	16	1,305	0-7.0	4.0
	Assam x F_1 (Assam x Cambod)	9	2,339	0-10.0	8.4
	Assam x F_1 (China x Cambod)	7	9,183	0.5-25.7	5.1
	Cambod x F_1 (Assam x Cambod)	1	1,155		24.1
	F_1 (Assam x Cambod) x Assam	6	840	0-44.9	16.6
	F_1 (China x Cambod) x Assam	2	2,475	24.7-62.2	47.7
Double cross	F_1(China x Cambod) x F_1(China x Cambod}	21	2,620	2.7-64.4	32.4
Multiple cross	F_2 (China x Cambod) x (China x Cambod) x F_2 (China x Cambod) x (China x Cambod)	6	1,081	1.0-45.7	16.9

The number of incompatible combinations were few among the double and multiple crosses. The percentage fruit-set was also generally high in these crosses, the highest average fruit-set of 64.4 per cent being recorded in a double cross.

The mean fruit-set of the 340 combinations shown in Table 28 works out at 15.1 per cent. This indicates that fruit-set in open-pollinated tea seed baries could be vastly improved by more efficient transfer of pollen.

Wu (1967) also studied intercompatibility in the Assam and China races in various crosses. His results too, reproduced in Table 29 for comparison, demonstrate higher rates of fertility in double and back crosses.

Table 29. Percentage fruit-set in different crosses (After Wu, 1967)

Crossing Method	No. of combinations	Percent fruit set	
		Range	Mean
Single cross	143	0-59.0	13.2± 10.8
Three way cross	27	0.8-29.2	16.1± 9.4
Back cross	23	0-52.2	22.7± 14.8
Double Cross	29	1.0-64.6	23.6± 17.2

Incompatibility in Tea

The cause of incompatibility in tea has not yet been fully elucidated. Simura and Osone (1956) reported slower growth of self pollen in the stylar tissues than that of pollen from another plant. On the other hand, Bezbarauah (1971) did not find any difference in the growth rates of pollen tubes in the stylar tissues of selfed, compatible and incompatible crosses. According to Tomo *et al.* (1956) and Fuchinoue and Fuchinoue (1956) the cause of self- incompatibility resides in the base of the style where pollen tube growth is inhabited. Here again the results differed from those of Bezbarauah who observed pollen tubes to reach the microphyle of the ovary both in compatible and incompatible crosses. Bezbarauah concludes from his observations that the cause of incompatibility in tea does not lie in the pollen. Stigma, style or wall of the ovary but in the failure of syngamy or triple fusion or breakdown of the zygote following fertilisation, as happens in many other flowering plants.

In this connection observations made by Cope (1958) in cacao is of interest. Cope found that nonfusion of about one quarter of the ovules in a cacao ovary could cause its abortion. A tea ovary contains, on an average, 13.5 ovules out of which only one to three seeds develop to maturity. As in cacao, fertlisation of a minimum number of ovules may be necessary for development of the tea ovary to maturity. Only a comprehensive embryological study of developing tea fruits can reveal whether the incompatibility in tea is due to pre-fertilisation blockage or post-fertilisation abnormalities.

Interspecific Compatibility

A number of species were successfully crossed with tea by using tea as the female parent. The crosses with *C. irrawadiensis, C. japonica, C. caudata* and *C. kissi* were successful while those with *C. sasanqua* did not succeed. Reciprocal crosses failed to produce viable seed in all cases (Bezbaruah and Saikia, 1977). Ackerman (1977) too was successful in crossing tea with a number of *Camellia* species but almost in all cases viable seeds were obtained only when tea was used as the female parent. Wu (1967) obtained 1.8 per cent fruit-set by crossing plants of the China race of tea with *C. tenuifolia*.

The interspecific hybrids resemble tea in their morphological features. The hybrids resulting from *C. assamica* x *C. irrawadiensis* crosses were indistinguishable from bushes in any field of Assam tea and, unlike the male parent *irrawadiensis*, were highly fertile: These results suggest uncontrolled hybridisation of these two species in the past in their natural habitat as surmised by Wood and Barua (1958) from chemical analysis and Barua and Wight (1958) and Barua (1965) from anatomical and floral characters (cf. Chapter 1). It is possible that some of these hybrids are growing undetected among cultivated tea.

Many ornamental *Camellia* species have been crossed successfully and their hybrids are in cultivation (Longly and Tourje, I959; 1960; Ackerman, 1977). Crossability of tea with other species of *Camellia* has opened the possibility of incorporating into tea the desirable characters of some of the *Camellia* species. The hybrids of *assamica* X *irrawadiensis* crosses are more vigorous than their parents although they produce inferior tea (Bezbaruah, 1971). However, improvement of chemical characters should be possible by systematic breeding. If the decisive odour of tea is the result of hybridity between tea and other allied species (Wight and Gilchrist, 1961 b), then it ought to be possible to breed tea of distinctive aroma by hybridisation with other species of *Camellia.*

CYTOLOGY

Except for the few natural triploids and polyploids reported by Simura (1935), Janaki Amal (1952) and Bezbaruah (1971), the cultivated tea plant is a diploid with a chromosome number of 2n = 30. Despite severe mutilation to which the plant has been subjected by pruning and plucking throughout its long history of cultivation, it is remarkable that cytological behaviour of tea has remained virtually unchanged, although polyploidy is of common occurrence in the ornamental *Camellias* (Longly and Tourje, 1959; Janaki Amal, 1952). Janaki Amal attributes this to deliberate elimination of polyploids wherever and whenever they occurred, by the conservative tea drinkers of China and Japan as the polyploids produced teas of different tastes. Some of the polyploids like the triploid discovered by Simura (1935) might have been grown as ornamentals.

The chromosome number in tea was determined by many investigators (Morinaga *et al.* 1929; Subba Rao, 1938; Janaki Amal, 1952; Ackerman, 1977; Bezbaruah, 1971) but karyotype analysis was not carried out by the early workers, perhaps due to the lack of a suitable technique which could bring out the details of the small chromosomes. Root-tip method was generally used for mitotic studies which necessitated digging up of roots. To avoid this, Bezbaruah (1968 a) adopted the shoot-tip method for examination of mitotic chromosomes in tea and other related species after necessary modification and standardisation.

Bezbaruah (1971) made detailed karyotype analysis of 30 tea clones belonging to the three races of tea, ten from each race, as well as of plants of a few allied species. The somatic chromosome number of 30 was common to all the tea clones and plants of the other species included in his studies. In fact, all diploid *Camellia*s possess the same number of 30 chromosomes. The chromosomes of tea, as of other *Camellia*s, are short but there is a gradation of size from the longest of the pairs to the shortest. The chromosomes have median to sub-median primary constrictions. In a few clones, one or two pairs of chromosomes may have secondary constrictions (Fig. 16; Plate 4).

Clones belonging to the three races of tea do not reveal any major difference in their karyotype, although some minor differences exist. However, none of the minor differences could be correlated with any morphological feature of the plants. No irregularity is observed in the meiosis of any of the clones. Together with high pollen fertility, this signifies regular microsporogenesis in tea.

In many genera and species, the process of evolution is accompanied by different types of karyotypic changes whereas in others morphologicai difference and divergence occur without any visible change in chromosome morphology. This phenomenon is attributed to kryptic gene mutation (Stebbins, 1950). In genera like *Pinus* and *Quercus*, the species differ in morphological characters but the gross structure of their chromosomes has remained closely similar. Close morphological similarity of the tea chromosomes suggests that the observed differences in growth and form of plants of the different races of tea are the results of mutative changes of the genes as in *Pinus* and *Quercus*.

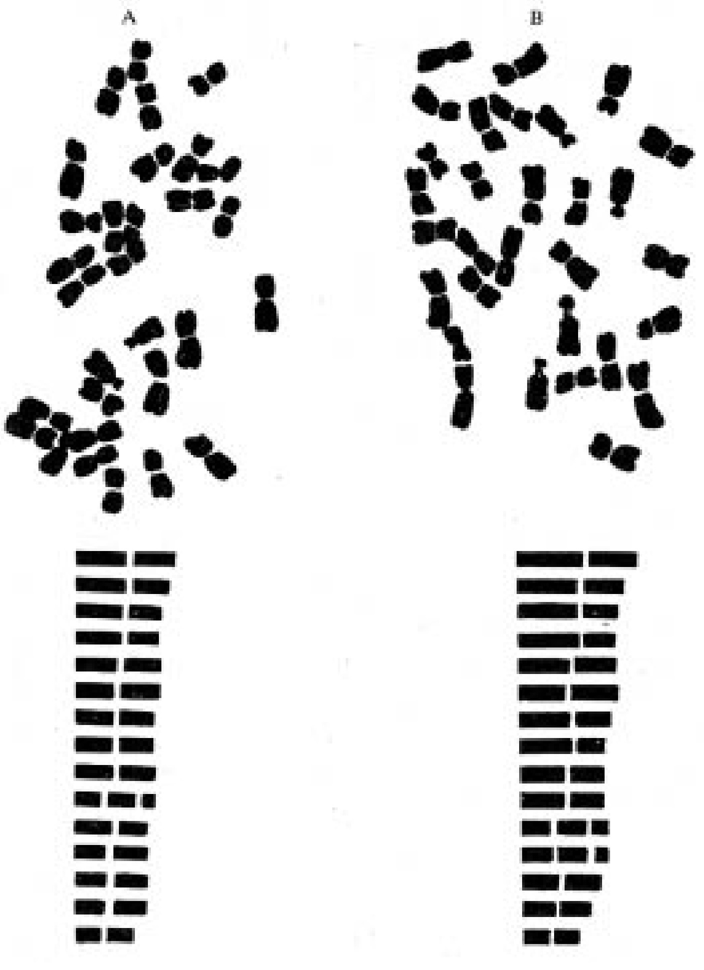

Fig. 16. *Camera lucida* drawings of the metaphase chromosomes of two clones representing the extreme forms of 'A' Assam and 'B' China races of tea. Magnification 2500X. The karyotype diagrams can be expressed as :

A—$1L^{sm} + 8M^{m,sm} + 6S^{m,sm,sat}$

B—$6L^{m,sm} + 7M^{m,sat} + 2S^{m}$

(After Bezbaruah, 1971)

Plate 4. Tea chromosomes (metaphase)

POLYPLOIDY AND MUTATION

Naturally evolved polyploids in tea are very rare. Only a few natural triploids (2n = 45) have so far been reported from Japan (Karasawa, 1932; 1935; Simura, 1935), N.E. India (TES Ann. Rep. 1969-70), South India (Venkataramani and Sharma, 1974) and the U.S.S.R. (Kapanadze and Eliseev, 1975). Natural tetraploids (2n = 60) have also been reported from N.E. India. Triploids in general are more vigorous and hardier than diploids. Simura (1956) found them to be more cold tolerant under conditions prevailing in Japan. Some tetraploids and aneuploids, as will be shown later, have also been found to possess superior vigour. However, the polyploids are generally poor in cup quality. The natural triploid found in N.E. India produces very poor tea (Bezbaruah, 1971) but tea of acceptable quality has also been made from triploid of which the South Indian triploid clone 'Sundaram' (Venkataratnani and Sharma, 1974) is an example. Genetic variation or mutation of diploid tea plants into polyploid can, therefore, be expected to improve vigour and hardiness. Since tea polyploids are scarce under natural conditions, their artificial production has become a necessity.

Mutagenic chemicals like colchicine and X and gamma rays are being tried on tea for the production of tetraploids. Katsuo (1966) applied 0.2 per cent colchicine to axillary buds on etiolated tea shoots and kept them in the dark. The treated shoots produced a tetraploid and a few chimeras. Sebastiampillai (1976) achieved better success by treating *in situ* the apices of growing shoots with colchicine. The terminal buds of shoots carrying 4-5 expanded leaves were dissected to expose the meristematic tissues which were then covered with 1.0 per cent blocks of agar impregnated with 0.2 or 0.5 per cent colchicine in gelatin capsules. The agar blocks with the capsules were removed after two to seven days and the shoots were allowed to grow and produce 4-5 more leaves. The activity of the treated meristem was enhanced by periodic removal of the axillary buds arising below the point of treatment. In most shoots, only one or two leaves arising just above the point of treatment showed morphological aberration. These leaves were propagated as internodal cuttings and the surviving plants were planted out in the field. Cuttings drawn from these plants were propagated in a nursery and root tips collected from the rooted cuttings were examined for chromosomes.

Treatments with 0.2 per cent colchicine for not less than five days and with 0.5 per cent for a minimum of three days induced tetraploidy. Exposure to 0.5 per cent colchicine for six days caused maximum mutation although one of the experimental clones failed to respond even to this treatment, thus displaying differential sensitivity of tea clones to colchicine. Many shoots died but 12 tetraploid plants could be isolated out of the 95 treated shoots.

Initial attempts at Tocklai to induce mutation by treatment of tea shoots with colchicine and ethyl methane sulphonate did not meet with success. (TES Ann. Rep., 1968-69; 1969-70). However, by resorting to more drastic treatments, Goswami and Sarma (1979) succeeded in inducing mutation. Growing apical buds of tea were kept immersed in 0.5 to 2.0 per cent solutions of colchicine for two to seven days without severing them from

Table 30. Chromosome numbers, morphological characters and pollen fertility of the open-pollinated progenies of a natural triploid (Bezbaruah, 1976)

μ

the plant. Many treated shoots died and .the survival rate decreased with severity of the treatment. Despite loss of a large number of shoots, they obtained 6.6, 13.3 and 20.0 per cent tetraploids from the three biclonal varieties of tea used in their experiments. Here again, the differential sensitivity of tea plants to colchicine treatment was clearly displayed.

Fertility and pollen viability of all triploids are extremely low but tetraploids in tea are generally fertile and produce a good crop of seed when fertilised with pollen from diploid tea plants (TES Ann. Rep., 1973-74). Only 2 per cent of the pollen grains of a natural triploid was found to be viable and thousands of pollinations with its own pollen and pollen from many diploid plants failed to produce any fruit on this plant (Bezbaruah, 1971). However, the plant produced a few seeds from open, natural pollinations. Chromosome counts of 18 plants of the progeny exhibited a wide range of variation in the number of chromosomes (Table 30).

Three out of the 18 plants were tetraploids, one each was a diploid and a pentaploid (2n=75), and the rest were aneuploids with an array of chromosome numbers around diploid (2n=32 and 33), triploid (2n=38 and 42) and tetraploid (2n=58, 59, 61 and 63). Three plants within the tetraploid range were aneusomatic whose chromosome numbers often differed within the same tissue. In morphological characters like growth, shape and size of leaf, size of stomata and pollen grains the plants varied widely. Many plants produced square and giant-sized pollen grains which is a characteristic of polyploids. The pollen grains of the pentaploid (11) and two other aneuploids (10 and 14) were completely sterile but with the exception of plants 8 and 13, the other plants had high pollen fertility (Bezbaruah, 1976).

When fertilised with pollen from diploid clones, the two tetraploids (2 and 4) and the hypo-tetraploid (9) (2n=58) produced fruits but the other plants were all sterile. Fruit-set on these plants was high, from 13 to 46 per cent, and its variation within and between the female parents can be attributed partly to the female and partly to the pollen parents (TES Ann. Rep., 1973-74).

Chromosome counts of nearly 100 open-pollinated seedlings of these three parents showed 63 of them to be triploids, 2 pentaploids, 3 aneuploids and the rest diploids i.e. the progeny was predominantly triploid. Crosses made subsequently between tetraploids and diploids produced only triplolids. (TES Ann. Rep., 1978-79). Thus, when tetraploids are available, triploids can be produced by crossing them with diploids. Since triploids can occasionally produce tetraploids as seen from Table 30, the two become complementary.

Amma (1974) succeeded in inducing tetraploidy by irradiating whole plants of the popular Japanese diploid clone Yabukita at 17.9 RF in a cobalt 60 gamma field. Of the shoots produced by the irradiated plant, one was found to be a tetraploid. The shoot was longer than those of the source material and it had shorter but thicker internodes, bigger and thicker leaves, heavier flowers with bigger ovary, thicker filaments and larger but less frequent stomata. Fertility and pollen viability of the tetraploid were low. Chemical analysis revealed Iower tannin content and higher total nitrogen in the tetraploid than in the diploid. Growth of the tetraploid cutting was also inferior to that of the original diploid. The morphological characters of this tetraploid are generally in agreement with those of Table 30.

However, induction of mutation in tea with the aid of radiations has not met with much success elsewhere. Attempts made at the TES to produce mutants by exposing seeds, cuttings and pollen grains to X and gamma radiations have not succeeded yet (TES Ann. Rep., 1979-80).

In another set of observations made at the TES, triploid and a few aneuploid plants produced 60 to 110 per cent heavier shoots than the diploids (TES Ann. Rep., 1979-80): Pentaploids are usually weak plants of stunted growth. These results clearly demonstrate the desirability of breeding for the production of triploids and tetraploids. It should be possible to combine good cup quality with the superior vigour and hardiness of the polyploids by crossing tetraploids with diploids of high quality and selecting from the triploid progenies elite vegetative clones. To our knowledge work on these lines is now progressing in a few countries.

INHERITANCE

Study of inheritance in tea is complicated by a number of factors many of which, such as large size of the plant and long life cycle, are common to most perennial plants. Because of its predominantly out breeding nature, hybridisation between the three races of tea and probably with other *Camellia*s has occurred over a long period of time, both under natural and cultivated conditions. The process of hybridisation is still continuing among the progenies. Like most other perennials, tea has a long life cycle; one generation from seed to seed takes five to ten years depending on climatic conditions and the kind of plant.

By looking at a hybrid tea plant, it is usually possible to form some idea about its ancestry. A small, matt-leaf China hybrid plant can be picked up easily from a population of plants having large leaves with prominent veins. Red-pink petiole pigmentation in Assam type of leaf is a sign of hybridity with plants of the Cambod race. The small and matt leaf and petiole pigmentation are hereditary characters but their mere presence does not explain the mode of inheritance of these characters. In a hybrid crop like tea, only detail analysis of the characters in the progenies of a wide range of crosses can throw light on the nature of inheritance. Unfortunately reports of such studies are very few, presumably because the tea breeders in different parts of the world are currently more concerned with the practical problems of selection and breeding of elite clones and seed progenies for which there is a large and pressing demand. However, the importance of the study of inheritance cannot be minimised if tea breeding is to be provided with a sound genetic base. Such studies have made significant contribution in the breeding of many perennial crops like rubber (Wycherley, 1969), forest species (Kedarnath, 1968) and fruit crops (Crane and Lawrence, 1956; Mukherjee and Mozumdar, 1965), to cite only a few.

Pure line breeding was attempted at the TES with the study of inheritance as a major objective but the scheme did not progress beyond the second generation in a few crosses, primarily on account of difficulties in producing selfed progenies.

However, a limited number of other studies conducted there and elsewhere have thrown some light on the inheritance of a few morphological and other characters.

Bezbaruah (1971) studied the inheritance of leaf size, yield and quality of made tea as assessed by tea taster. To study inheritance of leaf size, he selected three representative plants one each from China; Assam and Cambod races of tea and crossed them in all the three possible combinations. One reciprocal cross was also made. Size of mature leaves of the parents and progenies was determined on plants of equal age and receiving the same cultural treatments. The results are reproduced in Table 31.

Table 31. Mean leaf area of parents and their F_1 hybrids

Parents and crosses	Mean leaf area of progeny (cm^2)	Mid parent leaf area (cm^2)	Per cent increase or decrease over mid parent
A (China)	4.9		
B (Assam)	56.1		
C (Cambod)	31.4		
B x A	21.7	30.5	— 28.8
B x C	45.2	43.7	+ 3.4
A x C	15.4	18.2	— 15.1
C x A	14.5	18.2	— 20.3

In leaf size, the hybrids were more or less intermediate between the parents, suggesting additivity of genes governing this character. As Bezbaruah and Wu and Shyu (1966) had concluded, it is a case of quantitative inheritance. From an examination of the observations made earlier by Wellensiek (1940, 1947), Visser (1969) too arrived at the same conclusion. Decrease of 15 to 29 per cent leaf area in the progenies of crosses B x A, A x C and C x A, where A is the small-leaf China parent, is presumably indicative of partial dominance of the small-leaf type. Wu and Shyu (*loc. cit.*) also observed partial dominance of thick (China) over thin (Assam) leaf. Wight and Barua (1955) and

Wu and Shyu (1966) reported identical results from reciprocal crosses. In the trial by Bezbaruah, the absence of any difference between the two progenies, A x C and C x A of reciprocal crosses precludes maternal or cytoplasmic influence on the size of leaf.

The plants used by Bezbaruah in his crosses are most typical of the three races of tea which also implies genetical purity, at least to a large extent. Results similar to these cannot be expected from crosses between hybrid clones. The progenies of such crosses will be highly variable not only in leaf size but also in other characters. Visser (1969) is of the view that many properties of the tea plant are inherited in a polygenic and quantitative fashion. This fact is not always recognised because hybrid progenies exhibit a continuous transition of characteristics, only a small proportion of which conform to the narrowly defined phenotypic traits of the hybrid parents.

Some information on the inheritance of yield and quality is available from studies conducted at Tocklai and Taiwan. Analysis of data on yield and tea taster's assessment of cup-quality of a large number of biclonal progenies and their parents raised at Tocklai showed that in crosses between morphologically dissimilar clones, the progeny yield was always higher than the mean yield of the parents and the parent and progeny yields were closely related (0.86). This did not happen in crosses between morphologically similar clones (TES Ann. Rep., 1965). These results clearly indicate positive heterosis, meaning increase in vigour of the F_1 hybrid over the mean of the parents or better of the two parents. Analysis of the results of 10 crosses made between clones of diverse geographical origin corroborated these findings. In eight out of the 10 crosses including a reciprocal cross, the progeny yields were 21 to 85 per cent higher than the mid-parent yields. Progeny yields of the two remaining crosses were 11 to 16 per cent lower than the mid-parent yields (Bezbaruah, 1971), indicating negative heterosis. The yields of reciprocal crosses did not differ significantly, thereby confirming the results obtained by Wight and Barua (1955) and Wu and Shyu (1966) and excluding cytoplasmic effect on yield.

Wu and Shyu (*loc. cit.*) studied inheritance in a large number of crosses made within and between plants of the China and Assam races of tea. Their studies included, besides yield and quality, a number of morphological and chemical characters reference to a few of which has already been made. In more than 75 per cent of their crosses, progeny yield exceeded the mid-parent yield. No case of negative heterosis was reported in respect of yield. In more than 60 per cent of the crosses, progeny quality improved over the parental mean. As regards other characters, long internode of young shoot was completely dominant over short internode. The purple anthocyanin colour of young leaf of the China race was found to be dominant over the yellow-green colour while, in *assamica* x *sinensis* crosses, the yellow leaf colour of the Assam plant was partially dominant over the purple colour of the China plant.

Wight (I958) reported quantitative inheritance of calcium oxalate crystals in the petiole of tea leaf. Wu *et al.* (1958) and Wu (1964) observed that length and density of hair on the undersurface of young tea leaf were quantitatively inherited. Barua (1961 b) found size of tea seed to be a maternal character, the pollen parent seemed to have little, if any, effect on seed-size.

The foregoing analysis exposes the limitation of our knowledge on the breeding behaviour of the tea plant. In these circumstances the tea breeder cannot expect much guidance from examination of the morphological, physiological or chemical characters of the clones selected for crossing. None the less, the existing evidence leaves scope for the suggestion that progenies having high yield potential could be expected in about 60 per cent of the crosses made between vigorous parents, more so when the parental clones differ widely in their morphological features. Production of quality in the progeny is less certain. In as much as a combination of high yield, good cup quality and a resonable degree of morphological homogeneity in the progeny is the aim, currently the tea breeder is left with no choice than to try out a large number of crosses to isolate the desired pair/s of parental clones.

Tea breeders can make use of the fact that seed size is a maternal character. A large variation in the size of seeds of a seed bari is undesirable since it causes problems of grading and wastage. Very small seeds are usually rejected. On this account, a clonal seed bari should not be planted with clones bearing unusually small seeds in relation to the average seed-size of the bari. This applies with greater force to a biclonal seed bari where only two clones are used as parents.

TISSUE AND ORGAN CULTURE

Tissue and organ culture is just beginning to make an impact on tea breeding. Its potentialities are wide and varied, some of which have been successfully exploited in the breeding of other crops. Among the possibilities offered by these techniques mention may be made of anther culture for the production of haploids, endosperm culture for raising triploids, protoplast culture and somatic hybridisation, *in vitro* fertilisation of embryos to overcome fertility barriers, embryo culture for raising seedlings of wide crosses and production of plantlets for preservation of germplasm. Besides, callus tissues and suspension cell cultures have proved useful in the study of biosynthesis of caffeine (Ogutuga and Northcote, 1970) and of polyphenols (Forrest, 1969; Koretskaya and Zaprometov, 1975; Zaprometov *et al.*, 1979; Bagratishvilli *et al.,* 1980) in tea.

Wu (1976) and Wu *et al.,* (1981) at the Taiwan Tea Experimental Station were the pioneers in inducing the growth of tea plantlets from *in vitro* culture of callus derived from cotyledon. The plantlets were successfully transferred to soil and some of these are now being utilised in their tea breeding schemes. However, their attempts to induce organogenesis from calli derived from anther and shoot tip cultures did not succeed. More recently Phukan and Mitra (1983) and Barthakur and Mitra (1984) in N.E. India were successful first in producing plantlets of the shade tree *Albizzia odoratissima* from *in vitro* culture of shoot tip tissues and then in regenerating shoot buds from nodal explants of mature and seedling tea. Further progress in this field can now be envisaged.

Successful culture of organs and tissues will undoubtedly increase the scope for raising productivity of tea through interspecific and intergeneric hybridisation and production of polyploids. It will also assist evolution of genotypes for resistance to pests and diseases and environmental stresses like frost, drought and waterlogging. Embryo culture has already been successfully utilised for raising plants from some of the interspecific and intergeneric crosses of *Camellia* where seed development is abnormal (Ackerman, 1977).

Tissue culture as a commercial method of vegetative propagation of the tea plant is likely to be ineffectual since simple and cheap methods already exist. It can, however, play an important role in the preservation of germplasm.

PRESENT STATE OF TEA BREEDING

Use of Vegetative Clones

Vegetative clones have been selected and used for commercial propagation in many countries. Some of these clones were selected from mature sections of commercial tea and others from seedling populations. Early selections in N.E. India were made from mature tea fields but latter selections were mostly from progenies of clonal crosses. At present a scheme for the selection of vegetative clones and collection of germplasm in old fields of commercial tea is in operation and a large number of clones selected under this scheme are undergoing trials (TES Ann. Rep. 1981-82) and some have already been released for commercial cultivation.

Hybrid progenies resulting from crosses between different kinds of tea have been the main sources of vegetative clones selected in Japan. The popular 2000 series of Sri Lanka clones were selected out of a handful of seeds collected during 1937 from an open pollinated seed bearer at Tocklai (Richards, 1966). Subsequently a large number of clones have been selected from mature tea areas. A number of East and Central African countries have selected and used clones for commercial propagation. In Indonesia, clonal propagation is the current practice. Some good clones have been selected in the U.S.S.R. although clonal propagation on a commercial scale does not seem to have made much progress.

Estimates of the area so far planted with vegetatively propagated clonal material is not available from most countries. In some counties like Sri Lanka only vegetative clones are being used for commercial propagation. This has been made virtually obligatory by a legislation introduced during 1958. Under this legislation a tea grower in Sri Lanka can claim maximum tea planting subsidy only if he uses vegetative clones for commercial propagation. Estimate of the area planted there with clones is, however, not available.

An estimated 25 per cent of the total area under tea in Assam and West Bengal has been brought under vegetative clones. Until 1975, area planted with clones in Japan is estimated at 25 per cent (Takeo, 1975). In Malawi clonal tea accounts for about 7 per cent of the total area planted till 1983 (Ellis, 1983) while in Kenya, approximately 50 per cent of the 79,000 ha of tea has been planted with clones (Othieno, 1983).

Production of Seed Varieties and Other Aspects

Information available from different countries on production of seed varieties, breeding of polypioids, tissue and organ culture of tea is very limited. The following account, being based on available information, may not give an authentic picture of the progress achieved by different countries in these fields of tea breeding.

A fairly complete account of the procedure followed and progress made in the breeding of tea at the TES in N.E. India is available from the literature (Barua, 1963; Bezbaruah, 1968 b; 1974). The procedure followed at this station in breeding clonal seed varieties is, therefore, described in some detail.

A tea breeding programme was started at the TES in 1939. The work was interrupted by the Second World War and was resumed in 1946 with the dual objects of breeding seed varieties superior in yield and cup-characters to existing *jats* of commercial tea and selecting outstanding bushes and multiplying them as vegetative clones. Both these objectives were pursued simultaneously (Barua, 1963; TES Ann. Rep., 1967-68). The first lot of three vegetative clones was released to the tea growers of N.E. India in 1949 and more vegetative clones have since been released from time to time.

A polyclonal seed variety involving seven clones was developed in the mid-fifties as an interim measure to meet the pressing demand of the tea industry for a hardy *jat* of good quality and yield. Planting of this clonal seed stock was discontinued when biclonal seeds of superior merit became available to the growers. The first biclonal seed variety bred specially for the hill district of Darjeeling was released in 1967. This seed progeny produces flavoury tea characteristic of the Darjeeling district. Two biclonal stocks were released for the plains districts in 1970 followed by the release of three more stocks, one in 1975 and the other two in 1981 (TES Ann. Rep. 1969-70; 1975-76; 1981-82). A number of biclonal stocks are now in various stages of development. Seeds of the four early releases are now available to commercial growers, many of whom are opting for the use of these clonal seed varieties for replanting and extension planting in preference to clones.

The procedure followed in selecting the pairs of generative clones was described by Barua (1963). The two selected plants were crossed by hand transfer of pollen and the progeny was assessed for growth, yield and liquor characters. If found satisfactory and if the progeny had a fair degree of morphological uniformity, then the two parents were multiplied vegetatively and planted out in a small seed bari for the production of seed by open, random pollination under natural conditions. The open pollinated seed was tried out in agricultural trials and sent to different geographical and soil-climatic regions of N.E. India for adaptability tests. Final selection of the clone pair was made on the basis of all these tests. After selection, the parent clones were multiplied vegetatively for establishing commercial seed baries for the production of seed. From pollination to final selection of the generative clones it took about 20 years. Subsequently, the trial of hand pollinated seed progeny was dispensed with, although hand pollination is still considered necessary to ascertain whether the clones selected for crossing are compatible or not and to what extent they are self-fertile. This change from the previous procedure has cut down the time involved in the production of seed varieties to about 15 years.

Out of more than 400 crosses made until 1960, only six pairs of clones were chosen for planting micro seed baries. In retrospect, this would appear to be a wastage of effort, but in those early years the breeders had to work almost purely by intuition as they had no source to turn to for guidance in the breeding of clonal seed varieties superior to the existing *jats* of commercial tea. Apart from results of immediate benefit to the practical planters, these efforts produced a fund of knowledge which had a profound effect on tea taxonomy in general and our understanding of the cropping capacity, vigour, quality etc. of different kinds of tea and paved the way for inter-specific and intra-specific hybridisation. Later studies by Bezbaruah (1971) demonstrated the positive role which heterosis might play in improvement of tea varieties.

The progenies of inter-specific and wide crosses between different races of tea are usually vigorous but lack quality and morphological uniformity. Likewise vegetative clones when crossed among themselves more often than not produce mixed progenies, since the virtue of a vegetative clone is predominantly a consequence of its hybridity. Wight (1961), however, considered that morphological uniformity could be achieved to a large extent by using 'combiner clones' as the sources of pollen. The combiner clones are plants of the *assamica* type which are supposed to possess the capacity to assimilate morphological features of other races of tea and related species. However, the utility of such clones in practical tea breeding has yet to be proved.

Starting with the natural triploids and tetraploids discovered at the station (TES Ann. Rep.,1969-70), a stock of polyploid clones have been built up and utilised for breeding vigorous vegetative clones (Singh, 1980). Triploids produced by crossing tetraploids with diploids are currently under trial as vegetative clones.

It is yet too early to make any comment on the prospect of tissue and organ culture which is now progressing.

At present emphasis in Japan appears to be on the production of vegetative clones. These have been selected from hybrid progenies raised by crossing different types of tea. High yield, good cup characters and a high degree of tolerance to low temperature are the major considerations in the choice of clones. Big shoot size is another important criterion, but big-leaf *assamica* x *sinensis* hybrids are found to be less tolerant of low temperature than the small leaf China and China hybrid plants (Tomo *et al.*, 1966). A number of vegetative clones are now widely used for large-scale cultivation throughout Japan. Production of mutants and breeding of polyploids are other aspects of the tea breeding programme of Japan but details of the current state of progress in these fields are lacking.

A procedure similar to Japan is being followed in Taiwan where a number of excellent clones have been developed from the F_1 progenies of crosses made between and within the Assam and the China races of tea. Selection is made (Wu, I981) separately for the production of Oolong, Poachong and Black tea.

In the USSR. a large area was planted in the past with locally developed China *jats* of tea. With a view to replacing these *jats* with high-yielding and superior quality planting material, an intensive tea breeding programme was taken up some 40 years ago. Polycross breeding between China and Cambod races of tea resulted in the development of a number of seed varieties which yielded 50-60 per cent more than the old *jats*, besides producing teas of superior cup-quality. Frost damage being a serious problem, special care is taken to produce strains, which can withstand very low temperature. All the newly-bred varieties are frost resistant and some of these like Georgian hybrid No. 8 are said to thrive even at —22°C. These new varieties are replacing the old *jats* of tea and making it possible to extend tea cultivation to the northern regions.

A few outstanding clones have also been selected from mature tea areas. However, propagation by seed is still preferred in Russia because vegetatively propagated clones are considered to possess lower biological tenacity. Besides, production of clonal plants and their management are more labour intensive than seedling tea.

Mutation breeding is an important aspect of tea research in the U.S.S.R. Besides chemical mutagens, beta and gamma radiations as well as thermal neutrons have been tried for the induction of mutation. A few mutant strains have already been developed. The Russian workers are also trying to produce haploid plants through organ culture.

Breeding has been initiated in Sri Lanka using a few selected vegetative clones as the parents. However, the progenies of these crosses were found to be highly heterozygous and they fell far short of the parent clones in yield and quality (Richards, 1967). Mutation breeding has also been tried in Sri Lanka but the current state of progress is not known.

During the early years of the century, the Dutch in Indonesia started work on plant improvement by carefully selecting seedlings from 19 Indian and three local *jats* of tea on morphological characters and planting them out in isolation in an equal number of seed baries. Successive selection of the seed bearers continued for several years. When seeds from the remaining trees were finally tried, the result was not very encouraging (Harler, 1928). The discovery of grafting techniques for tea in the late twenties made it possible to multiply the selected mother bushes and test them as seed bearers or as vegetative clones. Development of a simple technique for propagation of the tea plant from cuttings made matters easy for the breeders. When the work on plant breeding was progressing, the War broke out. With it all activities came to a standstill and any benefit which could have accrued from the early efforts was completely lost. After the fifties, selection of vegetative clones had been taken up again and a few clones have been released for commercial cultivation.

In Malawi, besides selecting vegetative clones, a small polyclonal seed bari consisting of five clones was established in 1960. The clones were selected from a popular Assam *jat* of tea (Betjan) for their high fermenting ability and bright liquors. (TRFCA Ann. Rep., 1960-61). More polyclonal seed baries were planted up in the subsequent years, at first with ten and then with six clones. Seeds from these baries have been used for commercial cultivation since 1969, which now cover approximately 15 per cent of the tea areas of Malawi (Ellis, 1983).

In Kenya priority has now shifted from the selection of vegetative clones to the production of biclonal seed progenies, primarily for want of reliable selection criteria for vegetative clones. Clonal seed varieties have not yet been produced on a commercial scale (Othieno, 1983).

PRESERVATION OF TEA GERMPLASM

Uprooting of old tea areas and their replacement by vegetative clones and clonal seed progenies coupled with the encroachment of the natural habitats of ‘wild’ tea in the hilly regions of South-East Asia have drastically eroded the germplasm base of the tea plant. The situation is bound to deteriorate further with the passage of time. Unfortunately no central pool of tea germplasm exists anywhere in the world.

A description of the germplasm collection at the TES has been published (Bezbaruah and Dutta, 1977). Efforts have been made since 1971 to augment this collection by picking up the potentially valuable bushes from old sections of commercial tea due for uprooting and testing them for yield, quality and other desirable characters (TES Ann. Rep., 1971-72). The vegetatively propagated progenies of these bushes are being added to the central germplasm pool.

Tea research stations of other countries apparently have their own germplasm collections. Strengthening of these collections should be a part of the normal activities of each research station. For this purpose, all tea plants which exhibit special features in leaf and floral morphology, growth form, chemical characteristics, disease, pest, drought and frost resistance etc. should be brought to the local germplasm pool. Compared to other annual and short duration crops, preservation of tea germplasm is a relatively easy task. With normal maintenance, a tea plant is expected to live at least for 40-50 years. Besides, methods are now available for preserving in the laboratory seeds, stem and root cuttings and pollen grains of tea for five to seven years (Amma and Watanabe, 1983).

REGISTRATION OF TEA CULTIVARS

International authorities exist for registering cultivars of different crops bred or developed throughout the world. Complete records of the cultivars are maintained and these are made available for the purpose of research and crop improvement programmes. No such international agency exists for registering tea cultivars. It is true that being the progenies of seed baries whose compositions were not fixed, the old seed *jats* of tea were not amenable to registration. With the development of clones and clonal seed varieties, the situation has completely changed. The tea producing countries can now seriously consider having one central agency for the registration of tea cultivars. As in the cases of other crops, such an agency will be of great advantage to tea growers throughout the world.

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CHAPTER 7

PROPAGATION TECHNIQUE

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PROPAGATION BY SEED

Source of seed

For commercial propagation, tea seeds are produced in seed baries planted specially for the purpose. China and China-hybrid bushes under plucking produce some seeds in the unpruned years when pruning cycles are longer than of one year. Such seeds have occasionally been used for commercial propagation but this practice is now virtually dead due to availability of better seeds from commercial seed baries.

The tea fruit is allowed to dehisce on the tree and the dropped seeds are collected from the ground that is cleaned before seeds start to fall. As these seeds lose viability rapidly, the normal practice is to collect them everyday.

Seed-size and its significance

The tea seed is a spheroid slightly flattened on the side of the hilum. Usually one, sometimes two and rarely more than two seeds develop to maturity in the same loculus. When more than one seed are formed in the same loculus, they become flattened on the sides which come into contact (Plate 3). In spherical seeds, the greater diameter is a linear function of the lesser diameter (Barua, 1961 a). The seeds vary in size from 10 mm to 22 mm diameter. Within these limits, the seeds from a seed bari can be sorted into a series of size grades.

Barua (*loc. cit.*) has shown that the proportions of seeds of different size-grades vary from one seed bari to another. The size of seed is also influenced to some extent by nutritional and cultural factors but they do not obscure the difference that exists between large-seeded and small-seeded trees. Seed baries where the small-seeded trees predominate, produce a large proportion of small seeds than by baries where large-seeded trees are in abundance. It will, therefore, be wrong to expect a high proportion of large seed from a bari which is intrinsically small-seeded and *vice versa*. Small seeds produce seedlings which are notably small and their germination percentage is also low (Barua, *loc. cit.*). This justifies rejection of very small seeds, but because a modal seed size is one of the characteristics of the progeny of a seed bari, the smallness should be defined relative to the modal seed-size of the bari. So defined, the seed to be rejected should be only a small fraction of the total output of a bari.

Grading and sorting

After collection, seeds are brought to a central shed and passed through a rotary type sifter to eliminate the very small seeds. The mesh size used for the elimination of small seeds should not be determined arbitrarily; it should correspond to the modal seed-size of the bari. After eliminating the very small seeds, the remaining seeds are transferred to a tank or a trough filled with water and allowed to soak for 2-3 hours. The tank should be deep enough to allow at least 15 cm of water to remain above the level of the seeds that sink.

The sinker seeds are taken out of water and spread on a concrete floor, tarpaulin or a plastic sheet until the adhering water evaporates. After this, the usual practice is to cut open a sample of 50 to 100 seeds from the batch and examine them for mechanical, insect and pest damage. If the cotyledons of a certain percentage of seeds of the sample, generally 5 per cent, are found starred, cheesy, shrunken or otherwise damaged by pests and diseases, then experienced sorters are engaged to sort out the punctured, cracked and damaged seeds. A second sample from the remaining seed is examined in the same way and the operation of picking out bad seed is repeated until the proportion of sound seed reaches the acceptable level.

The seeds that float on the surface and those that remain suspended in water without sinking to the bottom are removed to a cool shed where they are kept in bins or pits covered with sand or soil which is just moist. This treatment may continue for two to seven days to separate out the otherwise good seeds which have slightly dried either on the ground or inside the dehisced capsule. Contraction of the cotyledons due to drying creates air pocket inside the seed coat and the seed remains afloat. Absorption of water in the course of storage in moist soil causes the cotyledons to expand and the locked up air is expelled. After this treatment, the stored seeds are again put through the sinker-floater test. Floaters are discarded and the sinkers are examined for damage caused by diseases and pests as described.

Floaters are frequently the result of punctures made by Tea Seed Bug (*Poecilocoris latus*). Starring is always caused by this insect, This insect is easily recognised from its brilliant orange colour with black markings. It grows to a size of 15-20 mm and occurs in clusters on the undersurface of leaves.

Many reputed seed dealers guarantee 85-90 per cent germination of their seed, provided that the consignment does not get unduly delayed in transit.

Storage

After grading and sorting, seed is stored for a minimum period in concrete bins or pits in a cool shed covered by a layer of moist sand or sub-soil. If storing has to be done for more than a week, the seed is subjected again to a floating test before packing and despatch.

Leach (1936) reported the possibility of storing tea seed in pits upto a year. Hume (1955) obtained more than 90 per cent germination after six months when tea seeds were stored at 4.4°C (40°F) in wooden boxes lined with paper. Storage in sealed tins spoiled the seeds. Visser and Tillekeratne (1958) reported 50 per cent germination of seeds stored for 10 months at 0°C and 100 per cent relative humidity. In a detailed study, Sebastiampillai and Anandappa (1979) observed rapid drying to be the main cause for the loss of viability of tea seeds on storage.

Seeds stored in the open at 23°-27°C lost moisture rapidly from an original 70-80 per cent to an equilibrium moisture content of 13 per cent in 10 days. They observed that when the moisture content of the seeds dropped approximately below 28 per cent, the embryos got permanently damaged and the seeds failed to germinate even when the moisture content was restored to the original level by soaking them in water. Fresh seeds could be stored for 9 months at 100 per cent relative humidity and 5°-7°C without appreciable loss of viability. Tea seed with its high moisture content could not be stored at the freezing temperature of —2°C without injuring the embryos.

Amma and Watanabe (1983) reported 74 per cent germination of tea seed after storage for seven years in airtight containers at a temperature of 1°C. The humidity inside the containers must have remained very high after reaching equilibrium.

These studies clearly show that the storage temperature must remain above freezing and humidity at near saturation. At a temperature of 1°C to 2°C and 90 – 100% relative humidity, it seems tea seeds can be stored in sealed containers for many years.

Packing

Seeds are packed after grading and sorting as soon as possible. For transport over long distances, packing is done in wooden boxes in units of 20 kg using moist sand, sub-soil, powdered charcoal or ash or mixtures of two or more of these as the packing material. Moisture content of the packing material varies from 10 to 30 per cent depending on the material used. The optimum moisture content of sub-soil of the sandy loam type is 10 to 12 per cent while in the case of powdered charcoal it may vary from 25 to 30 per cent.

Seeds are spread in layers along with some packing ,material and each layer is separated from the one on top by a thin sheet of tough paper. When the box is full, a sheet of paper is laid on top and the lid is nailed down.

Chemical disinfectants against fungus and insect larvae are not used at the time of storing and packing seeds as the chemicals so far tried have been found unsuitable. However, the trials have not been exhaustive and there may be scope for using chemical disinfectants.

A kilogram of graded and sorted seed may contain from 300 to 500 seeds depending on the size of the grader used.

Import and Export Restrictions

The import of tea seeds (also cutting and scions) is governed by various quarantine regulations of different tea producing countries. Some countries have imposed total ban on such imports. Most of these regulations have been promulagated after the appearance of blister light. Since the method of treatment of tea seed with disinfectants after its arrival at the port of entry has not yet been standardized, the tea producing countries do not want to take the risk of importing untreated seeds since it may carry diseases as well as other undesirable pests.

An embargo on tea seed and cutting material is also maintained by certain countries.

Seed Nursery

The nursery techniques for seed and vegetative propagation of the tea plant are described in detail by Barua (1972). Tea is grown on such a wide range of soils that it is difficult to define precisely the conditions suitable for a nursery site in different types of soil. Broadly speaking, the soil should be of good structure and depth and should be free-draining. The acidity of the nursery soil should be around pH 5.0 and it should be free from parasitic eelworms (*Meloidogyne* spp.) Proximity of the nursery site to a source of water is also desirable.

The soil should first be examined for pH and eelworm infestation. If found satisfactory, it should be cultivated deeply, preferably to a depth of about 60 cm, removing at the same time all undecomposed vegetable matter from the site. It is better to avoid periods of heavy rain for working on the soil since clods are difficult to break when the soil is wet. The soil should be worked to a fine tilth.

Virgin areas with the right type of soil are considered best for raising seed nurseries. If virgin soil is not available, nurseries can be located on old nursery sites or uprooted tea land provided the soil has been properly rehabilitated and tested for acidity and eelworm.

For the convenience of weeding and maintenance, the width of the nursery bed is generally limited to 120 cm but it can be of any convenient length. In sloping terrain, beds may have to be made narrow. While making the beds, special care is necessary in providing outlet channels for water so that the beds do not get waterlogged. In N.E. India beds are generally prepared flat, 10-15 cm above the surrounding ground level. Each bed is enclosed by a drain about 30 cm deep and 30 cm wide which is linked up with the drains of the other beds and finally to a bigger outlet drain. Type of soil and topography of the nursery site are major factors which determine the nature of drainage, elevation of nursery beds from the surrounding ground level and requirement of revetment on drain sides.

Shade

In hot, dry climate, artificial shade is essential for raising good nurseries. Shading of seed nurseries is not essential where temperature remains low and the soil does not suffer from desiccation. Shading may not be desirable also in areas where seed nurseries suffer from the incidence of blister blight.

Flat-topped, overhead shade is the most common type used in tea seed nurseries. The usual height of the top is 150-160 cm from the ground level. As the shade must stand upto strong winds, the uprights made usually of bamboo or wood are firmly driven into the ground at fairly close intervals of approximately 3 m, which may have to be reduced to 2 m or so depending on the velocity and frequency of strong wind at the nursery site. The shade itself is of thinly spread thatch, reed, grasses or ferns, whatever is available in the locality, tied between bamboo or wooden laths to make panels or woven into wire mesh. Woven bamboo laths can also be used. These panels are firmly tied to cross pieces on top of the uprights (Plate 5).

Plate 5. Flat-topped overhead shade over nursery beds used for planting tea seeds and cuttings.

The shade should be thinned progressively along with the growth of the seedlings, finally removing it completely after the seedlings complete a flush of growth.

Open coir matting, plastic net or even hessian net of the right mesh size can be used in place of thatch, reed or fern but gradual thinning of such overhead shade is a problem which has not yet been fully mastered. So is the case with bamboo laths. The fault with this type of overhead shade is its proneness to accidental fire which calls for due precaution. The overhead shade should be erected well in advance of sowing seed.

Low lath-frame (Plate 6) or tent-type shade can also be used in place of overhead shade, but this is rarely done in seed nurseries. Low shade is, however, widely used for growing tea cuttings. These are described under vegetative propagation.

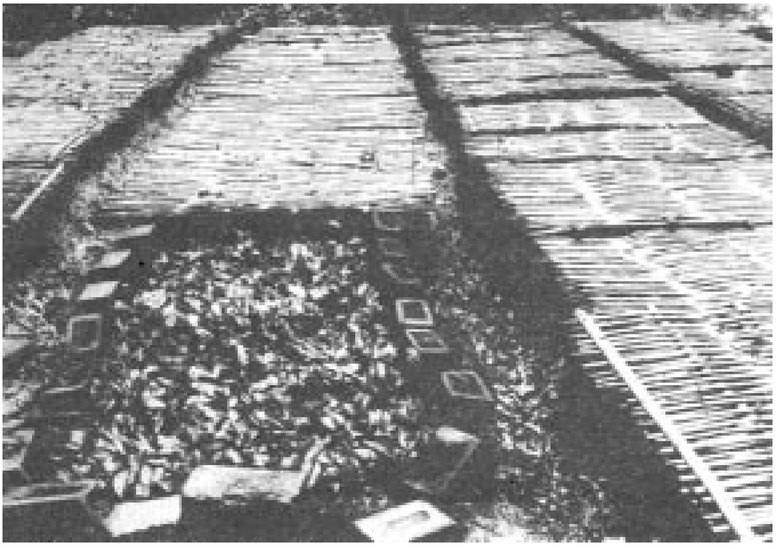

Plate 6. Low bamboo-lath shade used in north-east India for shading seed and cutting nurseries.

Shading of tea seed nurseries by growing rows of leguminous bush crops like the *Tephrosia*s, *Crotalaria*s, *Desmodium*s and *Priocropis cytisoides* has been a regular practice in the tea estates of N.E. India. However selection of the right species is extremely important since some of them are highly susceptible to certain diseases and pests which attack tea seedlings. For instance, the *Tephrosias* are prone to attack by Red rust (*Caphaleuros parasiticus)* and *Desmodiums* are infested by eelworm. *Crotalaria anagyroides* and *Priotropis cytisoides* are relatively immune from these pests. *Tephrosia candida* can be used provided it is removed within a year from sowing, before Red rust attacks the plants.

If the green crop is sown along the edge or in the middle of the seed bed, it competes with tea seedlings for water and nutrients. A suitable location of the green crop is a bed of its own between two adjacent seed beds. If the seed bed is 120 cm wide, then the green crop should be sown in beds of about 20 cm width, so that the lines of green crop are 180 cm apart.

In N.E. India nursery beds are usually prepared in the cold weather before the start of the rainy season. Tea seeds are sown in the following November-December soon after harvest. The green crop is sown in advance during April after the spring showers. The green crop seed is drilled in thinly with a phosphatic fertiliser. The recommended rate for superphosphate is 1.5 kg per 40 running metres. After the green crop has grown to a height of about 15 cm, a top dressing of wood ash or potash is advised. When the green crop plants are about 30 cm tall, they are thinned to one plant per every 0.6 m by cutting the unwanted plants at the ground level and leaving them on the seed bed as mulch. The remaining plants are not lopped but allowed to form a complete canopy over the seed bed.

Assuming tea seed to have been sown in November-December, the green crop should be left undisturbed till April of the following year. By May when the tea seedlings go banjhi after producing a flush of growth, the green crop is hedged and hedging is continued until the crop is finally removed. Along with hedging, the green crop is progressively thinned finally ending up with a spacing of 2.4 metres.

The thinned out green crop is completely removed in August if the tea seedlings are to be lifted for transplanting in October-November. For spring transplanting, removal of the green crop is delayed until the spring showers wet the soil.

If for some reason it is not possible to sow the green crop ahead of tea seeds then, climatic conditions permitting, both should be sown at the same time in November-December. In droughty situations and in the absence of irrigation facility if the sowing of the green crop is delayed till the following spring, germination of tea seeds and the few seeds that germinate suffer from exposure to the sun. Under such situations green crop shade cannot be used and seedlings have to be raised under artificial shade. In fact, green crop shade for seed nursery is inadvisable under droughty conditions. Excessive competition for moisture preludes the use of green crops for shading tea nurseries in different parts of Africa.

Planting of Seed

Seeds are planted in rows as soon after harvest as possible at a depth of about 1.5 cm with the eye (micropyle) pointing downward or parallel to the ground surface. The distance between seeds should be about 20 cm, if the seedlings are to be lifted with *'bheti'* i.e. a cylinder of earth about 15 cm in diameter and 20-25 cm in depth around the roots. When *bheti* is not necessary as in stump or carrot planting, the distance between seeds can be reduced to 15 cm or so.

After sowing the seeds, it is a common practice to cover the seed bed with a thin layer of mulch which may consist of cut grasses, leaves of green crops, cut weeds etc. The soil of the nursery bed should remain moist. The mulch helps in the retention of moisture and reduces compaction of the soil by breaking the impact of rain, irrigation water and drips from the overhead shade. Besides, mulch reduces erosion of nursery soil following heavy rain. Proneness to accidental fire in dry weather is a drawback of the surface mulch which calls for due precaution. The mulch can, however, offer obstruction to the germinating seeds and should be scrapped away when the seeds germinate. This calls for frequent inspection of the nursery.

Some tea seeds may germinate within a month from planting while some may take months to germinate. The slow starters suffer as a result of competition offered by the fast-growing seedlings. It is, therefore, advantageous to pre-germinate the seeds before sowing. This can be done by spreading the seeds on a clean sand bed and covering them with a thin layer of sand. The sand bed is kept moist and protected from the sun. The bed is examined preferably every day to pick out the cracked seeds which are then removed and planted from one end of the nursery bed, to prevent mixture of early and late germinating seedlings. It is detrimental to leave the seed in the sand bed until root initials emerge, which often get damaged during planting.

Polythene Tube Nursery

Introduction of polythene tube or sleeve has brought in drastic changes in the methods of raising and transplanting tea seedlings and plants raised from cuttings. The polythene tube became very popular within a short time because it facilitated transplanting with roots and soil intact and opened the possibility of having permanent nurseries complete with shade, drainage facility and watering arrangement.

The nursery beds and shade for sleeve planting are made in the same way as described above. In a permanent nursery site, the beds may have brick side walls and iron or concrete framework for overhead shade.

The size of sleeve to be used for planting seed depends on the age and size of plant at the time of transplanting. A convenient size for one year old seedlings is 17.5 cm layflat tube of 150 gauge polythene film cut to a length of 25-30 cm. Long and narrow sleeves of 10-13 cm breadth and 30-35 ern length have also been used for raising plants. The disadvantage of such sleeves is that they cannot be made to stand erect without support. The sleeves are staked side by side in a group for mutual support which leaves very little room between plants for their spread. If retained in these sleeves for long, the plants become tall and spindly and their subsequent pruning becomes a problem. Larger sleeve of heavier gauge will be necessary if the seedlings are retained in the nursery for longer duration. Big sleeves cost more and require a larger volume of soil for filling which increases the cost further.

The soil for filling sleeve should have an acceptable level of acidity (normally pH 4.5 to 5.5) and be free from pathogenic eelworm. Too heavy or too light soils are not suitable. After collection, the soil is stored in a covered shed where it is worked to a fine tilth. At the time of filling sleeves, the soil need not be very dry but it should remain friable. Many simple devices have been tried for speeding up the process of filling. One such device consists of two semicircular metal plates of the desired diameter, each attached to a long handle. The plates hold the sleeve open like a cylinder and soil is packed in the cavity. After filling, the plates are withdrawn, some more soil is added with a little pressure and the sleeve is ready. An automatic sleeve filling device is reported to be in operation in the U.S.S.R. (Dey, 1972).

The bottom end of the sleeve is not closed in N.E. India where the texture of the soil is such that after filling and wetting, the sleeve can be moved from the potting shed to the nursery without any loss of soil. However, soils everywhere are not equally cohesive. Wherever necessary, the bottom end of the sleeve should be closed by joining the edges with one or two staples.

The filled sleeves are arranged in rows on nursery beds and allowed to stand in rain. In the absence of rain, the sleeves are watered. If the soil sinks low in the tube, then fresh soil is added to bring the level up. Seed is not planted until the soil settles down in the tube for which 4 to 6 weeks are usually required. Only pre-germinated seeds should preferably be used for planting in sleeves since a certain percentage of seed always fails to germinate. If pre-germinated seeds are not available, then some seeds should be planted in nursery beds as a measure of precaution. The nursery seedlings can subsequently be transferred to those sleeves where seeds failed to germinate.

LIFTING AND TRANSPLANTING

Bheti Planting

A seedling cannot be lifted with *bheti* when the soil is wet and soft. Soils which lack cohesion are also not suitable for lifting *bheties.* In N.E. India both rainfall and soil conditions remain ideal in a part of the year for successful use of this method of transplanting. *Bheti* planting is done after the rains from November to early January and again in April-May before the onset of rains. The latter period is preferred in areas where the weather during winter and early spring remains very dry.

Bheti is usually lifted with a special cylindrical spade. When dug with ordinary spade, the operation becomes slow and costly. For one year old plants of 40-45 cm height, which is the usual time for lifting plants for transplanting, the *bheti* is 12-15 cm in diameter and 20-25 cm in length with a flat bottom so that it stands erect when placed on a flat surface. For lifting bigger plants, the size of the *bheti* has to be increased. When lifted with *bheti,* the tap root of the plant generally remains intact, but some of the lateral roots which grow at an angle from the vertical may get severed.

Bheti planting has a major disadvantage. Removal of a large mass of top soil along with the *bheties,* impoverishes the nursery site. Unless the soil is exceptionally rich, it cannot support healthy growth of seedlings for the second year in succession. This did not bother tea growers in the past when virgin soil was available in plenty. At present finding a fresh nursery site has become difficult in a large majority of the tea estates of N.E. India and elsewhere. Although polythene sleeve is displacing direct planting of seed (and cutting) in nursery beds, sowing seeds in nurseries and lifting young plants with *bheties* are still being practised on a fairly large scale. Good soil for filling sleeve is also getting scarce everywhere. The situation warrants greater attention to reclamation of used nursery sites and debilitated soil.

Stump or Carrot Planting

In Sri Lanka, Indonesia, Africa and other countries where the soil does not set firm and hard for lifting plants with *bheties,* stump or carrot planting is widely practised. The seedlings are allowed to grow in the nursery for two to three years until the plants attain a thickness of about 1.5 cm or more at the collar. The plants are then pruned 10-20 cm above ground and the stumps with the tap roots are pulled out from the loosened soil. The stumps are taken to the planting site in bundles.

The right stage of pruning seedlings for transplanting as stumps has been a controversial issue. In the absence of leaf, growth of laterals from the stump takes place at the expense of food stored in the tap root. On this consideration it is argued that a seedling should be allowed to remain in the nursery for a sufficiently long time to enable it to accumulate enough reserve in the root, so that it stands a better chance of withstanding adverse weather conditions that may follow transplanting. Others do not advocate holding back seedlings in the nursery longer than is absolutely necessary, since all growth made in the nursery is wasted when the seedling is pruned as a stump. Besides, the bigger cuts made on older seedlings take longer to heal, increasing the danger of infection by pathogens. Maintenance of well-grown seedlings in the nursery also involves expenditure, particularly where irrigation is needed. It is, therefore, necessary to arrive at a compromise which may vary with the situation of each locality, by balancing the opposing arguments. Apart from physiologIcal considerations, practicability of the transplanting operation at particular times of the year has also to be taken into account. Assuming that the correct physiological age of transplanting is known, the actual operation may not be possible at that precise time because of drought, heavy rain, non-availability of personnel etc.

Seed at Stake

In this method seed is planted directly in the field, avoiding the trouble and cost of raising plants in nurseries and transplanting them subsequently. In the past this method of propagation was used extensively in a number of countries. Although its popularity has waned, particularly after the introduction of vegetatively propagated clones for commercial planting, the method is still used in some countries like the U.S.S.R. and Japan. After marking the positions of the plants in the field, three to five seeds are planted in each spot, usually in a circle of 30-45 cm diameter. As a result, one multiple bush develops in each spot.

This method of propagation can succeed only under ideal conditions of soil and climate. In a hot climate the young seedlings suffer from scorch and under dry conditions the soil has to be kept moist. Where conditions are favourable, the young seedlings have to be carefully protected from weeds until they grow to a height of at least 45-50 cm. After this initial period, normal weeding should be adequate. Despite all these measures, the stand of tea may not be uniform due to failure of some seeds to germinate and death of some plants after germination due to attacks by diseases and pests and on account of other unforeseen causes.

MANAGEMENT OF NURSERY

Control of Diseases and Pests

A number of fungal parasites and insect pests attack tea seedlings in the nursery but the same diseases and pests are not prevalent in all regions. The severity of infestation by the same pest often differs from place to place. Collar rot caused by

Phomopsis sp. and damping off caused by *Pythium* sp. are, however, common to most regions. Heavy and damp soil favours the growth of these fungi. Among the insect pests, termites and crickets can do a lot of harm to nursery seedlings.

Among the other enemies of nursery plants, blister blight can cause serious damage wherever it is present. Mites too can be a major cause of worry. To say that the germinating seeds and young seedlings should be protected from pests and diseases by appropriate prophylactic and curative measures, will be a repetition of the obvious. Due precaution should also be taken against drought and waterlogging.

Control of Weeds

Weeding of nurseries is generally done by hand whenever necessary. However, in the initial stages care should be taken not to disturb the roots of the young plants. Before planting seeds, nursery beds can be treated with pre-emergent herbicide like Simazine (2-chloro-4, 6-bisethylamino-l, 3, 5-triazine) and Karmex (Diuron) (3-(3, 4-dichlorophenyl)-1, diethylurea) without harming the plants. Herbicides keep the nursery beds free of most weeds for a long time.

Manuring

Nurseries established in rich soil do not normally have to be manured, at least till the plants have completed a flush of growth. In case the plants are debilitated by attacks of diseases and pests, which should never have been allowed, then to encourage growth, judicious application of fertilisers may be resorted to without waiting for completion of the flush. In poor soil, manuring is necessary to accelerate the growth of the young plants so that transplanting is not delayed.

Organic manures like cattle manure and sterameal can be safely applied to plants in the nursery. These can either be broadcast or dibbled in when used dry. Use of liquid cattle manure is also possible, but it takes more time and labour and is cumbersome. If applied with care and discretion, inorganic manures can give equally good results. These can be applied as salts to nursery beds or dissolved in water and sprayed on the plants. However, inorganic salts like ammonium sulphate, potassium sulphate, potassium chloride scorch the plants if the salts or their concentrated solution are allowed to come into contact with the tender parts of the plants. It is, therefore, safer to use the salts in small quantities at a time and in dry weather, spray the plants with water after fertiliser application to wash down any salt particle that may adhere to the leaves. The same precaution is necessary if these chemicals are applied in the form of aquaous spray.

Foliar spray of any salt other than urea and ammonium phosphate is not favoured by the TES for plants in the nursery. These salts too can cause scorch but they are considered safe if the concentration in the spray fluid does not exceed 4 per cent in high volume spraying and 8 per cent when atomising sprayers are used. For spraying plants under shade, only one half of the concentrations is advised (S.K.D., 1970). Irrespective of the type of sprayers used, the undersurface of the tea leaf where the stomata occur, should be wetted because almost the entire amount of foliar sprayed nutrient is absorbed through the stomata (D.N.B. *et al.*, 1967). In Sri Lanka, Visser and Kehl (1961) sprayed young plants raised from cuttings soon after root formation with a fertiliser mixture containing ammonium sulphate, potassium sulphate, superphosphate and magnesium sulphate at 1.6 and 2.5 per cent salt concentrations, taking the precaution of spraying the plants with water after fertiliser application if the weather happened to be dry. No ill effect was observed on the plants. However, salts like ammonium sulphate have been known to scorch the leaves of young tea plants in hot and dry weather even at a lower concentration than the above. If these salts and their mixtures are to be used for spraying, this fact has to be kept in view. A rational approach will be to use small quantities of inorganic fertilisers at a time for soil application and dilute solutions as sprays and repeating application at frequent intervals.

As regards the quantity and composition of fertiliser mixtures, there can be no uniform criterion since physical and chemical properties of soil and growing conditions vary from place to place. For N.E. India, the TES recommends a fertiliser mixture containing 10 per cent nitrogen, 5 per cent phosphoric acid and 10 per cent potash. The mixture is to be applied at the rate of 2 kg nitrogen per round for 10 rounds to one hectare of nursery bed i.e. 0.2 g N per square metre per round of application. Fertiliser application may be increased by a few rounds if weather permits.

As against this very conservative recommendation, Visser and Kehl *(loc. cit.)* applied upto 4.0 g N per square metre of nursery bed per round of application together with other nutrients (P, K and Mg) in the fertiliser mixture. In one treatment this rate of application was maintained for 15 rounds at fortnightly intervals, adding in the process 600 kg N per hectare of nursery bed. This was 30 times higher than the quantity prescribed in N.E. India, with no adverse effect on the plants. Variation in the proportions of the nutrient constituents in the fertiliser mixture did not make appreciable difference to the growth of the nursery plants. In another experiment the same quantity of NPK fertiliser was applied to nursery plants in organic and inorganic forms. Quantity remaining the same, the fertilisers were applied in two to twelve rounds. Neither frequency of application nor the form of fertiliser made any difference to the growth of the young plants.

These results suffice to illustrate the extremely divergent nursery manuring policies pursued in different regions. The situation is no different in the manuring of field grown plants, as will be shown later. The causes for the differential response to nutrients apparently reside in the soil-climatic complex of a region but these remain to be identified to enable meaningful comparison. Meanwhile each region will have to determine by trial and error the best combination of fertilisers for nurseries as well as their quantum and mode of application.

PROPAGATION BY CUTTINGS

Early Work

Vegetative propagation of the tea plant by layers, marcots and woody cuttings was practised in China and Japan on a limited scale for a long time in the past (Hutchinson, 1904) but these methods were not suitable for large scale propagation. Tunstall

(1931 a, b) first showed that cuttings consisting of a single leaf and the associated piece of internode on current year's growth would root well and this was the method subsequently developed. Soon afterwards Tubbs (1937) in Sri Lanka and Wellensiek (1933) in Java were successful in rooting tea cuttings. Using solar propagators and hot houses, Kvarazkhelia (1934) in the U.S.S.R. obtained upto 40 per cent rooting of tea cuttings that carried one to four leaves.

Subsequent development of the method to its present state of efficiency is the result of efforts made by a large body of the tea scientists in different parts of the world. In this connection contributions made by tea planters in adapting the method to local conditions cannot be ignored. Basically the same method is now used throughout the world although local conditions determine the time of propagation, type of shade, size of polythene sleeve, frequency of watering etc. The basic propagation procedure is described below.

Source of Cuttings

Estates embarking on large-scale vegetative propagation should have a multiplication plot or nucleus area planted with the selected clones. The number of mother plants per clone is determined by the number of plants to be raised from each clone in a year. In the initial stages, it is advisable to estimate for at least double the number of cuttings (assuming that the clone is easy rooting) than the number of plants required from a clone, to guard against possible rooting failures. The number of mother bushes to be planted in the nucleus area is based on the estimated requirement of cuttings.

The plants in the nucleus area should not be very crowded. For Assam and Combod types of clones, a spacing of 120 cm triangular appears to be adequate but dwarf Chinery bushes may be planted closer, at about 100 cm. The plants in the nucleus area should be manured with balanced NPK fertiliser mixtures which, under certain conditions, may also need magnesium and zinc. Application of organic manure at suitable intervals is desirable if the soil is deficient of organic matter. The plants should be protected from pests and diseases.

Primary shoots arising from the frames of pruned bushes are used for making cuttings. Cuttings can also be taken from the well-grown branches of the primary shoots. Cuttings taken from unpruned bushes are inferior in strike to those taken from bushes that are pruned.

Unpruned mother bushes pass over to the reproductive phase when less leaf and more flowers are produced. Cuttings taken from shoots where flower initials have already formed do not root readily nor do they produce vigorous plants. The mother bush is, therefore, pruned at intervals to keep it in a vegetative state. The frequency and severity of the pruning operation, however, depends on growing conditions and the kind of plant. Where conditions are favourable for rapid growth, pruning has to be more frequent than where growth is slow. Wight (1955) advocated pruning of mother bushes twice a year in N.E. India after each one of the two optimal times of propagation. Kehl (1961) in Sri Lanka was of the view that mother bushes from which cuttings were drawn regularly should have a prune once in every 15 or 20 months. To ensure adequate reserve of carbohydrates for the production of regrowth, he suggested leaving sufficient leaves on the bushes at the time of pruning. He also proposed resting of mother bushes occasionally for a few months.

Thus, a hard and fast rule for pruning mother bushes cannot be laid down since it depends on the rate of growth of the bushes as well as on the time of propagation.

The nucleus bushes should not be grown under shade. If necessary, temporary shade may be used during the initial one or two years until the young plants get established in the field. A properly managed nucleus bush of a vigorous clone can be expected to provide at least 2000 cuttings in a year after about five years from planting.

Nature of Cuttings

A tea seedling grows at the expense of food, mainly carbohydrates and fats, stored in the cotyledons of the seed. A cutting does not have a store of food. If the leaf (in the case of a single-leaf tea cutting) gets enough water and its cells remain turgid, then it carries on photosynthesis and the accumulated products of photosynthesis meet the needs of the developing roots and shoots. Goodchild (1967) in East Africa observed gradual increase in the weight of internodal tea cuttings upto 51 days from planting by which date shoots appeared on some cuttings.

A cutting without root is a delicate object. It is constantly losing water into the atmosphere by transpiration, but its capacity to draw water from the soil is very limited. A cutting leaf cannot carry on photosynthesis unless water balance is maintained to keep its cells and tissues in turgid condition. Loss of water increases in proportion to the number of leaves on the cutting. Because of this, cuttings carrying more than one leaf are more liable to suffer from water stress than those with a single leaf, particularly in open air propagation under commercial conditions. Reduction of leaf area of single-leaf cuttings does not usually improve success appreciably unless the leaf happens to be very large. In large leaves each having an area of more than 80 cm^2, Bezbaruah (1977) observed better strike by cutting off the tip and reducing the area by a half. The most suitable type of cutting for large-scale propagation of the tea plant is, therefore, the one having a single leaf. Among the single leaf cuttings, the internode type is used throughout the world (Fig. 17), this being the most efficient type for large-scale propagation. These cuttings are drawn from maiden shoots produced by pruned bushes as well as from well-grown branches of the maiden shoots.

In warm, equatorial climate, some cuttings can be taken three-four months after pruning of the nucleus bushes (Kehl, 1951), but in regions where the winter is long and cold, bushes pruned in early winter cannot be expected to produce a sizeable number of cuttings until the following summer.

The topmost two-three tender leaves on shoots with growing apices are unsuitable for propagation under open air conditions. So are the bottom leaves on the hard and rough reddish-brown portion of the stem. The middle portion of the shoot which is neither too hard nor too soft makes the best cuttings. When cuttings are drawn from this portion of the shoot, the colour of the stem irrespective of whether it is green or brown does not make any difference to rooting (Wight, 1960). In shoots where the apical bud has gone banjhi, even the top leaves can make good cuttings (Table 32).

Table 32. Per cent rooted cuttings (Barua and Barua, 1960)

Kind of shoot	Position of leaf from th apex				
	2	3	4	5	6
Growing	1.5	14.0	35.8	30.5	39.7
Banjhi	25.2	44.1	24.5	37.8	47.4

Experiments at the TES have shown that a swollen axillary bud makes the best cutting. If the bud has already grown into a lateral with two-three young leaves, it can be pinched back to the janam. Eden and Bond (1941) advocated the same procedure. Kehl (1951) suggested breaking the tips of shoots about 15 days before taking cuttings, perhaps with a view to releasing the lower axillary buds from the effect of apical dominance. However, from other experiments (Barua, 1961 b) it is seen that the tipping stimulus is restricted to the top two-three axillary buds. Since the top leaves may be too tender for cuttings, it is doubtful whether breaking the tips of shoots would enhance growth of cuttings taken from the mature portion of the shoot. In practice all leaves with dormant, swollen and slightly growing axillary buds are made into cuttings. In spite of various investigations, it is not possible to assert categorically that dormant buds on the smooth, red part of the stem will make inferior cuttings than swollen or growing buds on the green portion.

For making the standard, internode type of cutting the stem is cut obliquely with a sharp knife about 0.5 cm above and 2.5 cm below the axil bud, both the cuts being made approximately parallel to the plane of the leaf. Sharpened secateurs with double cutting edges can also be used, but it is essential that the stem should not be bruised or squeezed. In clones having very short internodes, the length of the piece of stem below the leaf may be less than 2.5 cm. It cannot be helped, but extra care is necessary in planting such short cuttings firmly in the soil.

Cuttings with more than one leaf were tried in many countries with or without a basal node. In the standard internode cutting just described, the basal cut is made between two leaves, but the cut can also be made just below the next lower leaf leaving one full length of internode on the cutting. The lower leaf is discarded at the time of planting.

Results obtained by Barua and Barua (1960) with long cuttings carrying one to six leaves, all having basal nodes, are shown in Table 33. Cuttings were drawn at random from more than 50,000 seed-grown, mature bushes of the Assam type. Cuttings taken from shoots terminated by a growing bud were propagated separately from those taken from banjhi shoots. The mean rooting success for two types of propagation is shown in the table. A diminution of success in proportion to the number of leaves on the cutting is clearly seen. Similar results were obtained by Eden and Bond (*lac. cit.*) and Scarborough (1971) with cuttings carrying one to three and one to two leaves, respectively.

Table 33. Rooting percentages of long, short and standard cuttings

Type of stem	Number of leaves on the cutting							
	6	5	4	3	2	1 1+ node	1 Inter nodal	1 Short
Growing	6.6	4.8	12.9	15.7	25.6	42.0	25.8	32.6
Banjhi	4.6	2.8	9.6	13.3	22.8	40.9	39.1	32.7

Three types of single-leaf cuttings were used; those with a basal node (1+ node), the standard internode and very short internode cuttings with 6-8 mm of stem below the leaf. The results show a slight advantage in favour of a basal node on a single-leaf cutting, but analysis showed that it was due to chance. Even though the seemingly slight advantage in favour of 1+node might not be due to error, yet it would not compensate for the reduced number of cuttings which is one half of those possible. Secondly, internode length being variable both between and within clones, planting of 1+node cuttings cannot be standardised. The rooting percentage of short cuttings was not different from that of the internode type but they produced excessive callus and lagged behind the standard type in the growth of shoots. This can be seen from the number of well-grown plants of 40-50 cm height nine months after propagation (Table 34).

Table 34. Per cent well-grown plants 9 months after propagation

1 + node cutting	23.8
Internode cutting	20.4
Short cutting	14.0

State of the terminal bud on shoot from which cuttings were drawn, whether it was growing or banjhi, did not make any difference to the rooting of cuttings.

Time of Propagation

In equatorial regions, cuttings can be propagated throughout the year although success may not be uniform. Because of low temerature, the winter months are not suitable for open air propagation in temperate climate. Propagation during a very dry spell when atmospheric humidity is also low, results in the death of a large number of cuttings. It is, therefore, necessary for every tea-growing region to first ascertain the time of the year most suitable for planting cuttings. The pruning of the nucleus bushes should be so adjusted that the maximum number of cuttings are produced when conditions for propagation are most congenial.

There are certain advantages in planting all available cuttings within a short period of time, once or twice a year, instead of spreading out propagation over several months. In the former case, the plants become ready for transplanting at about the same time. This helps in planning and organising field operations. In N.E. India, April-June and September-October are the most suitable times for commercial propagation of tea cuttings (Wight, 1955).

Direct sunlight should not be allowed to fall on the cuttings. On a sunny day, cuttings are made and planted under a tent-type, movable canvas cover, ideally on wheels. Exposure to direct sunlight, even for a few minutes, is very harmful for the cutting. It is, therefore, advisable to propagate cuttings during the early morning hours or at night by artificial light. In dull weather, propagation may continue throughout the day.

Use of Hormones for Rooting

Investigations on the effect of growth substances on the rooting of tea cuttings were started in the late 1930s and have not stopped completely even today. Only the main findings of these investigations will be recorded here by referring to a few selected papers.

Tubbs (1937; 1938) in Sri Lanka did not observe any benefit from treatment of tea cuttings with phenylacetic acid (PAA), but Seradix A, a proprietory formulation, increased the weight of roots. Eden (1941) and Gadd (1942) reported slight speeding up of root development with Hortomone A, another proprietory formulation, but the effect was short-lived as the untreated cuttings rooted equally well in about four months' time. Van Emden (1941) in Java, on the other hand, obtained significant improvement in the rooting of tea cuttings with Hortomone A, particularly in conjunction with a nutrient spray applied on the cuttings. In his later experiments Eden (1949; 1954) tried 11 different growth substances out of which only Seradix B-2 and B-3 caused some improvement in rooting. Similar results were obtained at the TES in those early years. The variable results obtained by different workers or by the same worker in different trials can be attributed to different chemicals, their concentrations, methods of application, the experimental plants and the time of taking cuttings, all of which influence rooting of tea cuttings. In latter trials, Van Emden (1950) obtained better root development by treating cuttings with indole-3-butyric acid (IBA) and naphthalene-I-acetic acid (NAA), but these hormones did not improve strike. Indole-3-acetic acid (IAA) and indole-3-propionic acid (IPA) were less effective. The method of application of the chemicals, whether as powder, quick-dip or prolonged soak, did not make any difference. Venkataramani (1959) tried 2, 4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) in addition to IAA, IBA, NAA and IPA by quick-dip method and found maximum root weight with mixtures of IBA + NAA and IBA+IAA (5 mg of each in 50 ml alcohol). IAA and 2,4-D suppressed shoot growth and 2, 4, 5-T, even at 50 ppm, was harmful to the cuttings. Spraying of growth substances on cuttings did not improve strike.

Later investigations at Tocklai examined the effects of eight growth substances in conjunction with cane sugar and the trace elements copper, zinc, molybdenum and boron. Spraying of complete nutrient solution on the bushes prior to drawing cuttings was also examined (Barua, 1968a). None of the hormonal treatments improved the strike of cuttings, but IBA alone and IBA+NAA applied at 25 and 100 ppm by the prolonged soak method increased root weight. Sugar and the trace elements did not have significant effect on the growth of cuttings. Spraying of nutrient solution did not make significant difference to the rooting of good-rooting clones or of a poor-rooting clone when grown on a good piece of soil but improved strike significantly when the same clone was occupying a poor patch of soil. This finding clearly indicates the importance of proper nutrition of the stock bushes used for the production of cuttings.

These results and those obtained by Van Emden and Venkataramani clearly show that IBA is the only hormone which produces some beneficial effect on the growth of roots on tea cuttings. Combination of IBA and NAA has a similar effect. Since none of the hormones increases the per cent strike of cuttings, their use can not be commended for large-scale propagation of easy rooting tea clones under commercial conditions. When conditions for propagation are unfavourable or when a small number of plants are required from a difficult rooting clone, then treatment of cuttings with IBA or a combination of IBA and NAA may be justified. Concentrations of the hormones for use will depend on the method of application.

Transport of Stems

On a dry day, it is a fair precaution to spray the mother bushes with water before pruning the shoots for taking cuttings. For transport over short distances, the shoots are placed immediately after pruning in tall baskets made of bamboo, cane, wood or any other material, lined inside with wet cloth or hessian. The baskets are quickly removed to the shed or temporary cover where cuttings are made.

For transport over fairly long distances, the pruned stems are placed inside long polythene bags under shade. The sealed bags are arranged in boxes or baskets in such a way that the leaves do not get bruised or broken. Packed in this way, cuttings remain in good conditions for about 24 hr even at an ambient temperature of 25°-28°C. At 10°-12°C, the storage life is prolonged to 48 hr or more.

For transport over long distances by mail, pretreatment of cuttings becomes necessary. Pretreatment involves planting of cuttings in nursery beds at a close spacing and lifting them after four to six weeks when a thin layer of callus tissue covers the cut surface at the base of the cutting. After lifting; cuttings are washed, excess water shaken off and then packed in polythene bags in bundles of 20-30 cuttings in a bag. The sealed bags are packed in cardboard boxes for sending by mail. A large percentage of cuttings treated in this manner was observed to remain viable for 7 days (Wight and Barua, 1955).

Preparation of Cuttings

The practice in N.E. India is to keep the cuttings in a basket lined with wet cloth or hessian immediately after preparation and plant them as quickly as possible. As an alternative, cuttings are sprayed with water at intervals until planting. Kehl (1951) advocates putting cuttings in water contained in a bucket until planting. The basic idea is to keep the cuttings cool, turgid and sheltered from the sun during preparation and until they are planted in soil.

Preparation of Nursery Beds

The requirements of nursery site for vegetative propagation (V.P.) are almost the same as those of a seed nursery. The texture and tilth of the soil and micro-climatic environment are, however, more critical in the case of a V.P. nursery.

The soil should neither be too sandy nor too clayey. If the soil to a depth of about 45 cm is not reasonably uniform, care is needed in cultivation to make it as uniform as possible. The propagation medium must be free-draining. If soil of the right physical condition is not locally available, peat and coarse sand may be mixed with it. Soil under Guatemala *(Tripsecum laxum)* and other grasses is generally considered suitable for V.P. nurseries, but it is not always so. The soil, however, should not be rich in organic matter. Such a soil promotes excessive growth of callus by impeding aeration, due possibly to retention of too much moisture. In East Africa, Green (1964) observed best growth of cuttings when a layer of subsoil was spread on top of the nursery bed. Similar was the experience in Malawi (TRFCA Ann. Rep., 1957-58). However, subsoil is not necessarily a good medium for propagation in all situations. Wight (1955) is of the opinion that the soil for V.P. should not be a problem anywhere, possibly because local selection results in clones adapted to propagation in soils of the locality.

The beds should be prepared at least six to eight weeks in advance of planting cuttings in the manner described under seed nursery. The beds may be of any length depending on shape and size of the land, convenient for shading and drainage. After making the beds, the soil should be pressed lightly with the flat side of a hoe or with a light roller. Rain helps the soil to settle down. In the absence of rain, the beds should be watered after preparation. It is essential that soil should be compact but not hard. A little experience is necessary with each soil type to judge the optimum degree of compactness required for obtaining satisfactory rooting of cuttings.

Polythene Sleeve Nursery

The procedure for preparing sleeves for planting cuttings is the same as already described under seed nursery. The optimum degree of compactness of the soil in the polythene tube is a matter of judgement based on experience with the local types of soil.

Shade

In the initial stages until the cutting has produced roots, the prime necessity is to keep it cool in a humid atmosphere to reduce loss of water by transpiration. To enable the cutting to draw sufficient water from the soil to balance the quantity lost in transpiration, the soil should remain moist, but excess of water leading to clogging of air space in the soil is harmful for root development. Excessive callus growth is observed when the soil is waterlogged.

Even during the early stages, cuttings should receive some diffuse light for photosynthesis to recoup the respiratory loss of carbohydrates and to conserve some for the growth of root and shoot. Exposure of cuttings to direct sunlight in the early stages is, however, not desirable. Wight (1955) did not favour illumination of cuttings (direct illumination) during the first fourteen days. According to Visser (1959), 25 per cent is the limit of insulation during the early stages of propagation, which could be increased to 50 per cent after the cuttings have formed roots. The optimum insulation required at different stages of growth of tea cuttings, however, varies from clone to clone but it is difficult under conditions of commercial propagation to regulate light intensity to meet the precise requirements of every clone.

The shade for V.P. nurseries should, therefore, be designed in such a way that the beds remain cool and humid during the early stages of propagation when only diffuse light can reach the cuttings. Provision for exposure of the developing plants to increasing hours of sunlight should be inbuilt in the design.

The type of shade used in a particular region is dictated to a large extent by the nature of the raw materials available locally. Bamboo and thatch are available in plenty in N.E. India where these are used for the construction of overhead and lath frame shade. The fern *Gleichenia linerais* was extensively used in Sri Lanka for shading cuttings. Locally made coir net is used for shading V.P. nurseries in South India. Weather factors such as high or low temperature, atmospheric humidity, frequency of strong wind, and rainfall pattern determine the type of shade to be used in a region. Taking all these factors into consideration, the choice of the type of shade has to be made locally.

A description of the overhead type of shade has already been given. A variation of this type of shade is getting popular in N.E. India, wherein the nursery beds are oriented in the east-west direction and each bed is covered separately by an overhead shade of bamboo and thatch. The shade slopes towards the south, its edge ending on top of a drain between two parallel beds. The individual shades are enclosed by a common boundary wall made of the same material. This type of shade allows more diffuse light to reach the cuttings from the north and reduces the drip from the overhead cover.

Lath frame shade is made of 125-130 cm long and 2.5-3.0 cm thick split bamboo laths woven in the pattern seen in Plate 6. The four cross pieces seen in the plate are also of the same length and thickness. The open ends of the frame are tied with wire between similar pieces of bamboo. The nursery bed is surrounded by 20-30 cm high walls made of bricks or woven bamboo pieces. When conditions are hot and very humid, bamboo lath wall or gaps in the brick wall are found beneficial. In dry, windy conditions gaps are detrimental. The distance between the two side walls along the long axis of the bed is maintained at 120 cm, so that the frames can rest on the walls. The frames are placed one after another to cover the entire bed (See Plate 6).

To allow more sunlight to reach the plants as they grow, the frames are raised on the eastern side with the aid of props at first by about 30 cm and then gradually higher until the plants are fully hardened to permit complete removal of the frames. Since the frames are raised on the east, it is necessary to orient the beds in the north-south direction. With care the frames can be made to last for three years. When the beds are dry, water can be applied on top of the frames without removing them.

Similar frames can be made of wood and possibly of other material, but the cost factor will have to be taken into account.

Tent-type shade provided by open-weaved coir matting spread on top of iron or bamboo hoops has been successfully used for V.P. nurseries in Sri Lanka (Visser and Kehl, 1958) and South India. The semicircular iron or bamboo hoops with pointed ends and having a span of about 120 cm are driven into the ground at regular intervals along the length of the nursery bed. The hoops are held in position by crosspieces of iron or bamboo. Open-weaved coir matting is rolled out on top of the framework to cover the bed completely from side to side as well as the two ends. Gradual hardening of the nursery plants is, however, a laborious process with this type of shade. To expose the plants to the sun for the desired number of hours, the coir net has to be rolled in every evening and rolled out the next day at the chosen hour. Watering can be done on top of the coir cover.

When a tent-type shade has a polythene sheet or similar material underneath the coir mat and the ends and sides of the polythene sheet are buried in the soil, the bed becomes almost watertight, more humid and warmer than the surrounding air. Instead of coir, the polythene tent can be shaded by overhead or lath frame shade. The polythene cover has been found useful under cold and dry conditions. Green (1964) reported increased growth and less number of deaths of cuttings in East Africa when propagated under polythene tent shaded by lath frames. Polythene tent under overhead shade is a recommended procedure for propagation in the Darjeeling district of N.E. India. Polythene cover can, however, do more harm than good in hot and humid conditions. Even in the presence of a shade cover, temperature inside the tent may occasionally rise above the optimum for net photosynthesis by tea leaves. Secondly, hot and humid conditions encourage the growth of fungi, some of which may be pathogenic to tea.

The polythene tent should be removed after the cuttings produce roots and shoots while the shade on top should be thinned gradually to harden the plants.

Cuttings have been successfully propagated under all these types of shade and with manual watering. Sophisticated equipment is now available for watering nurseries. Electronic devices are set to switch on water automatically when the atmospheric humidity drops below a certain pre-set level. To make the best use of water when the supply is limited, it can be released in the form of a mist spray. If polythene tent nurseries are fitted with any of these automatic devices, watering becomes vastly easy.

Mist propagation has been tried successfully in tea (TRFCA Ann. Rep., 1957-58). This technique is now used extensively in the U.S.S.R., where outdoor conditions are too severe for a part of the year for vegetative propagation.

Whatever may be the type of shade used, success may be ensured only by its proper regulation at different stages of growth of the cuttings and judicious but not excessive application of water when the conditions are dry.

Planting Cuttings in Nursery Bed

The cuttings are planted in an orderly manner and not allowed to overlap. The position of the cutting on the bed is marked with a planting board or with notched strips of bamboo or wood or metal.

A wooden board of about 2.5 cm thickness with 2 cm nails projecting from it at fixed distances is placed on the nursery bed and nails are forced into the soil by applying pressure on the board. When the board is lifted, the marks left by the nails give the positions of the cuttings. If the soil is soft, the cuttings with the pointed ends can be pushed into the holes left by nails; if not, a dibber made of bamboo, wood or metal has to be used to enlarge the holes. The holes made by the dibber should, however, be slightly smaller than the length and thickness of the cuttings, so that they do not remain loose.

Notches are cut on three split bamboo laths, strips of wood or metal at the required intervals, two of which are placed alongside the two side walls of the bed and the third, across the bed. The notches on the third strip gives the positions of the cuttings on the first row. By sliding the cross lath backwards to the second notch on the side laths, the positions of the second row of cuttings are obtained and so the process continues. In this process a dibber has to be used to make the holes for planting cuttings.

For planting, the cutting is held between the thumb and the forefinger at the junction of the leaf and the stem with the tip of the leaf pointing away. The whole length of the cutting nearly upto the base of the petiole is inserted into the hole made by the dibber so that the fingers leave an impression on the soil. The pressure of the fingers should be adequate to fix the cuttings firmly in the soil. This can be tested by holding the leaf between fingers and giving it a gentle upward pull. If the cutting is dislodged, then planting has been faulty and pressure around the cuttings must be increased to make them firm. In no case cuttings should be planted loose.

The leaf of the cutting must remain clear of the ground and there should be no overlapping. If the leaf remains in contact with the soil, there is chance of fungal infection. The recommended methods of actual insertion of the cutting in soil varies from region to region. Kehl (1951) in Sri Lanka advocates planting as in (a) of Fig. 17. This type of planting is not recommended in N.E. India as the leaf gets splashed with soil particles exposing it to fungal infection. Besides the axil bud also has to grow at an angle initially. Planting as in (b) is recommended in N.E. India, keeping the base of the leaf petiole clear of the ground. All cuttings are planted in the same direction with the tip preferably pointing away from the sun so that only the upper surface of the leaf gets direct rays of the sun if it is accidently exposed. The objection to planting as in (b) is the possibility of the leaf getting bruised from strong wind.

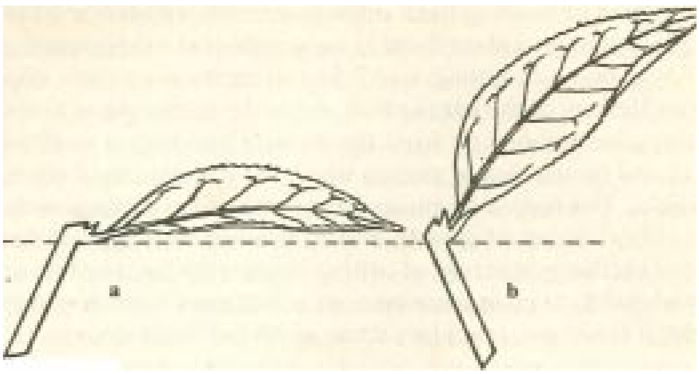

Fig. 17. Planting of single-leaf tea cuttings. Planting method recommended in (a) Sri Lanka and (b) North-East India.

After planting, the cuttings should be given a spray of water and the beds covered immediately with lath frame or tent type shade, if overhead shade is not used. As mentioned earlier, the beds should not be allowed to dry up but in no case should be over-watered.

Although the same basic considerations viz. age and size of the plant at lifting and the method of transplanting apply to both seedlings and V.P. plants yet there are certain points of difference. The tap root of the seedling grows vertically downward while the main roots of cuttings develop at an angle. A one-year old seedling dug up with 10-12 cm diameter *bheti* retains its roots almost intact, but a cutting plant dug up in the same way loses a portion of its main roots. The loss is more when the root angle is wide. When lifted as stumps, roots of plants raised from cuttings suffer more damage than those of seedlings. Loss of root is reduced if cuttings are spaced wider apart than seedlings and lifted with bigger *bheties*, but it takes more nursery space and the cost per plant increases. Alternative is to raise plants in baskets or polythene sleeves which are less expensive.

Planting in Sleeve

Method of raising seedling in sleeve has already been described. As in the case of nursery bed, the soil in the sleeve should be compact but not hard. Planting of cuttings is done in the same way. After planting the sleeves are watered and kept under shade.

Instead of planting fresh cuttings directly in sleeve, a more useful procedure is to plant them in nursery beds at a close spacing of 5 to 7.5 cm between cuttings and 7.5 to 10 cm between rows, depending on the size of the cutting leaf. After the formation of roots, the cuttings are scooped up from the nursery bed with a small ball of earth and transferred to sleeves where they remain until planted in the field. This is done to ensure better care of the cuttings in the initial critical stages of growth and to prevent wastage of sleeves, since a certain percentage of cuttings invariably die. For this reason it is advisable to plant some cuttings in bed even if direct planting in sleeve is preferred, to replace those which fail in the sleeves.

After care of V.P. Nursery

Apart from weeding, watering as and when required and manuring as discussed under seed propagation, much care is necessary in regulating the shade over cutting nurseries. Too early and sudden exposure to direct sun may kill the young plants while delayed exposure stunts growth.

When plants are completely hardened, these can be stored for a time in open beds until transplanting, to make room in the nursery for a fresh batch of cuttings. During storage in open beds, the plants should be looked after with as much care as they used to receive in the nursery.

GRAFTING

Grafting as a method of propagation of the tea plant was first tried in Java in the late twenties and then in N.E. India from the mid thirties. In these early years, only the patch budding technique was used; cleft grafting was introduced at a later stage. More recently another version of bud grafting known as shield budding or inverted T budding has also been used successfully. Grafting has been done for (a) rapid multiplication of vegetative clones to establish nucleus plots of mother bushes, (b) early production of seeds on generative clones used in experimental breeding schemes, (c) conversion of old non-clonal seed baries into clonal baries and (d) utilising mature, plucked bushes for clonal seed production.

A brief description of the grafting techniques used successfully in tea is given below.

Patch budding or Bud Grafting

This method of grafting as used in tea has been described by Barua (1968). Grafting can be done only on young stems from which the bark can be lifted easily. The stems should be healthy and 1 to 2.0 cm thick at the base. To produce such stems, both the stock and the scion bushes or seed trees are pruned approximately 7-18 months before grafting, depending on growing conditions. Suitable scion buds can be found only at the base of a stem on the axils of the caducous cataphylls. These are small buds which can be lifted easily with a patch of bark whereas the leaf axil- buds are bigger and are difficult to lift intact. The actual operation of bud grafting consists of the following steps: (a) A cut in the shape of the letter U is made on the bark of the stock stem 5-10 cm above its point of origin on the bush frame. The vertical cuts are about 2 cm long and 0.8 to 1.0 cm apart. The cuts should be deep enough to reach the wood. A grafting knife is most convenient for this operation. In its absence, a sharp penknife or even a razor blade can do. (b) The flap of the cut bark is lifted carefuly from the lower end with the scraper of the handle, if a grafting knife is used, or with the tip of the knife blade, at the time of bud insertion. (c) A rectangular cut of the same dimension, with the scion bud at the centre, is made on the scion wood. (d) The patch of bark with the scion bud is then lifted and inserted immediately under the flap of bark on the stock, care being taken that the scion bark does not get inverted in the process. The patch of scion bark is then pressed gently to bring it into contact with the exposed wood of the stock without leaving any air pocket between the two. The scion bark should preferably be slightly longer and wider than the flap of stock bark so that after placing the scion in position it can be trimmed to fit snugly in the cavity. The exposed cambium of the stock and the scion must not be touched with fingers. (e) The lifted portion of bark of the stock shoot is then laid on top of the scion. (f) The graft is held in position by wrapping a strip of waxed cloth or polythene round the stock stem. Wrapping should be done immediately after insertion of the bud, starting 4-5 cm below the graft, coil upward and end 4-5 cm above the graft. Water should not be allowed to enter into the grafting zone. The waxed cloth or polythene strip should be about 1.5 cm wide and 40-50 cm long. If waxed cloth is used, it will usually stick to the stock stem when pressed but polythene strip will need tying up with string. (g) Under favourable growing conditions, it requires three-four weeks for union of the stock and scion but it may take longer under cold or unfavourable climate. The wrappings should be removed after about four weeks for inspection of the graft. Growth of callus on the cut edges of the bark is a sign that the graft has taken. (h) The grafted shoot of the stock plant should be pruned after about a fortnight from the time of removal of the wrappings. The pruning cut should be made 2-3 cm above the graft union and the cut surface should be protected from fungal attack by applying a bituminous or some other suitable paint. The various steps of the grafting procedure are illustrated in Fig. 18.

The grafted bud starts growing after two to four months.

The following points need attention. Vigorous growth of the stock and the scion plants should be ensured by proper nutrition. Pruning may have to be done fairly low on the bush frame to produce strong, thick shoots. Weak, twiggy shoots which interfere with the operation may be removed at the time of grafting. Grafting should not be done during rains or when the stem is wet since water may infiltrate into the exposed portion of the wood. If graftings cannot be done soon after collecting the scion wood, then it can be stored for 2-3 days in a sealed polythene bag under cool conditions. Longer storage may be possible in a refrigerator. Grafting success varies at different times of the year. Suitable times for this operation will have to be determined locally. Cool afternoon hours are favourable for bud grafting.

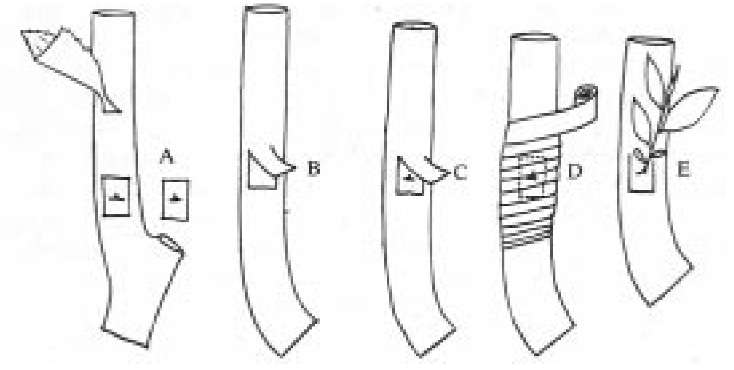

Fig. 18. Patch budding or bud grafting in tea. A, the scion bud before and after lifting. B, the nature of cut made on the stock stem to lift a piece of bark for insertion of the scion. C, the scion placed in position on the stock. D, wrapping of the graft with waxed cloth or polythene strip. E, a growing scion.

Cleft Grafting

Both plucked bushes and seed trees can be cleft-grafted, but plucked bushes must be rested for a minimum of about six months before grafting. Cleft grafting cannot usually be done in the open. The stock bushes or seed trees are first pruned at a convenient height and shade of the type used for cutting nurseries is erected above and around the pruned stock plant. The various steps of the cleft-grafting operations in tea have been described by Grice (1968). They are: (a) After erecting the shade, the branches of the stock plant on which grafting is to be done are cut horizontally and the cut surface polished with a sharp knife. The selected branches should be straight, 2.0 to 7.5 cm thick and there should be no lateral within about 10 cm below the cut. (b) The branch is then cleft in the middle, using a knife and a mallet. (c) The scion wood is taken from maiden shoots on a pruned bush. It consists of a straight piece of brown stem, 15 to 20 cm long and 0.5 to 1.5 cm thick, usually carrying three leaves. Scions with two or even one leaf can also be cleft-grafted. (d) Two slanting cuts starting below the lowermost leaf are made on the scion, to form a tapering wedge slightly wider on the side of the leaf. (e) The cleft is held open by driving in a wedge of the required size at its centre. (f) Two scions are inserted into the cleft, one on each side. If the stock branch is thinner than 2.5 cm, only one scion can be grafted on each branch. It is imperative that the cambium layers of both the stock and the scion are in close contact. The lowermost axil bud of the scion should point outward. (g) After placing the scion in position, the wedge is removed without disturbing the alignment of the cambial layers. The pressure exerted by the two halves of the split stem holds the scion in position. (h) The graft union is covered by coir or similar type of fibre that has been moistened with water and squeezed and then tied with string. (i) The whole graft is then enclosed in a polythene bag and tied firmly to the stock stem below the cleft. The above operations should be so organised that there is minimum of delay between polishing of the stem and finally covering the graft union with the polythene bag. (j) The polythene bag is examined at intervals of a day or two to see if the inside is dry. When dry, condensed particles of water do not appear on the inner surface of the bag. The bag should then be removed and replaced after dampening the coir fibre. When callus growth is observed between the stock and scion after four to six weeks from grafting, the polythene bag should be untied but not removed. Callusing may be delayed if growing conditions are not suitable. If the scion is observed to wither after untying of the bag, then it should be retied after moistening the fibre. If the scion does not wilt, the bag should be finally removed after nine-ten-days. It usually takes eight to twelve weeks between grafting and bag removal. (k) Shade is reduced gradually after removal of the bag. After removal of shade, the scion grows very rapidly, often outgrowing its own strength with the result that it is liable to break at the union even in a light breeze. To prevent this, the graft may have to be pruned at any convenient height, preferably 30-40 cm above the union, when the base of the scion has become hard and brown. The various operations carried out in cleft grafting are illustrated in Fig. 19.

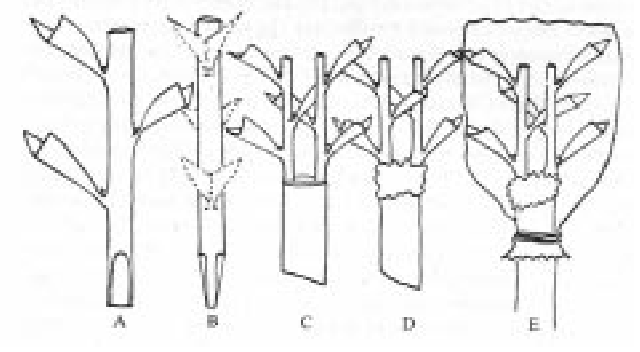

Fig. 19. Cleft grafting. A and B show the slanting cuts made at the base of the scion wood to form a tapering wedge. C, scions inserted on either side of a cleft stock stem. D, the grafting union covered by coir fibre. E, grafts enclosed in a polythene bag and tied firmly to the stock stem.

Like patch budding, the most suitable time of the year for cleft grafting has to be determined locally. The bud wood can be preserved upto 8 days in sealed polythene bags kept cool in a refrigerator (Bezbaruah, 1971). Cleft grafting can be carried out even on young plants in the nursery.

Shield or Inverted T Budding

In patch budding, only minute buds on the axils of caducous cataphylls at the base of a stem are used as scions while in this method, dormant leaf-axil buds can also be grafted. This is the main point of difference between patch and shield budding. Other operations in this method as described by Bezbaruah (1975) are similar to those in patch budding. Stock and the scion plants are prepared in the same way.

The actual operations, shown in Fig. 20, consist of : (a) Collection of bud wood. Dormant leaf axil buds from that portion of the shoot which is used for making cuttings are used for grafting. Budwood is collected just before grafting and carried to the site in a moist condition. For convenience of lifting the bud, the leaves in the bud-wood are trimmed just above the petiole. (b) Laterals on that portion of the stock stem where grafting is done, should be pruned off to leave a clean stem. Other weak and unwanted shoots should also be removed for convenience of grafting. If the stock shoot is too tall it can be pruned back to 40-50 cm from the base. (c) Grafting is preferably done at a height of 5-10 cm from the base

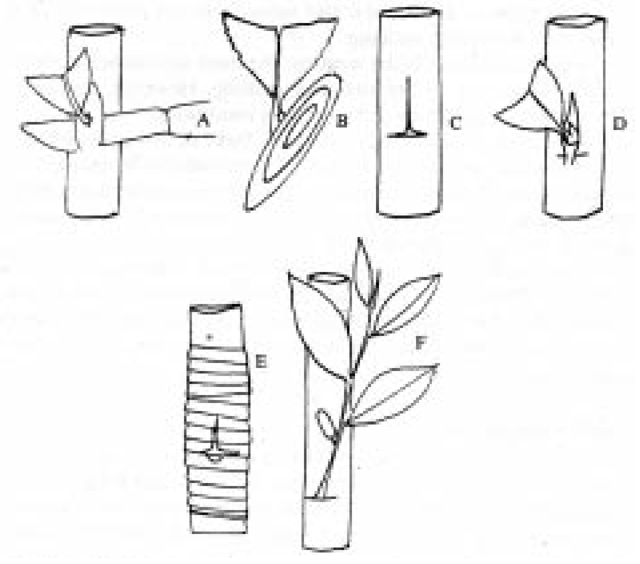

Fig. 20. Shield or inverted T budding. A, lifting of the bud wood. B, lifted bud wood. C, inverted T cut made on the stock stem. D, the scion inserted after lifting a portion of the bark on the stock stem. E, waxed cloth or polythene strip wrapped round the graft union. F, a growing scion.

of the shoot. If a higher level is chosen, control of shoots developing from the lower portion of the stock shoot becomes difficult. (d) Cuts in the shape of an inverted ‘T’ is made on a smooth portion of the stock shoot, the vertical and horizontal arms of which should be 2.5 to 3.0 cm and 1.0 to 1.5 cm, respectively. The incision should be deep enough to cut through the bark. (e) The scion bud is lifted from the shoot with the slice of bark underneath, taking care to lift as little wood as possible. This is a very important operation which largely determines the success of grafting. (f) Using the leaf stalk as a handle, the scion is inserted carefully into the T shaped opening on the stock stem with an upward movement. The lower portion of the scion bark remaining outside the horizontal cut is trimmed flush with the cut. The leaf stalk is also cut off at the base. (g) The bark of the stock shoot is laid on top of the scion and gently pressed to secure firm contact of the stock and the scion. (h) A strip of polythene is tied around the graft as explained under patch budding.

Inspection of graft union and subsequent operations are the same as those in patch budding.

If grafting is done in dry weather, the stock and the scion plants should be watered before and after grafting. However, success is low when grafting is done under very dry conditions.

For the purpose of seed production, three to five grafts are sufficient for each mature seed tree or plucked bush but for multiplication of nucleus bushes, the number of grafts per mature plant can be increased to 10 or even more. Constant vigil is required to eliminate growth produced by the stock plant.

Other forms of grafting e.g. splice grafting, chip budding (Anyuka and Othieno, 1982) and wedge grafting have also been tried successfully in tea. The technique used is immaterial so long as it suits the stock and the scion materials, is easy to carry out and gives good success.

Graft Compatibility

In tea as in other plants, grafting success depends on compatibility between the scion and the rootstock. Barua and Saikia (1973) showed that unless the clone used as rootstock was more vigorous than the scion, grafting would not succeed. A high positive correlation (0.82) was observed between rootstock vigour and percentage success of grafts, vigour being defined as weight of pruning (or plucking) per unit area of mature bush surface. Grafts failed completely when very vigorous clones were grafted on weak rootstocks. Bezbaruah and Saikia (1982) reported low grafting success with weak tea clones even when these were grafted on vigorous rootstocks.

The rootstock vigour influenced the leaf-yielding capacity of the scion positively, but it did not affect the liquor quality of the leaf (Barua and Saikia *loc. cit.*). No rootstock-scion interaction was observed in percent fruit-set but in graft combinations of vigorous clones, flower production was found to be additive (Bezbaruah and Saikia, *loc. cit.)*.

Graft compatibility has a special bearing on the conversion of old seed baries into clonal baries. Old seed baries were planted with seedlings differing in vigour. Vigorous generative clones will, therefore, be difficult to graft on seed trees of poor vigour. This fact is to be taken into account in attempting to convert old seed baries into clonal seed baries by grafting.

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CHAPTER 8

LAND PREPARATION AND PLANTING

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LAND PREPARATION AND PLANTING

LAND FOR PLANTING TEA

Land for the extension of tea cultivation is getting scarce everywhere although there is still some scope for expansion in a few countries where tea planting commenced in relatively recent times. Old and uneconomic fields of tea, however, exist in most countries particularly where planting started more than 80-100 years ago. Tea fields that have passed their prime should logically be uprooted and replanted with superior genotypes now available to the growers. Replanting of uneconomic sections of tea or their replacement on separate plots with genetically superior material is the only way to ensure the future well-being of the tea industry of any country. The rapidly rising cost of production can be counterbalanced only by increasing the yield of good quality tea per unit area of land.

Where sufficient land is available for extension, the existing tea may be left undisturbed so long as extension planting continues. If land for extension is limited, it is advisable to replace the uneconomic sections by planting an equivalent area and deferring uprooting until the newly planted area can compensate for the loss of yield from the old sections. The uneconomic area may then be uprooted and rehabilitated properly without undue haste. Where land for extension is non-available, there is no other option than to uproot and replant.

Replanting and planting of new clearings are expensive operations and the expenses are mounting everywhere along with the rising cost of labour and inputs. The actual expenditure at a particular point of time will vary from region to region and also between localities within a region. The last point was clearly demonstrated by the analysis carried out at the TES for the tea districts in the plains of N.E. India (Awasthi, 1980). It further showed that the costs of replanting and extension operations were almost the same when these were carried out under similar soil-climatic conditions. The invested capital was, however, recovered about a year earlier from extension planting than from replanting, primarily because crop is lost when tea bushes are uprooted for replanting and this adds up to the cost. The payback period increased or decreased in proportion to the yield of the newly planted tea. When the yield of the young tea was high, the capital of nearly half a lakh of rupees invested per hectare of newly planted tea at 11 per cent rate of interest was recovered in four to five years, while replanted tea took about a year more. This would possibly be the general pattern for all other tea-growing regions, although the expenditure involved and the length of the payback period will be subject to variation under different situations.

SOIL EROSION

More than 50 per cent of the land area used for growing tea is located on slopes of hills and mountains, occasionally at very steep gradients. A 60 per cent slope is not rare in many tea-growing regions like Darjeeling. All tea soils are not equally stable and deep. Heavy rainfall, at least during a part of the year, is characteristic of most tea-growing areas. A combination of these factors leads to erosion of soil. When the land is cleared for planting tea, the cover of vegetation which acts as a barrier to the movement of soil along the surface is destroyed, making it all the more easy for the rain to wash the loosened soil down the slope.

In the past soil conservation did not appear to have received equal attention everywhere. In Darjeeling, Java and Sumatra steep slopes were terraced. Hope (1916) gave a full description of the soil conservation measures adopted in Indonesia, some of which are relevant even in the present day context. Briefly, terraces were constructed on steep slopes and their edges were protected by growing a number of plant species or by encouraging the growth of naturally occurring species. Catch drains were dug at intervals along the inner edges of the terraces to catch the wash that would come from the terrace above. When the catch trenches were cleaned out, the earth that had collected in them was thrown up on the terrace above.

If the land was not steep enough for terracing, the system adopted was one of alternate contour lines of catch trenches and green crops with one or two lines of contour planted tea in between. In such cases the catch trenches were approximately 4 m long by 0.3 m wide by 0.5 m deep and were spaced about 4 m apart along the contours, so that if any earth was carried beyond one line between the catch trenches and past the hedge, it was caught by the trench below. When the catch trenches were cleaned out, the earth was thrown up the slope. The arrangement of terraces, catch trenches and hedges as described by Hope is shown diagramatically in Fig. 21.

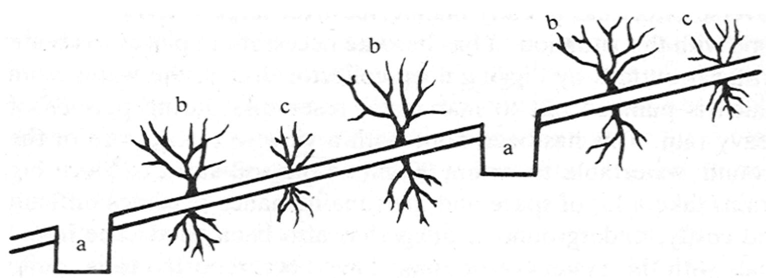

Fig. 21. Diagram illustrating the arrangement of catch trenches and hedges to prevent soil wash on sloping ground. (a) Catch trench, (b) Tea bush and (c) Hedge of a suitable leguminous plant. (After Hope, 1916).

In Sri Lanka tea is planted on hill slopes but soil conservation measures were not much in evidence in the old tea areas. Much of the early tea was planted up and down the slope, which resulted in the formation of gullies between rows of tea bushes. Soil erosion was so serious that the then Government of Sri Lanka had to apoint a commission to investigate and report on the problem (1931).

In sloping terrain where the soil too is not very deep, heavy and continuous rain can cause serious landslide if sufficient quantity of water percolates down to the bed rock on which the soil rests. Many tea estates in the hilly terrain of Darjeeling in the North-East and the Nilgiris and the High Range in South India have recurrently suffered from this type of soil erosion. In the drier parts of Africa where strong wind prevails, the tea soils, if left bare, are prone to erosion by wind.

Water Disposal Problem

Flat or gently sloping land sometime poses serious problems of disposal of surplus water under conditions of heavy rainfall. Assam is a good example of such a situation. This region experiences heavy rain during the summer months and movement of water slows down due to swelling of the rivers and streams which empty into the Brahmaputra and the Barak. Occasionally flood water flows back into some tea estates of the region. The problem has been aggravated by continuous rise of the river beds due to heavy deposit of silt, particularly after the great earthquake of 1950, which affected the entire land mass of the eastern Himalayas. As a sequel the ground watertable of the whole of Assam is rising steadily and its adverse effect has already manifested over large tracts of tea. To cope with this situation, it has become necessary in places to create artificial outfalls by digging deep collector drains, the water from which is pumped out to man-made reservoirs during periods of heavy rain. This has been done with a view to restricting rise of the ground watertable to within 90 cm of the soil surface. Since big drains take a lot of space and their maintenance becomes difficult and costly, underground drainage has also been tried. The initial trials with this system of drainage have been reported to be quite successful (Dey, 1981).

Excessive rainfall creates a different type of situation in some parts of this region. Certain localities of North Bengal occasionally receive 400-500 mm of rain within 24 hours. The huge volume of water gushing out of the estates through drains of much smaller capacity cuts away large chunks of earth from the sides of drains along with the standing tea bushes and carries them away in the strong current. Where the soil is light, the damage becomes more serious. As a measure of safety, the mouth of the main outlet drain is sometimes kept closed even at the risk of creating a condition of temporary waterlogging. However, this problem can be best tackled by providing main and subsidiary channels of adequate size to cope with the peak run-off flow rates.

SOIL AND WATER RELATIONSHIP

The soil acts as a reservoir of water. The rate of infiltration and the amount of water stored depend on the type of soil. In general, the percolation rate is low and the water holding capacity is high in a soil of fine texture, while the reverse is the case with coarse soil. After wetting the surface soil, rainwater percolates into the soil profile. When the profile is fully saturated with water, the soil is said to have reached field capacity. If more rain falls on a soil which is at field capacity, then the excess water percolates vertically downwards until reaching the ground water-table thereby raising its level. This happens so long as the rate of precipitation does not exceed the rate of percolation. When precipitation exceeds percolation, water runs off along the soil surface at right angles to the contour and finds its way into natural depressions, waterways and finally into rivers and seas. Water moving downhill along the soil surface carries away soil particles unless the movement of soil is prevented by natural or artifical barriers.

The lateral movement of sub-surface water is very sluggish but its direction of flow is the same as that of surface water. Where excess water cannot run off speedily due to absence of a suitable outfall, it accumulates in the soil profile and the ground water-table rises. If the water level is sufficiently high to submerge the roots of tea bushes, the bushes get waterlogged, a condition highly detrimental for growth.

This brief description is a simplification of the complicated process of soil-water relationship. It nevertheless should suffice to show that where there is runofff, there is soil erosion and that accumulation of water raises the ground watertable and in extreme cases causes flooding. Since surface and underground water moves at right angles to the contour, topography must be the deciding factor in any plan for the safe removal of excess water and its conservation during periods of water stress. This is best done by dividing a tea estate into catchments.

CATCHMENT PLANNING

A catchment is a self-contained unit insofar as ingress and outlet of water is concerned. It is bounded by ridges or high land and usually contain a main outlet for the outflow of water. The first requisite of catchment planning is to divide a tea estate into the major natural catchments which is followed by further sub-division into the minor catchments. The catchments can be identified only from a knowledge of the topography of the estate. A complete level survey, designed to pick out all major and minor topographical features is, therefore, an essential preliminary to catchment planning. The larger the scale, the clearer is the topography. According to Grice (1977) the scale should in no case be less than 16 inches to a mile (approximately 25 cm to a kilometre). For flat land and for areas of less than 240 ha, he advises making the scale twice as large. Where outfall becomes a problem during periods of heavy rain, the survey should indicate the highest flood water level of the nearest outfall, which may be a river, a stream or a lake.

The topography of an estate becomes obvious from the contour lines drawn on the survey map. The main ridges are first marked on the contour map. Each land mass enclosed by ridges into which water cannot enter from outside forms a catchment. Water flows down the ridges until meeting and flowing out along the lowest points of depression between the ridges. Some of these features are illustrated in Fig. 22 (Grice, *loc. cit.)*. After demarcating the major catchments, it often becomes necessary to mark out the minor catchments within each major catchment for laying out plucking paths as well as access roads connecting all parts of the tea estate. Main roads are preferably laid along crests of ridges. Secondary roads are laid along contours. Sometimes it may be necessary to construct additional roads. Such roads may be laid from the ridges to the water channels but artificial water outlet channels will be necessary between pairs of such roads.

In order to conserve water and check erosion of soil, drains are dug at predetermined vertical intervals along the contours across the flow of runoff water. These drains are graded in such a way that the excess water is carried to the outlet channels at a controlled

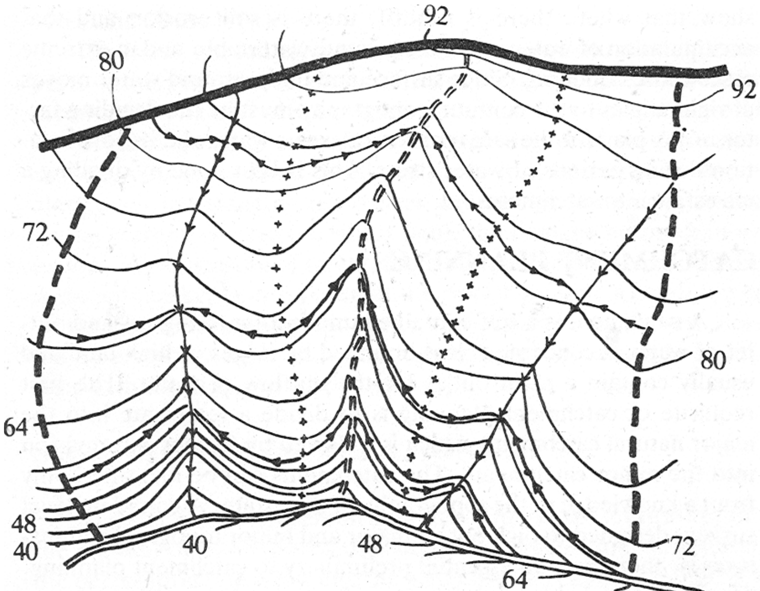

Fig. 22. Topographical plan of a catchment on undulating land. Main ridge ▬▬ Subsidiary ridge ▬ ▬ ▬ Minor ridge + + + Main water channel ═══ Subsidiary water course ≈≈≈ Minor water course →→→ Contour lines. 92 ∼ 92. A few of the contour drains are also shown.

speed. The vertical interval between the contour drains is determined by the percentage slope of the land, type of soil and intensity of rainfall. As such, the distance between contour drains has to be determined separately for each location. Various formulae have been devised for this purpose, but some adjustments are usually necessary in their actual application. The size, shape and gradations of the contour drains are then decided carefully. Each drain should be of sufficient size to discharge the runoff and underground water that collects between two contour drains, into the collector drains or natural channels. Thus, the area between two contour drains becomes man-made microcatchment within the main natural catchment. In areas of heavy rainfall, a small bund is constructed on the lower side of the contour drain as an additional precaution against soil wash.

The master plan of the estate is now ready. The various topographical features like main and subsidiary water channels and ridges marked on the survey map should then be verified and marked at site. The work of cleaning the site is taken up at the next phase; coinciding with that time of the year when the rainfall intensity is at a minimum. Clearing is done catchmentwise. If an entire catchment cannot be cleared at a time, the work should be taken up in stages commencing at the top. After laying out drains and paths in the top part of the catchment, work should be extended to the next lower portion and so on until the entire catchment is cleared. This procedure is particularly desirable in cleaning steep catchments to minimise erosion hazard.

Roots of trees and other vegetation are then dug up. Soil disturbance should be kept to the minimum particularly in sloping terrain. Special caution is necessary while working on steep slopes and in areas of high rainfall.

Topographical planning may appear unnecessary for estates located on flat terrain. It will, however, be apparent from the level survey that no piece of land is absolutely flat. Even an apparently flat piece of land is gently undulating and usually has a slight gradient and a natural water course. It is better and safer to take advantage of these topographical features in working out the drainage system of such flat land than digging drams without regard to the natural topography.

Terracing

Connected with the system of contour planting is the terracing of sloping land, the primary object of both being conservation of soil and water. The necessity of contour planting is accepted by all but opinion differs regarding the value of terraces. However, cultivation of various crops on terraces cut on hill slopes is an age-old practice in many parts of the world. When tea was first introduced into the Darjeeling district at the foot of the Himalayas during. the middle of the nineteenth century, terraces were a familiar feature of the area. The local inhabitants grew various crops on the terraces. The pioneering tea planters adopted the system for tea cultivation and constructed terraces even on very steep slopes. In Java, steep land was terraced but on gentle slopes tea was planted on the contour (Hope, 1916). Terraces are now considered to be an absolute necessity in the steep slopes of Sri Lanka where tea is grown (de Silva and Seevaratnam, 1968).

The main disadvantages of terraces are: large disturbance of the soil when terraces are first constructed which increases with the steepness of the land, exposure of the subsoil where tea has to be planted, difficulty in the movement of pluckers particularly in steeply sloping terrain, irregularity in the width of terraces making it difficult to follow a regular planting pattern, on certain aspects shading of plants of a lower terrace by the one just above and lastly, high cost of construction and maintenance of terraces.

Taking these factors into account terracing does not seem to provide additional advantage over properly planned contour planting insofar as the perennial tea plant is concerned. It is worth mentioning in this connection that the Government of Sri Lanka promulgated an ordinance in 1949 making it obligatory to plant tea "on the contour or as near the contour as the lie of the land may permit" (Daniel, 1951). Very steep slopes, where soil also is shallow and underlaid by stones and boulders, should not be used for planting tea. Such terrain is better put under suitable forest species. Besides protecting the soil, the trees will be an additional source of revenue for tea estates in the form of firewood for the labour force and fuel for the factory.

The terms very steep, steep, gentle, flat etc. used in these pages need some explanation. A slope of 45° (1:1) and above has been designed very steep. For the other terms the following criteria have been used. Steep: 25° to 45° (1:2 to 1:1); moderately steep: 15° to 25° (1:4 to 1:2); gently sloping: 5° to 15° (1:4 to 1:10); slightly sloping: 2° to 5° (1 :20 to 1: 10). Land if less than 2° slope is considered flat. The ratios shown in parenthesis are only approximate.

Catchmentwise Uprooting of Old Tea

New estates can be planned on the basis of catchments but catchment planning cannot be conveniently imposed on existing tea estates. However, topographical planning can be introduced gradually into existing tea estates along with the progress of uprooting and replanting old sections of tea. For this purpose each estate is required to draw up a long-term uprooting programme. Uprooting will have to be done catchmentwise without adhering to the existing boundaries of different sections of tea within an estate. If any old tea scheduled for uprooting falls outside a catchment to be uprooted, it should be left until uprooting the catchment in which it is located. Similarly if a section of tea not scheduled for uprooting is located in a catchment planned for uprooting then this section also will have to be uprooted to enable replanting of the whole area on a catchment basis.

Digging up large number of tea bushes manually is expensive and time consuming. Wherever possible, uprooting should be done mechanically. If a tractor is to be used for uprooting tea bushes, it is essential to use a winch together with a set of tackle designed for the purpose. While a tractor can be used directly to pull out one bush at a time, its efficiency is vastly improved when coupled to a winch and a properly designed tackle assembly. However, the winch, draw-bar and the uprooting tackle of chains and hooks should be of proper strength. Only the first bush or first two or three bushes, if double row or triple row chains are used, should be pulled out at a time, sparing the tractor, the winch and the chains from taking more strain than they are designed for (S.K.D. *et el.* 1971). All necessary precautions should be taken for the safety of the tractor driver and other workers.

Uprooting is best carried out when the soil is still soft. Tea bushes are winched out of soft soil with most of their big roots but smaller roots may have to be manually forked out later. Small shade trees, if present, can be uprooted like tea bushes. Big shade trees should preferably be ring-barked at least a year ahead of uprooting, then winched or dug out with roots. After completing the uprooting operation, a level survey of the clear catchment is carried out again for the alignment of drains, roads and paths.

Strip Uprooting

Uprooting of old tea bushes from land of steep gradient can cause serious problems of soil erosion, particularly in high rainfall belts. Erosion hazard can be reduced considerably by uprooting in contour strips. After preparation of the soil with proper care for soil conservation, the area is replanted first before extending the uprooting operation to the remaining parts of the catchment, which in their turn are uprooted and replanted in the same way. Depending on size and steepness of the catchment, the uprooting-replanting operations may have to be carried out in more than two phases. However, all phases of the operation must conform to a master plan prepared in advance for the entire catchment.

Only very small areas of tea have so far been uprooted by this method in a few localities. In view of the mounting necessity everywhere for uprooting old tea areas for replanting with improved planting material, wider use of the method in future can be anticipated.

Cultivation

The nature of cultivation to be carried out on virgin clearings is determined by the topography and the type of soil. In steep slopes, where soil disturbance should be kept to a minimum, cultivation is best avoided. Gentler slopes can be ploughed along contours and flat land ploughed crosswise on both directions.

Uprooted tea soil has to be rehabilitated properly to enable it to sustain healthy growth of a new stand of tea for another few decades. After uprooting old tea, the land should be ploughed and harrowed. In addition, sub-soiling will be necessary unless the soil is very sandy. The object of sub-soiling is to loosen any compact layer within the soil profile to permit free vertical movement of water and penetration of roots to lower layers of soil. The depth of sub-soiling is determined by the impeding layer within the soil profile, which may be a hard pan. In order to break up the layer, the sub-soiler should be set about 10 cm below the layer. The space between the sub-soiling slits has to be adjusted according to the depth of the sub-soiler so as to break up the impeding layer completely. In gentler slopes, these operations should be carried out along contours. Flat and gently sloping land can be ploughed and sub-soiled crosswise in any convenient direction.

On land of steep gradient where ploughing and sub-soiling are not possible, the planting pits should be made broader and deeper and the soil at the bottom of the pits should be loosened to a depth of 60-70 cm with an auger. Still better results can be expected from trench planting, provided the soil at the bottom of the trench is loosened to the same depth.

After ploughing and sub-soiling, the land is levelled and drainage channels, roads and paths are clearly marked out. The main drains and contour drains are then dug according to plan and the earth is used for filling depressions or spread out evenly over the soil surface. In making the roads, provision should be made for a full network of paths and alleys covering the entire catchment so that the pluckers do not experience difficulty in harvesting leaf and bringing it to the nearest points of collection.

All operations starting with the clearing of virgin land or uprooting of old tea and ending in the digging of drains and laying of roads and paths are to be completed within the shortest possible time to reduce chances of erosion of soil by rain and wind. Regions having a long dry season get enough time for completing these operations before the onset of rains. In the absence of a dry season, the work will have to be timed precisely to coincide with the period of minimum rain. Even then the risk of soil erosion during the progress of the work cannot be eliminated in areas where rain occurs throughout the year. The risk increases with the steepness of the terrain. It has been pointed out earlier that in such situations the work may have to be carried out in phases instead of clearing entire catchments of virgirn land or old tea at a time. However, level survey followed by meticulous advance planning is necessary for working on part catchments.

REHABILITATION OF UPROOTED TEA SOILS

The primary object of uprooting and replanting is to produce yields much higher than that of the uprooted tea. Low yield of the uprooted tea cannot be attributed solely to the age of the bushes. Sections due for uprooting usually carry many vacancies. Death and debility of bushes are caused by diseases and pests and faulty agronomic practices. Fertility status and physical condition of the soil deteriorate due to erosion, poor drainage, compaction and inadequate fertilisation. In other words a combination of faulty management practices and old age is the cause of low yield of the sections of tea that are marked for uprooting. Replanting immediately after uprooting without correcting the deficiencies of the soil cannot be expected to produce high yields. This is all too apparent from the lack of success of some of the replanting operations carried out in N.E. India and elsewhere, sometimes with high yielding clones. Proper rehabilitation of the uprooted soil is a pre condition for the success of any replanting operation.

Catchmentwise uprooting, ploughing and sub-soiling are a part of the rehabilitation process. The next phase is the incorporation of organic matter into the soil. The presence of an organic mulch on the surface protects the soil from the sun and rain and by chemical action it stabilises the soil by binding the particles into aggregates. The organic matter status is accepted to be a fairly reliable index of soil fertility. In Japan, deep ploughing, sub-soiling and incorporation of compost are recommended for soils to be replanted with tea (Sugii *et al.,* 1971).

The most convenient method of improving the organic matter status is by growing one or more green crops *in situ.* The crop selected for the purpose should be easy to grow in the particular locality and should produce luxuriant growth to provide a large amount of organic matter. Besides, the species grown should be amenable to repeated lopping. It should preferably possess a robust and deep root system which can penetrate to the lower depths of the soil. Provided the above conditions are satisfied, the plant need not be a legume.

A large number of plants, grasses, twining creepers, shrubs and small trees have been tried as mulch crops in different parts of the world. Among the species tried, *Leucaena glauca* and *Sesbania aegyptiaca* are small trees growing to a height of 5-6 metres. The Tephrosias *(T. candida,* T. *vogelii),* Crotalaries (*C. anagyroides,* C. *grahamiana,* C. *juncea),* Desmodiums *(D. gyroides, D. polycarpum)* are erect shrubs growing to a height of 2-3 metres. These legumes have been tried with varying degrees of success in different parts of the world sometimes as green crops for the production of mulch and sometimes as green crop-cum-temporary shade for young tea. *Mimosa invisa* and *Stylosanthes guianensis* are straggling undershrubs while *Calapogonium mucunoides, Centrosema pubescens, Pueraria phaseoloides* are twining creepers, all of the leguminous family, grown as soil cover for the production of mulch. Amongst the grasses Guatemala *(Tripsecum laxum),* a prolific grower, has been used extensively in many parts of the world. Another grass, Pusa Giant Hybrid Napier *(Pennisetum purpureum),* has been found equally satisfactory in N.E. India and Africa. The Citronella grass *(Cymbopogan wintarianus)* has also been used extensively in N.E. India. After extraction of the essential oil from the green leaves of the grass, the spent material is used as mulch. Mana grass *(Cymbopogan confertiflorus)* is widely used in Sri Lanka and *Eragrostis curvula,* in Africa. Soya bean and Lupins are used in the tea areas of the U.S.S.R. for soil rehabilitation as well as for mulching tea bushes.

The choice of a species is determined mainly by its growth potential under the particular soil-climatic conditions of the place. This has to be ascertained first. Many of the species just mentioned are highly susceptible to certain diseases e.g. *Tephrosias* to Red rust and root rot fungi and *Stylosanthes* to Black rot *(Corticium* spp.). While some of these and other species can be grown as mulch crop before planting tea, their continuance as cover crop between lines of tea bushes or as temporary shade has to be decided on merit.

It often pays to adopt corrective measures to improve the growth of a species. For instance, growth of all these species is facilitated by reducing acidity if the soil happens to be very acid. In very acid soils of less than pH 4.5, application of 2-3 tons of powdered slaked lime per hectare has been suggested at the time of preparation of the soil (F.R., 1970).

Sometimes it pays to grow two species in alternate rows. .For the purpose of soil rehabilitation, a grass-legume combination of Guatemala or Pusa Hybrid Napier and *Mimosa invisa* is the recommendation in N.E. India. A basal dressing with 15-20 quintals of cattle manure or compost or 2:1:2 NPK mixture (50 - 60 kg N ha^{-1}) in the absence of cattle manure is suggested. Seeds of *Mimosa* are drilled in with a phosphatic fertiliser following the same alignment as the future lines of tea. The grasses are propagated by stem cuttings consisting of two to three nodes or by division of root stocks. The grass cuttings are spaced 30-45cm apart following the same alignment as the legume.

The seed rate for *Mimosa* is 2-3 kg and for the grasses 10,000-12,000 cuttings per hectare. The seed rates for the other legumes vary from 2 to 16 kg per hectare. Planting is done in moist soil preferably when rain commences. Weeding of both grasses and legumes is necessary during the period of establishment. The grasses are very heavy feeders and require liberal application of fertilisers for high yields. When these are grown to provide mulch for other areas, it is all the more necessary to apply fertilisers liberally. The large depletion of nutrients along with the removal of grass loppings can be seen from Table 35 which is based on observations made at Tocklai (F.R. 1970).

Table 35. Weight of loppings and nutrients removed by grass

	Weight of loppings tons ha^{-1} $year^{-1}$		Nutrients removed kg ha^{-1} $year^{-1}$		
	Fresh	Dry	Nitrogen	Phosphate	Potash
Guatemala	90	19	314	124	327
Pusa Hybrid Napier	72	21	177	94	277

Well manured fields of Guatemala in the low country of Sri Lanka produced 94 tons of fresh loppings from three cuts made in a year although the quantity decreased at higher elevations. Planting of the grass at spacings of 45 x 45 cm and 75 x 75 cm made little difference to the annual yield, but doubling of the dose of fertiliser increased yield by more than 25 per cent. (TRIC Ann. Rep., 1959). The fertiliset mixture recommended for Guatemala consisted of 55 kg nitrogen, 40 kg phosphate (P_2O_5) and 50 kg potash (K_2O) per hectare after each lopping (Tolhurst, 1958).

The first lopping of the grasses can be done 12-16 weeks after planting and the subsequent loppings at intervals of 8 to 10 weeks depending on growth. *Mimosa* does not have to be lopped. It covers the ground completely and provides a very thick mulch cover. *Mimosa* does not grow well in cold climate.

Stylosanthes is niore tolerant of cold but it cannot survive frost. It should not, however, be grown along with a bush crop like *Crotalaria* as it does not do well under shade.

The period of rehabilitation depends on the state of the soil. Manuring of the tea till the year of its uprooting is a necessity which, by arresting the depletion of soil nutrients, helps the process of rehabilitation. The growth of the green crop gives an indication of the success of the rehabilitation operation. The soil cannot be considered to have been properly rehabilitated so long as the green crop does not grow satisfactorily. The period of rehabilitation has to be prolonged if the growth of the green crop is poor and the cause of poor growth has to be identified and remedied. For badly depleted soils, a long term tree forest rotation as proposed by Wight and Gokhale (1955) deserves consideration.

Apart from raising the level of fertility of uprooted tea soil, there is another aspect of rehabilitation which also requires a minimum period of rest for the soil. The soil-borne pests and diseases which parasitise on tea cannot thrive for long after uprooting and removal of the host plant. How long it takes to eliminate them completely is still a matter of conjecture. According to P.C.S. *et al.* (1980), the green crop should be retained for a minimum period of 18 months. Webster (1955) in Sri Lanka went a step further and suggested that after clearing, the land should be put under a green crop like Guatemala for two years since this grass is not susceptible to root rot fungi like Poria. The land should then be planted with an indicator plant like *Tephrosia vogelii* to isolate the patches where the disease persisted. These patches should be recleared until a clean stand of *T. vogelii* was obtained. The whole process could take three to four years. Loos (1955) also advocated a lapse of two years between uprooting of eelworm infested tea and replanting in order to eliminate the pest from the soil. Adequate measures are also necessary to clean the soil of other pests like termites before planting tea. On these considerations the rehabilitation process should continue at least for a period of two years, though from the point of soil fertility replanting may be possible earlier.

Preparation of the soil for replanting is a vital operation in the culture of tea which determines the vigour and yield of bushes for many decades. Unless close attention is paid to land preparation, which include uprooting, ploughing, sub-soiling, laying out an efficient drainage and soil conservation system, taking adequate precaution against soil erosion and giving the soil a reasonable spell under a suitable green crop, the very purpose of replanting may be defeated.

At the end of the rehabilitation period, the green crop is cut down at the ground level and the cut material left in *situ* as mulch. The stumps of grasses are uprooted and preferably left on the surface before replanting. Some of the holes made for uprooting the grasses have to be filled up with cut grasses and earth while the others, with some adjustment, can be used for planting tea. After removal of the green crop and grasses, the drainage is checked and the drains are regraded where necessary.

PLANTING

Age and Size of Plants

Plants raised in polythene sleeves are taken directly to the planting site but nursery plants are first dug up with *bheties* or as stumps. As mentioned earlier, plants are lifted as stumps only after two to three years in the nursery, but sleeve and *bheti* plants are transplanted usually between 10 to 20 months from sowing seeds or planting cuttings. Plants used for infilling are allowed to remain in the nursery for a longer period.

In warm climate, plants raised from cuttings and vigorous seed stocks of the large-leaf Assam and Cambod races of tea attain a height of 30-35 cm or more in seven-eight months if the nursery technique is not faulty. Such plants can be put out in the field but a longer period of about 12 months in the nursery is generally preferred. By that time well-grown plants attain a minimum height of 40-50 cm. The extra period in the nursery is utilised primarily for hardening the plants by gradual exposure to the sun. In cold climate where growth is slow and extension growth virtually stops during the long, cold winter, plants may have to be retained in the nursery for two full growing seasons i.e. from 18 to 24 months, depending on the time of propagation and the kind of plant.

There are both advantages and disadvantages in transferring plants from nursery to field earlier than the usual time of transplanting. Plants cannot develop properly in the nursery after the initial phase of growth. The soil contained in a sleeve is inadequate for sustaining healthy growth of plants for long. In nursery beds, competition between plants restricts growth. As the plants get bigger, competition for space above and below ground becomes stiffer and the development of the plant is impaired. When transferred to the field, limitation imposed by space is removed and the plants can grow freely. This is an advantage because the plants get an early start in an environment where they will remain for the rest of their life. Among the disadvantages, the young plants cannot be hardened properly by gradual exposure to the sun if they do not get sufficient time in the nursery. In consequence the plants suffer when suddenly exposed to the elements. Besides, young plants are more susceptible to damage by pests like cricket *(Brachytrypes achatinus)* and Cockshafer grub *(Holotrichia* sp.), where present. They also suffer more quickly from drought because of their small root systerns. Weeds can do greater harm to small than to big plants.

If plants can be given protection from these natural hazards, then transplanting can be done early with advantage. Where seed at stake planting is practised, the protection measures have to be even more thorough. Stumps too initially need a good measure of protection in the field. Delay in transplanting any more than is absolutely necessary on climatic considerations cannot, therefore, be justified. Even plants intended for infilling may not be retained in the nursery for more than two years.

Young plants are sometimes tipped, plucked or pruned in the nursery to encourage spread. Trials conducted in N.E. India have shown that this is not a sound practice as it reduces vigour of the young plants which affects their subsequent growth in the field. In a properly managed seed or cutting nursery, control of growth does not usually become necessary if transplanting can be done at the right time. If for some reason or other planting out is delayed or plants intended for infilling are deliberately retained in the nursery for a longer period, then they may become very tall and unmanageable. Growth of such plants has to be controlled judiciously. It is advantageous to prune the plants in the second year instead of tipping and plucking them. Dutta (1962) recommended pruning at a height of 40 cm from the ground when the plants grew to a height of 60 cm or more. Further pruning was generally not required. If it did become necessary, he recommended skiffing at 50 cm after the plants produced 20 cm or more growth following the 40 cm prune.

In Central Africa pruning in the nursery is strongly deprecated. Any type of pruning has been observed to reduce survival of transplants. Mortality increased with the severity of pruning (Scarborough, 1971).

For stimulating the growth of axillary shoots, debudding, decapitation and spraying of growth retarding chemicals on nursery plants have been suggested from time to time. However, the presence of laterals low down on the plant is a hindrance if plants are to be transplanted with *bheties.* Even with sleeve-grown plants, the tender laterals are liable to damage during transfer of plants from nursery to field as well as at the time of planting. Apart from physical problems, the bushy young plants are more prone to suffer from any deficit of water in the soil until they are firmly established in their new surroundings than less leafy plants. Furthermore, decapitation is likely to delay establishment of the plants in the field by retarding root growth. On these considerations any form of mutilation of plants in the nursery cannot be looked upon with favour. Nursery plants to be transplanted as stumps are naturally exceptions.

Mulching

After planting, the area should be mulched with cut grasses, loppings of green crop, leaf litter, water hyacinth where it occurs or any other easily decomposable vegetable matter. Straw and paddy husks can also be used in the absence of any other suitable material, but some nitrogen must be added with these to prevent depletion of soil nitrogen. Besides adding organic matter, the mulch helps in conserving moisture, checks erosion of soil and suppresses weed growth. Where blanket mulching is not possible due to shortage of material, mulching can be done in strips on the contour.

The need for controlling termites has already been stressed. Cricket and Cockshafer grubs are major enemies of young tea plants in many countries. Where these pests are present, the mulch material should be kept away from the tea plant in a ring of 15-20 cm diameter. Even otherwise, the mulch material should not be allowed to come into contact with the plant stem as it gets heated up and kills the stem tissues.

In dry weather, the mulch is a fire risk. To arrest the spread of fire, strips of land in both directions should be kept bare of the mulch.

Planting Hole

The actual positions of the tea plants and shade trees, where they are used, are marked with stakes prior to digging holes for planting. It always pays to transplant young plants into large sized holes but the correct size of the planting pit has to be determined with reference to the type of soil and the size of plant. Experimental results clearly show the superiority of large over small holes even in a light, sandy loam soil (Table 36).

In Sri Lanka, de Silva and Seevaratnam (1968) observed distinct advantage of bigger (20.5 cm diam. x 60 cm depth) over smaller (10 cm diam. x 20 cm depth) planting holes. As expected, the size of the planting hole had more pronounced effect in clayey than in sandy soil. It follows that the use of a standard implement for making planting holes in all types of soil is unjustified.

Rotating spades or augers are generally used for making holes for planting tea. When the soil is wet, the rotation of the implement compacts the side walls of the hole. In clayey soil, the walls may become so compact that the hole virtually becomes a plant pot. The soil packed in the hole at the time of planting does not mix with the soil outside the hole and the spread of the tea roots is confined to the space inside the hole. In areas of heavy and continuous rain such planting holes remain filled with water. This is a situation highly inimical to the growth of plants and should be avoided at all cost. It should be a standard practice to roughen the sides and bottom of the hole before planting tea.

Table 36. Size of the planting hole and growth at the end of the first year after transplanting (After Dutta, 1962)

Depth and diameter of hole (cm)	Mean fresh weight per plant (g)	Mean height of plant (cm)
30	210	79
60	332	108
C.D. at 5%	77	17

Difference exists in the average size of holes made for planting tea in different tea-growing countries. The reason for this difference lies more in tradition than in the condition of the soil. Experimental evidence everywhere is in favour of larger planting holes. Planting holes of 30-35 cm diameter and 45 cm depth are recommended by the TES, with the proviso that in clayey soil the bottom of the pit is to be forked to a further depth of 15-20 cm. Planting in trenches of 30-45 cm width and 45-60 cm depth is suggested for clayey and gravelly soils (P.C.S. *et al., loc. cit).* These specifications should meet the minimum requirements in most situations although the dimensions of planting pits could be increased with advantage except where the soil is very sandy.

Manurial Mixtures for Planting

Phosphate applied at the time of planting is found beneficial for the growth of young plants. The phosphatic fertiliser is mixed with the soil that is excavated from the planting hole and returned to the hole at the time of planting. Dry well-rotted cattle manure mixed with phosphate can be used with advantage as a planting mixture. Besides providing nutrition to the young plants, cattle manure keeps the soil of the planting pit in good physical condition. If cattle manure is not available, then well-made compost can be used as a substitute. However, too high a concentration of organic matter can adversely affect the pH of the soil in the planting pit and may cause retention of excess moisture both of which are detrimental for plant growth. In N.E. India where the organic matter content of the soil is generally low, only 4 kg cattle manure is recommended per hole.

Mustard or rape seed cake along with phosphate and sterilised animal carcass meal (sterameal) have also been found useful as planting mixtures. Both of these are widely used in N.E. India. Mortalities occur if these organic manures come into cntact with the roots of the young tea plants immediately after transplanting. The injurious effect of the manures can be overcome by mixing them with the excavated soil at least four to six weeks before planting. After mixing, the soil-manure mixture is returned to the pit. At the time of planting some soil is scooped out of the planting hole and the plant fixed in position.

Inorganic fertiliser mixtures are better not applied until the plants have been firmly established in their new locations.

Planting Operation

After breaking any clods and lumps, the soil manure mixture is packed firmly on the bottom of the pit to a level which brings the top of the sleeve or *bheti* flush with the ground. After placing the sleeve*/bheti* in position, the sleeve is slit longitudinally and removed. The remainder of the soil manure mixture is than packed firrmly round the *bheti*. There is no two opinion that the soil in the planting hole should be reasonably dense to bring the roots of the tea plant into intimate contact with the soil and to eliminate large air pockets. The degree of compactness is, however, a matter which depends on the type of soil and its moisture content at the time of planting. Experience under local conditions is necessary to judge whether the soil has been properly consolidated or not. When planting is done on a light dry soil, ramming is necessary for consolidation.

If the sleeve or the *bheti* sinks below the ground level, water temporarily accumulates in the depression and may cause rotting of the soft stem, particularly under conditions of high ambient temperature. Secondly, Cockchafer and Cricket, which cut through the plant at the collar region, do more damage when the sleeve */bheti* sinks. This aspect needs particular attention at the time of consolidating the soil in the planting pit.

Eden (1976) advocates planting one cm lower than the nursery level to keep the base of the stem protected from scorch and to keep some buds alive that otherwise may die. He cautions against this practice in areas infested by termites. While this practice may have advantage in areas exposed to highly desiccating conditions, it cannot be advocated for a hot, humid climate where rainfall is also heavy. The reasons are already mentioned. Besides, this practice may be more suitable when plants are put out as stumps. In other respects stumps are planted in the same way as plants in sleeves or *bheties*.

Time of Planting

Tea is grown under such diverse environmental conditions that a common planting time suitable for all regions cannot be conceived. In general, a cool, humid climate and a soil moist but not soaking wet favour transplanting. More important, however, is favourable soil-climatic conditions following transplanting to encourage growth of the young plants till they are firmly established in the field.

Favourable growing conditions prevail for a large part of the year in a few countries in the tropical belt. In a large part of the tea areas of Indonesia and Sri Lanka, temperatures are moderate, rainfall is adequate and fairly well-distributed and the soil remains moist for most of the year. Here transplanting can be done almost at any time according to administrative convenience. But all tropical countries do not enjoy the same advantage. The tea areas of East Africa situated within a few degrees of the equator suffer from a deficit of water in the soil during the early part of the year. Despite low temperature, evapo-transpirational losses are high due to strong winds experienced in this region. Choice of a suitable transplanting time is even more limited in Central African territones.

A long, cool and dry winter and a hot, wet summer are characteristics of the tea areas of N.E. India which falls just inside the temperate zone. Occurrence of thick mist in the cool hours of night and morning is an important feature of the otherwise dry winter. The eastern part of Assam receives a few light showers between November and January. February is usually a dry month but spring showers normally start in March. Cool, misty weather accompanied by occasional showers makes transplanting possible in this part of Assam during late autumn and early winter. The middle and western parts of Assam including Cachar and the tea districts in the plains of North Bengal experience droughty conditions throughout the winter season. In some years, these areas may not get any rain from November to April. Under such conditions, transplanting is safe only during spring and early summer after a few showers.

In the northern latitudes of Japan and the U.S.S.R. winter is wet but much too cold for successful transplanting.

Irrigation helps in the establishment of young tea. Where a convenient source of water and facilities for irrigation are available, transplanting can be advanced under most situations without waiting for the favourable weather to break. However, economics of irrigation will have to be worked out separately for each situation.

Shading

The young plants put out in the field require protection from the sun and desiccating wind. The degree of protection and the type of shade necessary differ according to the climatic conditions. Under certain situations so serious is the damage caused to the young plants by strong wind that the plants have to be tied to sticks driven firmly into the ground.

Lines of green crop grown between rows of tea is a convenient way of providing protection to the young plants form the sun and wind. However, a green crop shade may be dangerous in areas of marginal rainfall due to excessive drain on soil moisture. Even in areas of heavy, seasonal rain, the green crop may harm the tea plants during dry spells when there is shortage of water in the soil.

It is, therefore, safer to use mechanical shade in areas where water resources are limited. Cut grasses, ferns or any available material may be used for shading the young plants. Small earthenware pot placed like a hood on top of stumps was found quite useful in Malawi (Laycock, 1957).

Among the bush crops used for shading young tea, legumes are preferred for their ability to fix nitrogen although non-legumes of suitable growth habit can serve the same purpose. Some of the species so far tried have already been mentioned under shading of tea seed nurseries. To avoid direct exposure to the sun, tea is planted in a standing green crop. Planting into a standing green crop poses some problems but these are not unsurmountable provided planning has been done in advance. The plan should also provide for the establishment of a species like *Crotalaria anagyroides* ahead of planting tea.

While shading is beneficial, heavy shade is harmful for the growth of the young tea plants. This calls for proper control of the green crop. The best course is to lop the side branches and allow the plant to grow vertically to a height of 2.0-2.5 m before hedging. Hedging and progressive thinning out of the green crop is continued until it is finally removed after about two years.

Permanent and temporary shade trees should be planted at the same time as tea, if these are considered necessary (See chapter 12). If the shade trees are properly nursed, they develop sufficiently to afford protection to the tea plants by the time the green crop is removed after about two years.

SEED AT STAKE

After the introduction of vegetatively propagated clones, this method of propagation has fallen into disuse in Japan and Indonesia. Revival of the method can be expected if emphasis shifts to clonal seed. The method is practised in the U.S.S.R. where seed propagation still predominates.

As pointed out earlier, this method is less cumbersome than the other methods involving transplanting. Two to five seeds are planted closely sometimes in a circle, to produce a composite bush. However, protection of the seed and the young seedlings from weed, pest, diseases and drought poses difficult problems which limits the use of the method to regions where conditions are highly favourable.

SPACING AND ARRANGEMENT OF BUSHES

Spacing has been a hotly debated issue ever since tea became a plantation industry from the middle of the last century. The controversy has not died even today. In the early days of the tea industry in India, tea was planted 150 cm to 180 cm apart in square pattern. The change from this to closer spacing has been a very slow process. Even in the thirties of this century, 120 cm spacing was considered to be very close. Triangular or diagonal planting was a later development to accommodate more bushes in a given area at the same spacing. Rectangular or hedge planting was a more recent introduction into the countries of South-East Asia, although this method was practised in the old tea growing countries since a long time past.

Surprisingly, only two spacing trials seem to have been conducted before the Second World War. Of these the first and probably the earliest spacing trial on tea was started in India during 1864-65. Two 5 ha blocks were used for this trial, one of which was planted at a spacing of 75 x 75 cm with 17780 bushes ha^{-1} and the other at 90 x 120 cm with 9260 bushes per hectare. The closely spaced block gave consistently higher yield. The second trial was established in Indonesia during 1927 at six different spacings, covering a population range of 4117 to 16536 bushes per hectare. Unfortunately the experiment had to be terminated in 1942 but the yields from 1930 to 1942 were recorded by Von Roggen (1943). The closest spaced plots gave the highest yield throughout this period.

Two spacing experiments were started at Toeklai immediately after the War and a few experiments in Malawi during the early fifties. In these trials the stand density ranged from 6944 to 18518 bushes per hectare. The yield data from the Indonesian experiment and those available from the Assam and Malawi experiments until 1960 were analysed by Laycock (1961). The analysis led him to the conclusion that the yield-population relationship in tea was asymptotic for all age groups and that there was no optimum plant population beyond which yield declined. The yield differences between high and low bush populations were maximum during the early years and levelled off with age as the widely spaced bushes gradually filled up the ground area. These findings conform to those of Holliday (1960) according to whom the yield-population relationship is asymptotic when vegetative parts are harvested as crop while the relationship becomes parabolic when yield consists of reproductive parts.

In these experiments the yields of bushes after the first

5-7 years from planting did not increase substantially when the population increased to more than approximately 12000 bushes per hectare. A few more spacing trials conducted after 1960 in Sri Lanka, East Africa, Bangladesh and N.E. India produced similar results (Rahman and Fareed, 1977). However, the results of two spacing experiments conducted at Tocklai in recent years using very high bush populations have not conformed to this general pattern. In the first of these experiments started in 1966, where the treatments ranged from 9260 to 37,040 bushes ha^{-1}, a distinct advantage of closer spacing was observed even after 15 years as can be seen from Table 37.

Table 37: Spacing and yield in the 5th and 15th years (After Rahman and Fareed, *loc. cit.)*

Spacing (cm)	Number of bushes ha^{-1}	Yield of made tea (kg ha^{-1})	
		5th year	15th year
120 x 90	9,260	748 (100)	1388 (100)
120 x 45	18,250	1337 (171)	1471 (106)
120 x 30	27,780	1274 (162)	1647 (118)
120 x 22.5	37,040	1658 (211)	1808 (130)

Figures in parenthesis are percentages.

The other experiment was started in 1974. It had 23 spacing treatments from 15 x 15 cm to 150 x 150 cm where bush populations ranged from 4444 to 444444 per hectare. Planting was done in concentric areas in a systematic fan design. Due to large number of deaths in the first six very closely spaced treatments, scrutiny was confined to the remaining 17 spacing treatments covering the population range of 4444 to 126000 bushes per hectare. Due to unequal plot size for different treatments, the yield data from this experiment are not amenable to statistical analysis. Graphical examination showed that yield increased with population density only upto a limit, beyond which it started declining. This is an important finding which shows that at very high population densities, the yield-population relationship in tea takes the form of a parabola while at lower populations, the relationship is asymptotic as Laycock (1961) had demonstrated earlier. The yield maxima shifted from high to low bush populations as the plants became older. During 1976, the maximum yield was obtained from a population of 63697 bushes ha^{-1}. The maxima shifted to 22208, 21950 and 17509 bushes ha^{-1}, respectively, during 1977, 1978 and 1979 (TES Ann. Rep., 1981-82). This clearly has shown that a tea bush must get a certain minimum space for its development and that the space requirement increases as the bush gets older. The demand for space virtually ceases at some point of equilibrium which is determined by the vigour of the planting material, cultural operations like spacing, pruning and plucking as well as by nutritional and environmental factors that influence growth. The capacity of a bush for the production of shoot is impaired if it does not get the required minimum space at different stages of its growth.

Spacing experiments are costly and time consuming. They can provide broad guidelines but not specific answers for different situations. In view of the limitations of spacing experiments, Barua and Dutta (1971; 1973) approached the problem of spacing from a different angle. They determined the distribution of shoots on the plucking surface of mature tea bushes planted at different spacings and came up with a few important conclusions. The maximum number of shoots occur in the central region of the plucking surface of all tea bushes and the number drops towards the bush periphery. This happens at all spacings although plucking point distribution is more even on bushes which get equal room for development on all sides (e.g. square or triangular planted). There is an upper limit to the number of bushes that can be planted profitably in a unit area. If more bushes are accommodated in the same area, yield declines after the bushes cover the ground. For the Assam and Cambod kinds of tea the upper limit is around 27500 bushes per hectare under N.E. Indian conditions, provided a minimum distance of about 60 cm is maintained between the bushes. To obtain full benefit from such close planting, frame and plucking heights of bushes must be kept low, the latter not higher than 75-80 cm from the ground level. If this cannot be done, then the bushes have to be spaced wider apart. Planting closer than 60 cm is unlikely to increase the number of shoots after the bushes touch (Barua and Dutta, 1973).

High yield during the early years is a major advantage of close planting because it expedites recovery of the heavy cost of planting operations. Closely planted tea covers the ground quickly and more completely thereby protecting the soil and reducing the cost of weed control. The need for infilling is also obviated to a large extent since isolated vacancies are quickly filled up by the growth of neighbouring bushes.

Advantages notwithstanding, there are practical difficulties and theoretical objections to very high density planting. The main disadvantage of close planting is growth suppression. The growth of each plant in a population is suppressed in proportion to the closeness of planting. This was shown by Barua (1973) and confirmed by Rahman and Fareed (1977) in their analysis of the spacing experiment started at Tocklai in 1974. Diameter of plants at the collar region, angle of branching, spread, depth and weight of roots decreased in proportion to the number of plants per unit area. Restricted development of the root system makes these plants easily susceptible to deficit of water in the soil. Besides, moisture depletion in the soil during the dry part of the year was observed to increase with population density (Dey, 1975). Economic evaluation of plant density under conditions of N.E. India led Chakravorty and Awasthi (1981) to the conclusion that from the cost benefit angle, stand density should be limited to 14000 bushes ha^{-1}, although yield might continue to increase upto 30,000 or more bushes per hectare.

Because the plants get less and less robust as space for their development gets more and more restricted, closely planted bushes are liable to have a shorter economic life span which will require more frequent replanting. But judging from the current slow rate of replanting everywhere, the tea industry is unlikely to relish such a prospect.

The practical necessity of providing easy access of pluckers to all parts of a tea field also limits the number of plants that could be accommodated in any given area. Steepness of slope, fertility status of soil, liability to water stress, growth characteristics of the planting material all enter into considerations of spacing and arrangement of bushes.

Taking into account the necessity of keeping the bushes in the rows at least 60 cm apart and the rows spaced sufficiently wide for free movement of pluckers, a maximum of 20,000 bushes can be accommodated in a hectare of land. To accommodate such a large number of bushes, planting will have to be done in staggered double hedges at 60 x 60 cm spacing, leaving a minimum gap of 105 cm between hedges. Such an arrangement of bushes is possible only on flat or gently sloping land not subject to water stress or where irrigation facilities are available. If the interrow space is increased to 120 cm, which will be necessary in rich soil planted with vigorous clones of spreading habit, then the number will drop approximately to 18,000 bushes per hectare. Triple hedges are not desirable since growth of bushes in the central row is suppressed by the two rows on either side.

In steep and moderate slopes and in areas liable to suffer from a deficit of water in the soil where irrigation facilities are also not available, stand density has to be kept low. Double hedges are not suitable in such areas. Planting has to be done in single hedges accommodating 12,000 to 15,000 bushes per hectare. Further reduction of stand density is not desirable as it adversely affects not only early yield but yield at maturity also.

With the dwarf Chinery type bushes a somewhat closer than 60 cm spacing in the hedge row is likely to be advantageous from the point of yield and quick ground coverage. In the U.S.S.R., 21,000 to 24,000 Chinery bushes are planted per hectare. A spacing of 33 cm between bushes in the single hedge rows and 125 to 140 cm between hedges has become popular in recent years. The wider spacing between hedges facilitates mechanised field operations including plucking (Dey, 1972). Double hedge planting at 30 x 30 cm spacing between plants in the hedge rows and a wide gap of 180 cm between hedges is currently favoured in Japan where bushes are of the China type. This spacing permits planting of approximately 32,000 bushes per hectare (Sarronwala and Dutta, 1977). A 30 cm gap between bushes in the hedge row seems much too close even for the China kind of tea. Success of such closely packed stands of tea in these countries may be attributed to the slow rate of growth during a large part of the year on account of low ambient temperature and irrigation in times of water stress.

If vigorously growing bushes in closely planted fields obstruct the movement of pluckers and other personnel by producing thick branches in the interrow spaces, the sides of bushes may be trimmed occasionally as and when the need arises. Judicious trimming of side branches does not necessarily reduce yield. Infact, yield over a pruning cycle may actually increase as the experiments by Visser and Tillekenatne (1958) had clearly shown.

Number of Plants per Unit Area

While on the subject of spacing, the formula derived by Barua (1967) for calculating the number of bushes per unit area at all spacings and arrangements of bushes is worth recording. The number of bushes per unit area is given by the formula :

$$\text{Number of bushes} = \frac{n \times \text{unit area}}{y\,(x + z)}$$

Where n is the number of rows in the hedge, x is the perpendicular distance between hedge rows, y is the distance between bushes within a row and z is the perpendicular distance between rows of bushes in double and triple hedges. All measurements are expressed in the same unit. The following examples illustrate the use of the formula.

(a) Number of bushes per hectare when planted at 120 x 120 cm spacing?

Here n = 1, since square or triangular planting is taken as single hedge .

Unit area = 1 hectare = 10^8 sq. centimetre
x = 120 cm, y = 120 cm and z = 0 cm (a sIngle hedge)

$$\text{Number of bushes} = \frac{1 \times 10^8}{120\,(120 + 0)} = 6944\ \text{ha}^{-1}$$

(b) Number of bushes per hectare when planted in double hedges at 105 x 75 x 75 cm spacing?

Here n = 2 (double hedge),

x = 105 cm. y = 75 cm and z = 75 cm

$$\text{Number of bushes} = \frac{2 \times 10^8}{75\,(105 + 75)} = 14815 \text{ ha}^{-1}$$

If x, y and z are measured in feet, then the number of bushes per acre is given by:

$$\frac{n \times 43560}{y\,(x+z)} \text{ ; since one acre = 43560 sq feet}$$

INFILLING

Some plants usually die after a field has been freshly planted with tea. The number of deaths may be high or low depending on a large number of genetical, environmental and management factors. The dead plants are replaced with fresh supplies and a uniform stand is ultimately achieved if infilling is continued with patience. Even after establishment of a full stand of tea, deaths continue to occur due to adverse climatic conditions, attacks by diseases and pests, inherent weakness of some plants and bad management practices. The last one includes heavy pruning of weak bushes and bushes depleted of carbohydrate resources, exposure of thick pruning cuts to infection by pathogenic fungi and bacteria, continuous hard plucking, improper drainage and nutrition, weed infestation etc.

Presence of vacant patches in tea is undesirable since it may increase soil erosion, specially in steep slopes, cause collapse of soil structure and act as focal points of weed infestation. Above all, loss of bushes reduces yield. Grice (1971) reported reduction of yield of 10 to 20 years old sections of tea in proportion to the number of dead bushes upto 30 per cent of the total, when the stand density was below 8500 bushes per hectare. A similar trend was observed in stands of 8500 to 10,000 bushes ha^{-1} but above 10,000 bushes, the crop loss upto 10 per cent vacancy was much less.

When a bush dies in a closely planted field, the neigbouring bushes cover partly or fully the vacant space with productive branches. This can rarely happen in widely spaced tea. Because of this infilling, though desirable, may not be essential in very closely spaced fields of 15,000 or more bushes per hectare, so long as the number of deaths does not exceed a certain limit. This limit may be around 10 per cent, assuming that the vacancies are distributed uniformly over the .entire area. If death occurs in patches, these necessarily have to be filled up with fresh supplies.

In young stands of tea, infilling does not pose many problems, but establishment of infills in stands of mature tea needs a good deal of care and attention on account of competition from the mature bushes. In view of the difficulties associated with infilling in mature tea, the fresh supplies are unlikely to thrive in shallow soils under laid by boulders and impervious pans, very steep slopes where terraces cannot be built around the infills, water-logged areas unless the area can be drained and ground watertable lowered and in very sandy soils of drought-prone localities. In such situations the vacant spots should not be left bare but planted with some suitable grasses or legumes.

If infection by primary root diseases is suspected, then after carefully uprooting the dead plants with as much of the root systems as possible, the area should be fumigated with such suitable chemicals as Vapum (Sodium N-methyl dithiocarbamate), Dichloroethane, Durofume (Methyl bromide and Ethelene-dibromide in 50:50 proportion). The methods of soil fumigation have been described by a number of workers e.g. Kerr and Vytilingam (1966), Shanmugathan (1970) and Satyanarayana (1975). Satyanarayana suggested extention of the fumigated area to include two healthy pushes on all four sides of the affected bush. Fumigation is better done in moist soil; if dry, the soil is watered after fumigation. Replanting can be done 12 weeks after fumigation. This is a great advantage since it eliminates the long period of rest that is necessary to clear the soil of the infested pathogens.

Soil infested with eelworm should be treated with nematicides like Furadan (Carbofuran) before infilling. de Silva and Manipura (1975) recommended placing of a 10 per cent formulation of Nemagon (1, 2-dibromo-3-chloropropane) at the bottom of the planting pit. Nemagon is an efficient nematicide and its use in the recommended manner cannot have any objection. However, the tea industry of N.E. India has voluntarily banned the use of Nemagon along with all other chlorinated hydrocarbons in apprehension of accidental contamination of tea by these chemicals.

Well-grown plants of vigorous clones or proven seed stocks should be used for infilling. Bigger plants can be raised only in large sleeves. Where transplanting is done with *bheties*, the plants should be lifted with bigger *bheties*. The planting pits should be sufficiently big and, depending on the type of soil, the bottom of the pit should be forked to a further depth. In stiff or stoney soil, trench planting gives better result.

An infill cannot be treated and shaped in the same way as a plant of the original stand. Its growth is restricted by the surrounding mature bushes. A combination of these factors reduces the yield potential of an infill to less than that of an average bush of the original stand. Where the original spacing of the bushes is 120 cm or more, it is a sound policy to space the infills closer. The accepted policy in N.E. India is to replace one dead bush in widely spaced fields by two fresh supplies plus one i.e. three infills for one vacancy and five for two contiguous vacancies.

The chances of establishment of the infills improve when the top hamper of the surrounding mature bushes is removed by pruning. It is advantageous to infill in heavily pruned sections of tea since the plants take longer to recover from heavy pruning, giving the young supplies more time for establishment. It may be necessary in the subsequent years to trim the side branches of the mature plants in the immediate vicinity of the infills to provide room for their growth. Manuring, mulching, control of diseases, pests and weeds will have to be very efficient for successful establishment of infills.

Pruning of the infills naturally depends on the vigour of the young plants, spacing and arrangement of the old bushes, their height of pruning, topography and other soil-climatic factors. Ideally, the young infills should be pruned well before the regrowth of the mature bushes. This is hardly possible since the time between planting of the supplies and regrowth of the pruned bushes is usually very short. Pruning has to be carried out sometime after the old bushes have produced new growth. If pruned and centered at the usual height for young tea, then the growth of the infills is suppressed by the canopy of the mature bushes. The only alternative is to prune the infills sufficiently high and do a light centering. Bushes treated in this way produce narrow frames which limit their capacity for producing shoots. This is the reason for the suggestion that the infills should be planted closer to compensate for the loss of shoot-yielding capacity of each individual bush. In this connection it is worth considering whether the infills could be pegged within a few weeks from planting to enable them to produce some growth before the regrowth of mature neighbours fills up the area.

Block Infilling

At times bushes in a section of tea die in patches. Localised waterlogging, presence of shallow or sandy pockets of soil inside the section and spread of primary root rots from a focal point of infection are the major causes of patchy death. Bushes die in groups also when lightning strikes them. If remedial measures against the cause of death can be instituted, the vacant patches should be infilled. Otherwise these patches should be kept covered by planting some grasses or legumes.

After carefully uprooting the dead bushes together with any living plant among them, the area should be put through the same rehabilitation procedure as is applicable to sections of uprooted tea before replanting. Sub-soiling may not be possible in isolated pockets of soil inside a section of tea. In the absence of subsoiling, the planting pits should be made bigger and deeper and the bottom of the pits forked to a lower depth. After replanting, the patches should be treated as any freshly planted field of tea. Initially the plucking height of the newly planted bushes may have to be different from that of the old bushes but this difference can be set right at the end of the first pruning cycle.

There is no point in infilling sections of tea which are due for uprooting within the next 10-12 years.

PLANTING OF SEED BARI

Except in the matter of spacing, all other operations in the planting of seed bari are the same as those for plucking tea. Seeds are produced over the entire surface of a seed tree. The planting distance between seed trees should, therefore, be such that at maturity, the lower branches where the diameter of the tree is the widest, just touch. Spaced in this way, the total bearing surface of a seed bari will be 60 to 80 per cent more than the ground area, depending on whether planting is done in square or triangular pattern. If the trees are planted closer, the bearing surface at maturity will decrease with consequent reduction of seed yield.

It is impractical to plant closely and thin out the bari afterwards. The planting pattern of most clonal seed baries will not permit thinning out at a later stage. Furthermore, clonal seed bearers are expensive and it will be wasteful to use them largely as ground cover to be thinned out subsequently.

The planting distance of seed trees depends on the kind of plant and growing conditions. Since growing conditions differ widely, space requirement by seed bearers belonging to the different races of tea can only be roughly indicated. A planting distance of 3 to 4 m should be adequate for seed trees of the dwarf China kind of tea, while seed bearers of the Assam and Cambod races have to be spaced 5-6 m apart. Planting pattern may either be square or triangular, but the latter is preferable since it accommodates roughly 15 per cent more plants in any given area.

The young plants need protection from the sun and strong wind. Where green crop shade can be used, it is preferable to sow the green crop in lines between rows of young seed trees rather than in circles around them. This makes inspection easy. *Stylosanthes* or *Mimosa* can be planted between the lines of green crop and the tea plants to protect the soil from exposure and to suppress weeds but it is necessary to sickle these cover crops periodically. Seed bearers are as susceptible to bad drainage as tea under plucking, for which proper precaution is needed.

Very dry weather conditions are detrimental for flowering and fruit set. Desiccating wind scorches the flower buds which drop off before opening. Seed baries should, therefore, be sited in sheltered spots. In dry conditions, irrigation helps in increasing fruit set.

Seed trees are rarely pruned. If a bari becomes very congested, then branches may be removed judiciously to let in more light and air. Seed tree pruning is, however, a skilled operation. Selection of branches and the positions where these are to be pruned need experience. Only diseased and old branches should be pruned and the pruning cuts protected from fungal attack.

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CHAPTER 9

PRUNING

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OBJECT

Freely growing tea plants produce flowers and fruits in due course but very few shoots for the manufacture of tea. Young plants are, therefore, pruned to (a) produce a low, spreading frame for quick ground coverage, (b) facilitate manual or mechanical harvesting, (c) develop a sturdy framework that can sustain luxuriant vegetative growth in the future years and (d) harvest maximum crop even in the early years to recover in the shortest possible time the capital invested in planting. Mature bushes are pruned at intervals to renovate the branch system and keep the bush in the vegetative phase. Pruning stimulates the production of a new set of vigorously growing, leafy branches in replacement of the old set from which most of the leaves would have dropped off. The importance of the leaves (maintenance leaves) on carbohydrate economy of the tea bush will be explained in Chapter 10. There are other reasons necessitating renewal of the branch system from time to time. As the age from pruning increases, shoots become smaller, increasing number of banjhi shoots appear at the plucking table and more and more buds fail to grow. In other words, the branch system on the bush becomes increasingly unproductive. Besides providing maintenance foliage, pruning reestablishes a clean branch system devoid of knots, possessing the impetus of the previous system for economic production of vigorously growing shoots. Occasionally drastic pruning may become necessary for the elimination of disease and pest-ridden branches, renewal of moribund frames and reduction of the load of unproductive wood.

The plucking table continues to rise as the age from pruning increases. This is another reason for periodical pruning. The plucking height has to be kept within easy reach of pluckers for manual plucking and at a convenient height for mechanical plucking.

Except for some variation in height, age of plants and timing of puning and tipping operations, young tea pruning does not differ materially from place to place. However, the pruning system of mature tea followed in N.E. India and Bangladesh differs substantially from the methods followed elsewhere. These latter methods do not differ in principle although there may be some variation in detail. Based on past traditions, each region has modified the system of mature tea pruning to suit its local requirements.

The difference between the two major systems of mature tea pruning cannot be attributed either to the kinds of plant or soil-climatic environment, but tipping and plucking procedures could be major factors for the difference. Comparative evaluation of these pruning systems does not seem to have been undertaken anywhere. In consequence, pruning still remains a controversial matter in tea culture.

The harvesting operation in tea is known as plucking. Tender shoots are plucked at intervals of 5 to 14 days except in Japan and China where plucking intervals are much longer. Plucking is, therefore, a milder form of pruning repeated at short intervals which justifies dealing with the operations of plucking and pruning under a single head. However, there are basic differences between the two operations. Pruning provides the bush with its above-ground functional organs which mainly are the leaves, while plucking removes them. Thus, the two operations are mutually opposing. It will, therefore, be more appropriate to treat them separately.

PAST PRACTICE

In the past, generality of planters firmly believed that young tea plants should be allowed to get ‘firmly established’ in the field before applying the knife. The term obviously referred to a deep, robust root system capable of resisting drought and supporting the regrowth of shoots from the ‘centered’ plant by storing enough carbohydrates. In N. E. India plants put out in the field were allowed to grow undisturbed for at least two years, longer if the growing conditions were unfavourable, until the main stems thickened and attained a diameter of 1.5 - 2.5 cm at the collar. The plants were then cut across at 45 - 50 cm from the ground and the main stems were pruned at a height of 15 to 23 cm. The latter operation is known in the industry as centering. The purpose of centering was to induce branching at a low height. The branches were then shaped by frame-forming prunes into well balanced and spreading frameworks. Centering was done above two-three lateral branches but there are many plants which may have only one lateral below 23 cm and some none at all. Such plants were also centered at or below 23 cm. The plants having no lateral below the height of centering, the single stemmers, were the ones most affected by unfavourable soil-climatic conditions.

In countries where plants were raised directly in the field by planting seed at stake, centering was and still is done at about 30 cm. Since seeds are generally planted very close, sometimes in circles or in clusters, the aim is to produce a composite bush at every spot. For this purpose, a comparatively light centering operation proves adequate.

In stump planting which is still practised in many countries, plants remain in the nursery for two-three years. The nursery plants are pruned between 10 and 20 cm when the collar diameter is 1.5 cm or more and then transferred to the field as stumps. Since these plants have already been centered in the nursery, no further centering is usually necessary afterwards.

Pruning and centering of young plants following transplanting continued essentially in the same way for a long time. Gradually the emphasis on very thick stems was relaxed and stems of pencil thickness also (0.7 to 1.0 cm) were considered adequate for the purpose of centering. The choice of plants with thinner stems, indirectly helped in the treatment of the single stemmers. These plants were broken at the centering height by leaving a portion of the wood and bark still attached to the plant and the broken top was left bending to the ground. After the start of bud break on the stump, the broken top was pruned, off. This treatment enhanced the chances of survival of the single stemmers. No major change was noticeable in the subsequent frame-forming pruning methods followed in different countries.

Need for a Change

After the Second World War the tea industry, particularly in the traditional tea-producing countries, found itself in a situation where cost of production was mounting steeply, without corresponding increase in yield and the price of tea. This situation obliged the industry to have a fresh look at different aspects of culture and manufacture. It became apparent that the viability of the industry depended largely on increased productivity of the existing fields since scope for bringing new areas under tea was very limited. Emphasis was laid on raising the yields of the existing tea fields, wherever possible, by adopting improved management practices and uprooting of uneconomic areas and replanting them with improved planting material. Various measures have since been adopted for raising productivity. That these measures have been successful to a large extent is reflected in increased productivity throughout the world. Uprooting and replanting of uneconomic fields, however, have not progressed as well as it should have been.

Along with other management practices, pruning of young and mature tea has also received a good deal of attention in the recent past. Considerable improvement has been effected in the bringing up of young tea but mature tea pruning has changed but little over the years.

BRINGING UP OF YOUNG TEA

Selection and breeding of vigorous planting material and use of polythene sleeves for raising plants have aided in the development of the new techniques for young tea pruning. Transplanting with sleeves ensures quicker establishment of the plants in the field. The vigorous clones and seed stocks developed since the War grow faster and, in warm climate, the plants become ready for pruning within three to six months from transplanting. Bending and pegging of the plants, which can dispense with the initial cut are getting increasingly popular, These operations can be carried out within a few weeks from transplanting. In cold climate where growth is slow, plants naturally take longer to become ready for pruning but pegging can be carried out after the plants have grown to a height of 30-40 cm.

By pruning

Survey of the current methods of young tea pruning shows that the centering heights vary from 10 to 25 cm, tipping heights from 40 to 60 cm and age of the plant at first centering from a few weeks to about 12 months after transplanting. The subsequent pruning-centering operations carried out during the initial four-five years differ to some extent from place to place. Theoretically the combinations of pruning and tipping heights, growth stages of the plant and subsequent operations could be unlimited. Many of these combinations have been tried out in some place or the other. We shall not attempt to review these trials but try to illustrate the basic operations in young tea pruning or pegging by a few examples.

In N .E. India young plants are pruned when they become about one cm thick at the collar. Before pruning, the usual practice is to examine a sample of plants for root starch by a rapid visual method (described below). Pruning is delayed if roots are deficient of starch and the plants are flushing. The plants are cut across at a height of 35-45 cm and centered immediately afterwards between 10-20 cm, preferably above three laterals. Single-stemmers are finger pruned as earlier described; The schedule of operations currently recommended by Tocklai is shown above (F.R., 1979).

The second part of the recommendation is intended for the hill district of Darjeeling where, with rare exceptions, only the China bushes are cultivated above 1300 m elevation. The hybrids pre-dominate at lower elevations although scattered sections of Assam tea are also seen. The Chinery bushes produce strong and wide-angled branches from a lower height which gives these plants a bushy appearance. Short internode length makes pruning and centering of these plants possible at a height lower than on Assam type bushes without drastic reduction of the number of branches left on the bushes after these operations. For the same reason tipping and plucking can also be done at a lower height. These heights need adjustments in the hybrid forms, according to their affinity to the Assam or the China type. For this purpose the length of an average internode can be taken as the guide.

For non-droughty areas			For droughty areas		
Year	Month	Operation	Year	Month	Operation
0	Oct.	Plant tea	0	May/Jun	Plant tea
1	Jan./Feb.	Cut across at 35 cm. Center below 20 cm. Tip at 50-55 cm.	1	Jan.	Cut across at 35 cm. Center below 20 cm. Tip at 55 cm
2	Jan./Feb.	Cut across at 40 cm. Recenter where necessary.	1	Dec.	Deep skiff at 45 cm. Tip at 55 cm.
		Tip at 60 cm and pluck.	2		Continue plucking, raising by a leaf when table is full.
3		Continue plucking raising by a leaf when table is full	3	Jan.	Cut across at 40 cm. Recenter where necessary.
4		Same as in Year 3			Tip and pluck at 60 cm.
4	Dec.	Cut across at 45 cm. Tip at 65 cm.	4		Continue plucking, raising by a leaf when table is full.
		Thereafter follow the normal pruning cycle.	5		Same as in Year 4.
			5	Dec.	Cut across at 45 cm. tip at 65 cm. Thereafter follow the normal pruning cycle.

Secondly, due to limited space available to a bush within a closely spaced hedgerow, it does not get enough room for spreading equally in all directions as a bush in a conventional square or triangular planted field does. Since spread is restricted at least in two directions, it has to be pruned and plucked low in conformity with the allotted space for maximising production. The above recommendations do not appear to have taken this factor into account.

Medium and high elevation			Low elevation (<600 m)		
Year	Month	Operation	Year	Month	Operation
0	Jun/Jul.	Plant tea. Tip at 50 cm.	0	Jun.	Plant tea Tip at 50 cm.
1	Sep.	Cut across at 30 cm. Center at 10-15 cm (a). Tip at 50 cm.	1	Sep.	Cut across at 30 cm. Center at 10-15 cm. Tip at 50 cm.
2		Continue plucking, raisig by a leaf when table is full.	2		Continue plucking, raising by a leaf when table is full.
3		As in year 2.	2	Dec.	Cut across at 30 cm. Recenter where necessary.
3	Dec.	Cut across at 30 cm Recenter where necessary			
4		Tip at 50 cm. Continue plucking, raising by a leaf when table is full.	3		Tip at 50 cm. Continue plucking raising by a leaf when table is full.
5		As in year 4.	4		As in year 3.
6.	Dec	Final frame-forming prune at 35 cm. Tip at 55 cm. Thereafter follow the normal pruning cycle.	5	Dec	Final frame forming prune at 35 cm. Tip at 55 cm. Thereafter follow the normal pruning cycle.

(a) Centering may have to be postponed to January of year 2 where growth is very slow.

It may also be noted that sections of hybrid tea grown in the plains of N.E. India require to be treated as hybrids and not as Assam tea. The same is the case with Assam tea grown in the Darjeeling district.

These recommendations expose the limitations of standardising pruning, plucking and other cultural operations for an area without taking plant type and other interacting factors into account. This applies equally to N.E. India as well as to the other tea-growing areas of the world.

In N.E. India plucking is done to janam which does not permit growth of any maintenance foliage above the tipping level. This system of plucking makes it necessary to start with a long tipping measure and raise the plucking level at intervals if plucking continues for more than a year. In the recommended method, one step up in a year sometime in June-July is considered adequate unless the bushes show signs of debility. However, the term 'when table is full' does not indicate the precise time for raising the plucking table. The term 'deep skiff' as explained later, is another device for renewing maintenance foliage without resorting to a normal cut across prune. .

The need for a second prune and recenter within a year of the first operation is, however, disputed. It was not included in the earlier recommendations of Tocklai (S. K. D.,1971). After the initial pruning, centering and tipping operations, the bushes were plucked. continuously for the next four to five years by stepping up at intervals. By the time the frame-forming prune was given at the end of four or five years, the plucking height would have risen to about 85 cm. It was observed that bushes treated in this manner did not produce well-developed frames. After the frame-farming prune, not only did yield decline but the bushes also failed to cover the ground. The original recommendations were, therefore, withdrawn In favour of those given above.

The following examples illustrate the similarity of approach to young tea pruning in different countries. The standard procedure at the Tea Research Institute of East Africa is to prune sleeve-grown plants at 15 cm when they attain a height of 30 cm or more leaving at least three leaves below the pruning height. The laterals growing from the stump are cut across at 28 cm when they are one cm thick at that height. Pruning is repeated at 41 cm when majority of the shoots become one cm thick at that height. The bushes are then tipped at about 61 cm when three leaves are produced above the pruning measure. Plucking continues until pruning at the end of three-four years.

Several methods of pruning are employed in Sri Lanka to bring young tea into bearing. In one of the methods, the first pruning is done at 23 cm eight to nine months after planting. The bushes are next pruned at 35-38 cm four to five months after the first prune and tipped at 45 cm. Plucking continues without any more pruning for about five years after which the final frame-forming prune is given at 45 cm.

In another method generally practised in the low country, plants are allowed to grow freely for about a year after transplanting and then cut across at 30 cm. The next cut is given at 35-40 cm depending on the growth made by the plants. After tipping at 45-50 cm, plucking is continued until the final frame-forming prune at the end of three years.

In all these methods, the plants are cut twice after transplaning and before the final frame-forming prune. This indicates that one prune is considered insufficient to produce a well-formed bush. Close similarity between regions is observed also in the height of the final frame-forming prune which lies between 35-45 cm.

Any form of pruning throws the bushes out of plucking and the loss of crop following pruning increases with the severity of the cut. For this reason it is worth considering whether the second cut given for shaping the young plants could be avoided. The wisdom of keeping yield as one of the objectives of young tea pruning may well be questioned. Admittedly, in the initial years of shaping the tea bush yield should not be the primary consideration at the expense of future performance of the bush. However, in view of the very high and ever increasing cost of planting operations, yield becomes an important consideration even during the first few years from planting. Any return obtained from the young bushes helps in reducing the payback period which is a decisive factor in the economics of planting new areas or uprooting and replanting old fields of tea (Awasthi, 1981).

A long tipping measure is not necessary when plucking is done over a leaf since maintenance leaves are added to the bush at every plucking round. The combination of short tipping measure and single-leaf plucking provides better opportunity for regulating growth of the bush than janam plucking over a long tipping height. A few rounds of hard plucking i.e. janam or fish leaf, at some stage after tipping, can stimulate the growth of more laterals from the bush frame to fill up the gaps in the canopy and increase spread. The tipped primaries in the central zone of a bush may get excessively thick when plucking is lenient. Such stems create problems at the time of the final frame-forming prune. Hard plucking judiciously interspersed with the single-leaf method can check excessive girth of stems. Another alternative will be to head back the thick stems without suspending plucking. Thicker the stem harder should be the cut. Proper utilisation of these measures may eliminate the necessity of a second cut before the frame-forming prune.

Under congenial climate, finger pruning appears to be the safest and the most practical method for centering young tea. It can be carried out soon after transplanting without waiting for the build up of carbohydrates in the roots and for the plants to go banjhi. So long as they do not suffer from desiccation, the leaves on the semi-detached stem can carry on photosynthesis, Hence this operation should be carried cut only when the soil is well-supplied with water and the ambient conditions are not very dry.

By Bending and pegging

In recent years bending and pegging as a method of bringing up young tea is gaining rapidly in popularity. The method involves bending the main stem and branches of the young plants and holding them in that position with the aid of pegs. Pegs are made of pruned tea stems, cut branches of trees, bamboo, iron and, in fact, of any convenient material that is readily and cheaply available. The peg should preferably have a hook or catch at the top end to hold on to the branch. The lower end of the peg is driven into the soil to keep the branch in the bent position.

Two other variants of the method have also been tried. In one of these, a ring made of any convenient material is placed centrally on the plant at the desired height and held in that position with the aid of pegs. The main stem and branches are pushed underneath the ring when they become 40-60 cm tall. In the second method, two long strips of bamboo are fixed on either side of a row of plants usually at a height of 30 to 40 cm depending on the kind of plant. Similar strips are fixed across the rows. The main stem and branches of the plant are pushed underneath the strips when they grow to the desired height. Where bamboo is not available, ropes may serve the purpose provided the ropes are held taut in position and not allowed to yield to the upward thrust of the bent branches.

The choice of a pegging method depends primarily on availability of material for pegging. The method is immaterial so long as it produces bushes of the desired shape and size.

Attention to certain details is necessary for the success of pegging. These may be listed as follows :

(a) Pegging can start soon after the mulch has settled down. Under wet conditions, this may take two-three weeks from planting. When conditions are dry, the interval between planting and pegging may have to be longer.
(b) The main stem should be 40-60 cm tall at the commencement of pegging but should not be too thick and rigid. Thick stems are liable to break on bending and are difficult to hold in a bent pbsition. Normally 8-10 mm should be the limit of thickness of the stem at the collar.
(c) Branches should be allowed to grow 40-60 cm tall before bending and pegging. Spindly and drooping branches may be headed back to make them stand at an angle with the vertical axis of the plant.
(d) The main stem should be bent gently near the ground making an angle of 60° to 70° with the vertical axis. Branches also should be bent likewise. At this angle of bending regrowth usually takes place from the basal part. If the bent stem is allowed to form an arch, shoots tend to develop from the top of the arch giving rise to a lop-sided frame.
(e) Pegging should continue until the branches produce a star pattern. Four to five well-formed branches are all that is needed to produce a good frame.

The importance of bending geometry in the regrowth of shoots has been stressed in a number of reports (Manipura and Yatawatte, 1974; Furst, 1976; Bezbaruah and Barbora, 1983) . A bending angle of 60°-70° with the vertical appears to give the best results. The reason for this is not clear. However, results of analysis of the xylem sap of erect (10°-40° from vertical) and inclined (45° plus) shoots carried out by Kathiravetpillai and Kulasegaram (1981 a) suggest large decrease of gibberellin: cytokinin ratio to be the possible cause of poorer regrowth obtained on shoots bent at a wide angle.

Pegging is also done after a standard cut across and decenter, primarily because it is easier to develop a well-formed bush by pegging the laterals developing from the pruned stump than by pegging the intact plant. However, growth is lost and the plant gets a set-back from the prune, the avoidance of which is the major objective of pegging. This is an important argument against the propriety of pruning bushes which are going to be pegged. In the case of plants which are already pruned in the nursery and transplanted as stumps, bending and pegging will naturally have to be carried out on the laterals arising from the stump.

As shoots do not get ready at the same time pegging has to be continued until bushes are properly shaped. This may take longer in some than in other clones. When no more pegging is required, the regrowth is tipped. Depending on the kind of plant, terrain and climatic conditions, the tipping height falls usually between 35 and 50 cm from the ground. The object of the initial tipping operation is to produce uniformly thick stems distributed evenly on the bush frame. A tipping height which allows on an average five maintenance leaves to remain on a primary is generally sufficient for the purpose when plucking is done to the janam. When plucking is done to the leaf, the same objective can be achieved by tipping at a lower height as already mentioned. It is sometimes useful to tip the peripheral branches at a higher level for thickening them up. This method is equally applicable in the case of pruned bushes.

As with the pruning method, opinion differs on the pruning frequency of bushes pegged without centering. Some favour a prune at a height of 30-40 cm when the plucked stems are approximately one cm thick at the base, removing at the same time weak and crossing branches and heading back very thick stems to a lower height. Loss of crop is the main argument against this prune. Nevertheless, such a prune would be desirable in the case of vigorous tea unless the final frame-forming prune is done fairly early, not later than the end of the third year. A prune would be helpful also in areas subject to periodic drought. In the case of bushes pegged after a decentre, another prune before the final frame-forming pruning may not be necessary if tipping and plucking are properly controlled.

Cultural Treatments

The greatest enemy of young tea is weeds. Successful establishment of young tea irrespective of the method of pruning or pegging depends largely on the control of weeds. Protection of the plants from pests and diseases and proper manuring are also equally important in the bringing up of young tea.

Pruning vs pegging

In East-Africa, pegging following a cut across and decentre was giving significantly higher yields than any form of pruning including the Standard TRI pruning, even at the end of two pruning cycles (TRIEA Ann.Rep., 1977). Barbora (1984) obtained higher crop in N. E. India from pegging with or without centering than from any type of pruning during the first three years, until the bushes were given the final frame-forming prune. Pegging without centering yielded more only in the first year than pegging following centering. In the second pruning cycle, the two pegging treatments and the standard TES method of pruning gave the same yield. These three treatments increased the size of bushes and the number of pruning sticks per unit area to the same extent which were more than that of any other form of pruning. Pegging has proved superior to pruning in Sri Lanka too (Manipura and Yatawatte, 1974).

Advantages notwithstanding, the pegging method suffers from a number of drawbacks. Pegging requires a certain amount of skill and a good deal of supervision. Since all branches do not form at the same time, the pegging operation has to be repeated at least for three-four rounds. Pegs get loose when the soil is softened by rain and are dislodged by wind. These require constant refixing.

Manuring and weeding, particularly the latter, is more difficult in pegged than in pruned sections of young tea. Not the least of all is the damage caused by the sun to the exposed bark of the pegged bushes, The extent of damage due to sunscorch varies from clone to clone. In hot climate, some clones seem to be least suited to this method of bringing up (Barbora *et al.,* 1982). Pegged plants are more prone to damage by hail than pruned plants. Barbora and Saha (1978) reported nearly three-fold more damage to 10-month old pegged plants than pruned plants of the same age. Yieldwise also, the advantage of pegging appears to be short-lived as indicated above. Taking an overall view, it appears that pegging cannot be a commercially viable method of bringing up young tea under all situations. Where conditions are favourable, this method can be used profitably.

Use of Chemical Pruning Agents

A number of chemicals are known to stimulate branching by suppressing meristematic activity in the apical zone of leading stems. Some of these chemicals, viz. Ethephon or Ethrel (2-chloroethyl phosphonic acid), CCC or Cyclocel (2-chloroethyl trimethyl ammonium chloride), SADH or Alar (Deminozide), Goal (Oxyfluorfen), Morphactin (Chlorflurenol methylester), Paclobutrazol etc. were tried at Tocklai for promoting branching of young plants. When applied as foliar sprays, a few of these chemicals induced branching. For instance, Ethephon at 1000 ppm, Goal at 500 ppm and Morphactin at 50-100 ppm sprayed on transplanted young plants produced more branches than normal pruning and centering. When the same chemicals were sprayed on nursery plants at half the concentrations, some clones responded by producing as many branches as debudded plants, but the response was not so pronounced on other clones. Besides, the chemicals, their spray concentrations, the growth stages of the plants as well as the kinds of plant interacted in a complex way to modify the effects (TES Ann. Rep.,1979-80; 1980-81; 1984-85).

Observations made by Kathiravetpillai and Kulasegaram in Sri Lanka (1981 b) provide some clues to these complex interactions. They sprayed 4 to 12 weeks old cuttings with solutions of CCC at 2000 to 16000 ppm concentrations and observed growth retardation at concentrations of 8000 ppm and above. Interestingly, the effect was more pronounced on cuttings after the formation of roots and on plants which were dormant at the time of spraying. Branching was induced only on plants which had completed a flush of growth. Soil application of the chemical was also effective when the plants were in the dormant condition but at a much higher concentration of the order of 50,000 ppm. The presence of roots and the state of dormancy appear to be prerequisites for the action of the chemical.

Obviously our knowledge of the action of growth retarding chemicals on branching of the tea plant is still very inadequate. Firm conclusion regarding their use as chemical 'pruning' agents for tea must await further investigation.

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Bringing up Young tea vis-a-vis Spacing

High density planting in hedge rows (See Chapter 8) has necessitated a change from the traditional concept of a large tea bush spreading equally in all directions but the changed situation does not seem to have made much impact on the current practices of pruning and pegging of young tea. In single-hedge planting, bushes along the hedge are usually spaced 60 to 75 cm apart while the space between hedges is approximately twice as much. In double-hedge planting, a bush is restricted to a spread of 60 to 75 cm on three sides. It can spread to about120 cm only on one side. The ultimate shape of a bush in single-hedge planting resembles a rectangle while in double-hedge planting the rectangle is truncated at one end. To cover the space alloted to a bush, which is approximately a half of what it used to be in the past, it requires a much smaller frame.

The heights of pruning, tipping and plucking also need adjustment in relation to spacing. At close spacing, the bush-frame cannot be kept high as otherwise the branches of neighbouring bushes intermingle. This may not cause difficulty in plucking but pruning of each bush has to be done individually at a low height to remove the criss-crossing branches. When pruning is low, tipping and plucking necessarily commence at a lower height. If low-pruned bushes are plucked over a long tipping measure, the top hamper gets highly congested. Congestion makes the stems twiggy, reduces penetration of light and increases abscission of leaves. A combination of these factors reduces yield.

The current systems of bringing up young tea do not seem to have paid enough attention to the need for training the bush in respect of shape, size and height to fit in with the space allotted to it. The space allotted being unequal in different directions, it is necessary to devise methods of pruning or pegging that can ensure maximum utilisation of the allotted space. As shown elsewhere, production of shoots on a plucked tea bush decreases from the centre to the periphery. Efforts should be directed to extend the zone of high shoot density to the wider space available to the bush between hedge rows by training it appropriately in the formative stage. This aspect needs thorough study to get maximum return from a given area of ground.

Time of Pruning and Pegging

The correct time for pruning young tea is determined by the climate of a place and the state of growth of the plants. Moisture status of the soil and availability of labour are also important factors in timing of the pruning operation. Although the presence of irrigation facilities widens the scope, certain norms applicable under all situations influence the final choice of a suitable time.

Actively growing plants usually have low reserves of carbohydrates in the roots and may not be in a position to support their recovery from pruning. To assist recovery, the number of leaves removed from the plants at pruning should never exceed the minimum necessary for carrying out the operation. Single stemmed plants are to be finger pruned as already explained. A cool dormant season where it exists, is a good time for pruning young tea, provided the soil retains some moisture and pruning is not followed by a long spell of hot and dry weather. Pruning in the dormant season must be completed well in advance of the time when regrowth normally starts.

Pruning should not be done when atmospheric conditions are hot and dry. Under such conditions pruning causes dieback and death of the young plants. Small plants with a few leaves stand better chances of survival under short dry spells since they can exert a stronger transpirational pull and draw in more water into the system than plants without leaves.

Irrigation can ensure the availability of water to the plants but it has little impact on the drynes of the atmosphere. Hence dependance on irrigation alone for pruning young tea is inadvisable when atmospheric conditions are very dry.

The soil-climatic conditions in the period following pruning should be favourable for growth. This is an important consideration everywhere, particularly in areas that experience wide climatic fluctuations.

Pegging of intact plants offers a wider scope for the selection of a suitable time. However, pegging should not be undertaken in hot, sunny weather as the pegged stems are liable to damage from sunscorch.

PRUNING OF MATURE TEA IN N.E. INDIA

Mature tea pruning in N. E. India differs in certain respects from the pruning methods followed in other countries. In the plains of N.E. India, tea used to be pruned annually when bushes became dormant at the end of the growing season. This method is no longer followed but unlike in other parts of the world, it is still the usual practice to cut the bushes very lightly at the end of each year, although leaving bushes unpruned for two successive years is no longer uncommon. The light cut referred to above is known as SKIFFING. Introduction of skiffing as a substitute for the annual or light prune (LP) is not more than three decades old. In order to appreciate the present system, it is necessary to have an idea of the old system of annual pruning.

In annual pruning, bushes were pruned every year approximately 1.5 cm above the previous pruning height. The height of the bush frame continued to rise every year until the bush became too high for plucking. This happened at the end of 15 to 20 years depending on the height of the previous heavy prune. When the bush had reached an unmanageable height, it was cut back to a low height above the original frame-forming prune. This low cut-back operation is known as MEDIUM pruning. At the end of a year or two after the medium prune, bushes were light pruned 4 to 5 cm above the level of the heavy cuts. Thereafter pruning was done every year until the time of the next medium prune.

Skiffing

Introduction of skiffing has eleminated the necessity of light pruning every year. At the end of the pruned year, the bushes may be deep skiffed, medium skiffed, light skiffed or just levelled by giving a level skiff and skiffing may be repeated in the succeeding two to six years. A description of the skiffing operation is given below :

Deep skiff (DS): When deep skiffing is done after a light prune, it is a cut given midway between the pruning and the tipping levels. For instance tea tipped at 20 cm is deep skiffed at 10 cm above the previous pruning level.

Deep skiffing after one or more years of level skiff (see below) is a cut midway between the pruning level and the height of the plucking table at the end of the season, provided not more than 25 cm of growth is removed by the skiff. For instance if the plucking height at the end of the year is 30 cm above the pruning mark, the tea will be deep skiffed at 15 cm.

The new growth pruduced by deep skiffed bushes is tipped at the previous tipping level over a minimum of two leaves.

Medium skiff (MS): When done on light-pruned tea tipped at 20 cm or deep-skiffed tea tipped at 10 cm, this will be a cut given at 15 cm above the previous pruning mark or 5 cm below the last year's tipping level. When done after one or more light or level-skiffed years, medium skiff is given just below the 'crows feet' formed during plucking.

Medium-skiffed tea is tipped at the previous tipping level by leaving a minimum of one leaf on each newly developed primary.

Light skiff (LS): This skiff is done at or within one centimetre of the previous tiping level which removes majority of the plucking points but spares the 'crows feet'.

Shoots are plucked at the skiffing level.

Level skiff (LVS): This is a skiff done to level off the plucking table by removing any plucking stubs or old leaves that stick above the plucking surface. The height of the cut above the previous tipping level is determined by the rise of the plucking table in the course of the year.

Light and level skiffs served as a prelude to the introduction of continuous plucking for more than one season without a skiff in between. Tea plucked continuously goes under the designation of unpruned (UP) (See Fig. 23).

In the absence of a tipping measure, the plucking level of light-skiffed, level-skiffed and unpruned tea is allowed to rise by a leaf, sometime before the peak growing season but preferably early or late in the year. However, keeping tea unpruned, light or level skiffed for two years in succession with the addition of a single layer of maintenance foliage in a year can be debilitating for bushes growing under the warm climate of the plains districts. Except for vigorous bushes producing a large number of leafy laterals below the plucking level, this treatment appears to be too harsh for bushes of average vigour.

Effect of Extension of Pruning Cycles by Skiffing

Substitution of annual pruning by longer pruning cycles through the introduction of skiffs has, in general, increased productivity of the tea areas of N.E. India. However, exceptions are not uncommon. In areas prone to drought, lighter forms of skiff and unprune have been observed to cause dieback and occassionally death of bushes when spring showers are delayed. If conditions do not become inimical, the gain in crop from various forms of skiffing over annual pruning can be of the following order (Dutta, 1969).

Deep skiff	10-15 Per cent
Medium skiff	15-20 ”
Light skiff	20-25 ”
Level skiff and unprune	25-35 ”

Dry condition of the soil during the early part of the growing season reduces yield of both pruned and skiffed bushes, but the adverse effects of drought increase with the lightness of the skiffing operation along with the increased load of maintenance foliage carried by the skiffed bushes. Dry condition of the soil during winter and early spring is a regular feature in many parts of N.E. India but, in some years, the droughty conditions unpredictably persist much longer than usual, causing serious distress to tea bushes. The hazard of light skiffing in the drought-prone areas of Terai, the Dooars, Cachar and a few other parts of Assam cannot, therefore, be overlooked.

Skiffed tea gets more heavily infested by red spider mites *(Oligonychus coffeae)* during the first half of the year and by tea mosquito bug *(Helopeltis theivora)* in the wet season. Loss of crop following their infestation can be quite high if control measures are not fully effective.

Plucking of annually pruned bushes commences from end March or early April but light skiffed and unpruned bushes can be plucked about a month to a month and a half earlier. However, these latter bushes stop flushing earlier than pruned bushes. The overall distribution of crop differs between various forms of skiffing as can be seen from Table 38.

Length of Pruning Cycles of Skiffed tea

With a view to increasing crop and even out its distribution various combinations of skiffs and unprune have been tried in cycles of two to six years. Two to four times the number of pluckers are needed to harvest leaf from light-skiffed and unpruned than from pruned sections of tea, which makes availability of pluckers a vital consideration in the choice of a pruning cycle.

A three-year pruning cycle has proved most satisfactory for the plains districts, subject to proper adjustment of the various skiffing combinations. At the higher elevations of Darjeeling where growth is slow and only Chinery bushes are cultivated, pruning cycles may extend upto six years. At lower elevations (upto 1200 m), longer than three-year pruning cycles appear to be less productive (Biswas, 1977).

Table 38. Per cent of annual harvest (After Dutta, 1969)

Type of pruning or skiffing	1st flush till mid April	2nd flush Mid April to early July	Rains flush Early July to mid October	Back end crop Mid October to end of season
Light pruned	2	20	63	15
Deep skiffed	3	25	63	9
Medium skiffed	5	27	61	7
Light skiffed	10	30	55	5
Level skiffed or Unpruned	12	33	52	3

The higher crop and its more even distribution obtained from longer pruning cycles are to be viewed against certain limitations. Attention has already been drawn to the high cost of plucking skiffed and unpruned tea and their greater susceptibility to drought and pests. Skiffing reportedly reduces quality of the finished tea. Choudhury (1969) observed maximum price realisation by teas made from light-pruned bushes which was not appreciably better than those from deep-skiffed bushes. From medium skiffing to unpruned, the value of teas declined as skiffing became lighter, except during the early part of the year when unpruned and light-skiffed teas fetched better prices.

In a three-year pruning cycle of say P-LS-UP, leaf from all the three treatments get mixed up during plucking and manufacture. It is not administratively feasible under the existing set up of tea estates to manufacture and market the teas separately. The leaf from all treatments is manufactured and sold in bulk. The price realised is the weighted average of the pruning-skiffing treatments. If the average price happens to be lower than the price realised by teas from the pruned or deep-skiffed bushes which usually is the case then estates reputed for the high quality of their products may stand to lose by adopting lighter forms of skiff. In a buoyant market loss of quality due to lighter forms of skiffing may not affect the overall economy of an estate, but in a selective market where quality counts, higher yields from light skiffing may not compensate for the drop in the value of the product.

At the end of a cycle bushes are light pruned about 2.5 cm above the previous pruning level. In sections of vigorous tea, stems at this pruning height often get much too thick for a light prune, necessitating raising of the pruning height to avoid cutting into very thick stems and to reduce loss of crop in the pruned year.

Other Uses of Skiffing

Sometimes it is not possible to pluck a part or a whole estate due to shortage of labour or other reasons. This situation arises mainly in areas where growth is seasonal. In N.E. India there is a very heavy rush of crop for about four months of the year. Few estates can maintain during the long lean season a permanent labour force adequate for strict plucking in the main growing season. The planter is faced with the alternatives of suspending plucking in a part of the estate or taking very coarse leaf of poor quality at long intervals or hiring temporary labour for plucking, if they are available. When plucking has to be suspended for a few rounds, the normal practice is to skiff the bushes when resumption of plucking becomes possible.

Cooper (1932 b) investigated this problem in N.E. India and arrived at a number of important conclusions which are likely to be applicable to other situations. He observed four weeks of less crop after skiffing followed by two weeks of larger crop than that produced by normally plucked tea. The loss or gain in crop during the six weeks increased as the interval between skiffing and previous plucking lengthened. This was followed by three weeks of reduced crop after which the skiffed tea bushes produced the same crop as those plucked regularly. If tea was skiffed after leaving unplucked for two rounds, then the total loss of crop was equal to two weeks crop. He advised that skiffing should not be delayed beyond two weeks of unplucked. If after skiffing once the tea cannot be plucked, it should be skiffed again after a fortnight instead of skiffing at the end of four weeks. This reduces the loss of crop. Cooper perferred skiffing above a foliage leaf to skiffing at the previous plucking level.

The advantage of skiffing above a leaf is obviously due to the addition of fresh maintenance foliage to the bush. This raises the important question whether it would not be advantageous to establish a new plucking table at a higher level by tipping the shoots instead of skiffing them down to the previous plucking level. This may not always be possible if the last plucking level was too high. Wherever possible, this procedure can be expected to benefit the bush by increasing the size of the maintenance leaf canopy. The enhanced vigour of the bush can be exploited by plucking harder for a few rounds to compensate, at least partially, for the crop lost during the period of enforced rest. If skiffing has to be repeated fortnightly for two-three times, establishment of a new plucking table can replace the last skiffing operation.

Very light skiffing is sometimes done to level off uneven plucking table if normal breaking back proves inadequate.

Skiffing for the reduction of foliage during severe drought is not a common practice and its value also is highly questionable.

Recovery from Heavy Pruning

Heavy cut back to a low height as in medium pruning, makes the bush leafless and brings photosynthetic activities to a complete halt. Respiration continues unremittingly, forcing the bush to depend for its metabolic needs on the carbohydrates stored mainly in the roots upto the time of pruning. A part of the energy derived from the stored carbohydrates is utilised for promoting growth of some of the dormant buds on the pruned stems. The dependence of the bush on the stored carbohydrates lasts so long as the leaves on the newly grown shoots cannot take over the burden of manufacturing its needs.

Gadd (1928) at TRI Sri Lanka first drew attention to the importance of starch reserves in the roots of tea bushes for their recovery following pruning. Extending the enquiry Tubbs (1936; 1937) showed that dieback and death of bushes following pruning in the forcing climate of the low country of Sri Lanka were caused by inadequacy of hydrolysable carbohydrates in the roots (hydrolysed, by 2.25 per cent hydrochloric acid). At elevations of approximately 1000 m and above bushes rarely died after pruning. Analysis showed the roots of those bushes to contain much more total carbohydrates than those of the low-grown bushes. In fact, the carbohydrate contents in the roots of comparable bushes increased at the rate of 2 per cent for every 300 m rise of elevation. The gradual drop of temperature at increassing heights above sea level is worth noting in this connection.

These findings made the tea industry throughout the world conscious of the necessity of building up corbohydrate reserves in the roots before carrying out heavy pruning. In Sri Lanka, the practice of keeping a few branches on each plant unpruned (‘lung’ pruning) till about the time of tipping was soon introduced and resting of bushes for a period before heavy pruning was encouraged. These measures gradually spread to other parts of the world where they are now widely used.

Besides supplementing the carbohydrate resources of the plant, the leaves carried by the lungs help to draw in more water and nutrients into the plant by exerting transpirational pull than by pruned plants devoid of leaves. The lungs, however, are reported to retard the growth of new shoots (Pethiyagoda, 1965). Production of growth retarding substances by the old leaves and banjhi buds may be the cause of growth suppression. The lungs need not be retained after some of the leaves on the newly grown shoots have expanded to full size (See Chapter 10).

Of late Kandiah (1971), on the basis of his studies carried out at TRI Sri Lanka, has advanced the suggestion that the growth of buds from pruned bushes takes place at the expense of carbohydrate resources stored in the stem bark. The root carbohydrates are used locally for the metabolic functions of the roots. However, this proposition fails to account for the growth of new shoots from collar-pruned bushes where the stem bark consists of a very narrow band of tissues and secondly, for the dieback and death of bushes low in root carbohydrates. The stem bark may well be the immediate source of energy for the developing buds but the meagre resources in the bark can hardly be expected to support growth of the new shoots until they become independent of the resources stored in the plant. A state of dynamic equilibrium can be conceived between the resources of the bark and the roots, the latter by a steady flow preventing depletion of the former. Depletion of root carbohydrates during bud break and early growth of shoots on pruned bushes

(Selvendran, 1971; Manivel, 1981) also does not support the absoulte role of bark carbohydrates in the recovery of bushes following pruning.

Medium Pruning

As mentioned earlier, the main purpose of medium pruning is height reduction. Removal of knots, unproductive wood, congestion of the bush frame and its sanitation are the other objectives of cut-back pruning. The maximum permissible height of the plucking table in the plains of N. E. India is 100 cm but recent ergonomic studies have shown that it should be nearer 80 cm for efficient performance of the plucking operation (Venkatakrishnan and Sen, 1981). For the mountain slopes of Darjeeling, the plucking table is normally lower than in the plains. For efficient plucking, the height of the bush there has to be adjusted to the slope of the terrain.

Medium pruning is carried out above the height of the original frame-forming prune. If the farme-forming prune was given at 45 cm, medium pruning can be done at any point above this height. The maximum height for medium pruning is not well-defined although 65 cm is tacitly assumed to be the limit. However, low cut-back prune is generally not preferred since loss of crop in the year of pruning increases in proportion to the thickness of the cuts. Besides, the costs of pruning and protection of the cuts from fungal infection also go up when pruning is done on thick wood. In order to bring the plucking table down to a reasonable height with the minimum loss of crop, lighter forms of cut above 65 cm is often resorted to. This type of pruning is a stop-gap measure which merely postpones medium pruning for a few years. It neither benefits the bush nor improves the economy of an estate in the long run.

In view of the rapid rise in the cost of plucking on the one hand and productivity of tea estates on the other, the ergonomic findings referred to earlier deserve serious consideration throughout the tea areas where plucking is done by hand. Body dimensions of the pluckers determine the optimum height of the plucking table. For pluckers having an average height of 125 cm, 80 cm was found to be the optimum height. Implementation of the ergonomic findings will restrict the height of medium pruning to a maximum of 60 cm although, in practice, pruning will have to be done lower, at 45-50 cm, to restrict the plucking height to 80 cm without having to cut back the bushes at frequent intervals.

A few precautionary measures are necessary before and after medium or any form of heavy pruning to prevent dieback and death of bushes. The bushes must have adequate reserve of carbohydrates in the roots. In N.E. India bushes are thrown out of plucking towards the end of the season in mid October and are cut-back in December after 6 to 8 weeks of 'resting'. Resting normally ensures adequacy of carbohydrates in the roots. At low elevations leaving three-four 'lungs' on a bush will be an additional insurance against carbohydrate starvation during the process of recovery.

Having decided upon the height of the medium prune above ground level, the pruning cuts are made obliquely and polished with a sharp knife so that water cannot adhere to the cut surface. Dead, damaged and diseased branches are removed, if necessary from below the pruning level. All large cuts are covered with a fungicide spray and a protective bituminous paint within a few hours from pruning. In hot climate, heavily pruned bushes are liable to suffer from sunscorch due to removal of the top hamper and exposure of the bush frame to the sun all of a sudden. Damage caused by sun scorch exposes the bush to infection by various organisms causing wood rots. Damage from sunscorch can be reduced by covering the bush frame with the pruning litter immediately after pruning. A lime wash of the frame is also advised as a protective measure against sunscorch (F.R., 1979). If the tea is hidebound and has a history of black rot *(Corticium* spp.) or for that matter of any other fungus like blister blight, a lime and caustic wash immediately after pruning helps. This wash is particularly effective in removing lichens and mosses from the bush frame.

The medium pruned bushes are plucked to a generous tipping measure of 25 to 30 cm. In the following year, the bushes are given a skiff but at the end of the skiffed year, pruning 5 cm above the level of the medium prune is carried out to remove any dead wood and snags. The cut surfaces are polished and treated as before and the tea is brought into the normal pruning cycle.

Cleaning out

This operation is carried out soon after pruning but always before bud-break on the pruned bushes. The operation involves removal of dead, diseased and crossing branches, dwarf banjhi shoots and snags from the pruned bushes. It can be carried to excess by cutting out fringe branches and low-lying laterals arising from the base of the frame and severely thinning out the pruned sticks to 'make room' for those left on the bush. Excessive cleaning out results in drastic reduction of crop and spread of bushes (Cooper, 1932 a).

Bush sanitation is the main purpose of cleaning out. Cleaned out bushes are observed to produce regrowth earlier than those not cleaned out. Although the exact mechanism has not been elucidated, it seems the banjhi buds and mature leaves left on cut-across bushes produce growth inhibiting substances which retard sprouting of new buds. The practice of pulling out dwarf banjhi shoots without using knife, known in N. E. India as 'hand banjhi', stems from this belief. Moderate cleaning out of annually pruned bushes caused slight increase in yield in comparison with bushes not cleaned, but the latter bushes looked healthier at the end of the year (Cooper, 1932 b) due obviously to the photosynthetic activity of the old leaves remaining on them.

Heavy Pruning

Heavy pruning including collar pruning did not persist in N.E. India for long after the First World War, except in the hill district of Darjeeling. However, this system of pruning has been revived in recent years with the sole object of improving the yielding capacity of some old but reasonably good sections of tea to minimise loss of crop during uprooting and replanting of uneconomic sections. Heavy pruning as practised today in N. E. India is, therefore, a part of the package of practices aimed at renovating sections of run-down tea. The entire series of operations goes under the term 'rejuvenation'.

Increasing importance is being paid to the rejuvenation of old sections of tea by the aging tea industries in many parts of the world. In view of its growing importance, rejuvenation is discussed below under a separate head.

MATURE TEA PRUNING IN OTHER COUNTRIES

The systems of mature tea pruning followed by most countries do not differ in principle from those of South India and Sri Lanka. In South India after the final frame-forming prune, the regrowth is tipped for a few rounds and then plucked continuously for the rest of the pruning cycle. The length of the pruning cycle may vary from three to six years, depending on elevation of the place. There is a general tendency to add a year to the pruning cycle for every thousand feet (300 m) rise of elevation. At the end of the pruning cycle, tea is cut back approximately 5 cm above the previous pruning level and then tipped and plucked until the bushes are pruned again. At the end of four or five cycles when the frames reach a height of 60 cm, bushes are pruned down to a height of 35-40 cm.

Essentially the same system of pruning is followed in Sri Lanka, with a tendency for hard cuts and more thorough cleaning out.

Heavy Pruning

Heavy or down-pruning after a few pruning cycles serves the same purpose as medium pruning of N. E. India, although these two operations differ in the severity of the cut. Medium pruning is rarely done below 50 cm while heavy pruning rarely goes above 45 cm. Periodic hard pruning has the advantage of keeping the bush frame clean and free of knots which the light height-reduction prune of N.E. India cannot achieve.

As mentioned earlier, the loss of crop in the year of pruning increases with the severity of the cut. The adverse effect of the heavy cut may persist longer if recovery is slow. The bush has to subsist on the reserve carbohydrate resources for a longer period when recovery is delayed. Heavy pruning exposes the bush frame to the sun all of a sudden. The stems which remained under heavy shade of the top hamper for a number of years get scorched on exposure to the sun and the wounds resulting from scorch attract infection by pathogenic fungi.

The few leaves that may be retained by the pruned bush on low-lying laterals and fringe branches make some contribution to its carbohydrate pool. Very hard pruning or excessive cleaning out deprives the bush of these leaves also. The spread of the bush is restricted at the same time. Drastic pruning and cleaning out has not met with the approval of the scientists at the TRI Sri Lanka either in the past (Tubbs, 1937; 1946) or at present (Kulasegaram and Kathiravetpillai, 1981).

Periodic hard pruning is unavoidable but there is no sound reason for making the operation too drastic. While it is not possible to suggest an optimum pruning height for all situations, the height of the initial frame-forming prune can serve as the best guide. Pruning much below this height and indiscriminate cutting off of leaf-bearing fringe branches do not increase the efficiency of these operations. On the contrary they harm the bushes. Presence of mature leaves may delay bud break but it cannot have any significant effect on yield during the year of heavy pruning when yield remains low in any case. Drastic pruning and cleaning out cannot, however, be avoided in rejuvenating old sections of tea.

Pruning Cycles

In long pruning cycles, pruning should logically be done when yield starts declining. This is not always possible due to a number of practical difficulties. Sometimes early pruning becomes necessary owing to excessive rise of the plucking table or production of a large number of small and banjhi shoots. Too many small and banjhi shoots increase the cost of plucking besides having adverse effect on the quality of made tea. Yield decline sets in early in the cycle in weak sections of tea irrespective of whether the cause of weakness is genetical, environmental or cultural. Loss of vigour is accompanied by the production of too many small and banjhi shoots. In contrast, rapid growth limits the length of pruning cycles in vigorous tea. In vigorous tea under favourable growth conditions stems thicken up rapidly. Pruning of such tea cannot be delayed until yield starts declining. If pruning is delayed, then stems at the normal pruning height of approximately 5 cm above the previous cut becomes much too thick. Raising of the height of pruning to avoid cutting very thick stems causes rapid increase of frame height, requiring heavy pruning at shorter intervals. Competition between strong and weak branches is another factor which militates against long pruning cycles. Weaker branches which would have survived in a shorter cycle get killed when the cycle is prolonged.

Differential response of clones to long and short pruning cycles has also come to light. It appears that some clones do not respond favourably to long pruning cycles. (TES Ann. Rep., 1970-71).

In cold climate where regrowth is slow and loss of crop in the pruned year is very heavy, it often pays to defer pruning by a year or two even after the yield shows a downward trend.

Pruning of each section of tea in an estate has to be decided on merit. A pruning cycle of fixed duration for all sections is not conducive to crop maximisation. Furthermore, agronomic, management and economic considerations require from time to time variation in the length of pruning cycles of different sections of tea within an estate.

REJUVENATION

The term rejuvenation implies restoration of young age which is possible only by removing the inhibition of old age. Some of the ill effects which ageing produces on a section of tea are: (a) increase in the number of vacancies due to death of the weaker bushes (b) incidence at an accelerating rate of diseases affecting the top and the roots, causing debility and death of bushes, (c) depletion of soil nutrients due to removal by crop and prunings and loss from leaching, in addition to the large quantities that remain locked up in the permanent parts of tea bushes and shade trees and (d) increase in the proportion of unproductive tissues. All brown itssues on a plant may be regarded as unproductive. They merely serve as channels for conduction of water, organic and inorganic chemicals from one part of the plant body to another. As the unproductive load increases with age, more and more of the assimilates produced by the green tissues and nutrients absorbed by roots are diverted to support this load. To that extent the production of crop suffers.

Purpose

Rejuvenation aims at improving the yielding capacity of some of the old sections of tea by arresting their deterioration. In practice this is accomplished by (a) removing as much of the unproductive bush frame as possible by pruning at a low height. (The unproductive root tissues unfortunately have to be left behind), (b) thorough cleaning out of the remaining portion of the bush of all diseased and damaged parts, (c) creating conditions favourable for quick regrowth of shoots and absorbing roots and (d) restoring stand density by infilling.

Selection of Sections

As the types of tea, their yields, incidence of diseases and pests, location, soil condition etc. vary widely not only between estates within a locality but also from section to section within an estate, it is possible only to indicate the broad principles on which selection of sections for rejuvenation may be based. Economics and estate policy which also can play a significant role in the choice of sections are not included in this purview.

Sections due for uprooting in the next 10-15 years should not be considered for rejuvenation. Among the rest, the sections that would be amenable to rejuvenation should be selected in order of priority. The broad criteria for selection are : (a) The sections should not be affected by primary root diseases although isolated infection of a few bushes need not debar a section from selection if the disease can be eradicated well in advance of heavy pruning. (b) Rejuvenation may not succeed if the soil is very shallow or too sandy and the area is prone ot recurrent drought. (c) Unless drainage can be improved, waterlogged sections should not be selected for rejuvenation. (d) Sections with more than 30 per cent vacancy should not normally be chosen if the number of bushes suffering from stem diseases like *Poria, Aglospora, Hypoxylon* etc. also happen to exceed this number. (e) Recovery potential of the bushes from heavy pruning is an important factor in the choice of a section. Chinery and hybrid *jats* can stand hard pruning better than bushes of the Assam kind.

Planning for Rejuvenation

Having identified the sections for rejuvenation in order of priority, it is necessary to plan ahead for the actual field operations. Eastablishment of nursery with elite planting material to be subsequently used for infilling, planting of nursery with shade tree species where necessary and removal of old shade trees have to be done in advance. The success of the whole operation depends largely on forward planning and execution of various operations on a preset time schedule.

Field Operations

If removal of the old shade trees is considered necessary, these should be ring-barked at least two years ahead of pruning of the tea bushes. The trees should be felled and removed with stumps just before the pruning operation. Where digging up of the tree stumps is not possible, these should be cut down at a depth of 20 to 30 cm below the ground level and then covered with earth.

As a precuationary measure, it is useful to test the recovery potential of sections planted with the Assam *jats* of tea. This can be done by pruning samples of bushes two years before the scheduled time of pruning the entire section.

It would be a wrong policy to discontinue manuring of the section but in the year of pruning, fertilisers should be applied five to six months ahead of pruning. Prior to pruning, the section should be rested for a time to build up carbohydrate resources. However, the period of rest and the time of pruning have to be adjusted to the climatic conditions of the locality as in normal pruning operations.

The bushes are then cut back at a general height, leaving three-four lungs per bush. The pruning height will normally lie between 20 and 40 cm. Leaving of lungs is not considered necessary at higher elevations of South India (Venkata Ram, 1976), but this may not be applicable to all localities. The necessity of a period of rest and keeping of lungs on the pruned bushes should be decided by examining the carbohydrate resources in the roots.

In the next phase of the operation, each bush is cleaned out thoroughly on individual merit, cutting out dead and dying branches down to healthy wood. In some cases cleaning out may involve cutting down to the collar region and scooping out dead tissues from the junction of branches near the collar. Cavities may sometimes be formed in the bole of the plant as a result of cleaning. It has been claimed from South India that filling up of such cavities with cement mortar after painting the wound with a slurry of copper sulphate and linseed oil did not affect recovery of the bushes (Venkata Ram, *loc. cit.)*.

To prevent removal of leaves and softer parts of prunings from the fields along with the woody stems, it is worth skiffing the bushes before heavy pruning.

After completing the pruning and cleaning out operations, all dead and moribund bushes are dug up and removed from site. Drainage and terraces, where present, are improved and soil conservation measures undertaken according to necessity. The ground is then levelled in preparation for planting supplies.

The procedure for infilling and treatment of infills are described in Chapter 8. In widely spaced fields on flat or gently sloping terrain, it may be possible, besides infilling, to interplant another row of supplies between every two alternate rows of old bushes. Interplanting has proved more profitable in N. E. India than infilling alone. Where necessasry shade trees are planted at the same time as the supplies. Conditions permitting, bush crops like *Crotalaria* may be grown in the initial years for temporary shade. Rejuvenated sections are treated as newly planted fields of tea in respect of manuring and control of diseases, pests and weeds.

REJUVENATION AND REPLANTING

From available accounts (Venkata Ram, 1974), .rejuvenation has proved to be a success in South India. According to report from N. E. India, normal rejuvenation and rejuvenation with interplanting raised yields by 24 and 47 per cent, respectively, in the seventh year from heavy pruning (Sarkar, 1981). Rejuvenation pruning after 40-50 years from planting has become a standard practice in the U.S.S.R. After about 5 years from pruning, on an average 10 per cent higher yield than the yield level prior to rejuvenation is easily achieved (Dey, 1972). Thus, rejuvenation has been effective in halting the deterioration of old sections of tea and raising their pruductivity. The payback period for rejuvenation has also been found to be less than that of replanting (TES Ann. Rep., 1981-82). However, many replanted sections of tea in N. E. India have produced 25 q or more tea per hectare in the third year and yields of some of the sections are expected to rise to 50 q or more at maturity. Yields of this order cannot be anticipated from rejuvenated sections of seed-grown tea even with interplanting. Besides, rejuvenated sections are unlikely to remain economically viable for long because of the presence of old bushes and planting of supplies among them on unrehabilitated soil. However, rejuvenation can still serve the useful purpose of bolstering temporarily the economy of a tea estate while uneconomic sections are uprooted and replanted. To that extent it can be an important adjunct to extension planting and replanting in the long-term plan of development of tea estates.

PRUNING SURFACE

With rare exceptions, tea is pruned to a flat surface which, on level ground, is kept parallel to the ground surface. The same type of pruning is generally carried out on bushes on gentle slopes but not universally. On gentle slopes upto a gradient of about 30°, pruning parallel to the ground surface or slope pruning has many advantages. In sloping terrain, slope-pruning is more convenient than pruning stepwise. Slope-pruned bushes provide better ground coverage. Since plucking of such bushes is also done parallel to the slope, supervision becomes easier. Spraying operations in tea plucked to the slope can also be carried out appropriately.

On steep slopes, planting is usually done on terraces where the question of slope-pruning does not arise. In the absence of terraces, slope pruning on land at very steep gradient is not practicable.

Mechanical Pruning

Mechanical pruning would appear to have better prospect than mechincal plucking since pruning does not have to be selective. Nonetheless, mechanisation of pruning poses many problems. Light and portable tools like shears cannot be used for pruning thick and hard stems although skiffing is possible with such mechnical aids. What is required for pruning is a sturdy, self-propelled machine equipped with proper cutting heads and capable of moving freely inside tea fields. Such machines are operating in the tea areas of the U.S.S.R. These multipurpose machines have been used for pruning, plucking, spraying and applying fertilisers.

A machine moving on its own traction was designed at Tocklai during 1955 (Mc Tear, 1956),primarily for the purpose of plucking: but by replacing the plucking head with cutting attachment, the same machine could be used for pruning (Mc Tear, 1958). The prototype was used successfully for pruning mature tea although its performance as a plucking machine was not very satisfactory in the early trials. Besides, movement of the machine was restricted by the presence of shade trees and drains. For these and other non-technical reasons, work on the machine was unfortunately abandoned.

From experience gained during the trial of the machine, topography appeared to be the major constraint for proper functioning of a self-propelled pruning/plucking machine. Such a machine cannot be made to operate successfully on steep slopes, broken up terrain and land traversed by many drains. This still leaves many tea areas where such machines could be profitably used as has been done in the U.S.S.R.

VISUAL METHOD FOR RATING ROOT STARCH

Quantitative determination of carbohydrates in tea roots is possible only in a laboratory equipped for the purpose, but a rough estimate of the amount of starch present in roots can be made by a simple, visual method, taking advantage of the colour change produced in starch by a solution of iodine.

In this method, iodine solution is applied to cut ends of roots and the quantity of starch present in the root is rated visually from the depth and spread of the blue starch-idodine colouration. In the absence of starch, the root does not change colour while a deep blue colour spread over the entire cross section of the root indicating high concentration of starch. With experience a number of intergrades can be distinguished between these two extremes, both in intensity and spread of colour.

The iodine solution is prepared by weighing one gram of iodine and one gram of potassium iodide into a glass beaker, adding 1 to 2 ml of distilled water and shaking the container gently. When the iodine dissolves completely, the volume is made up to 100 ml with distilled water. The iodine solution should be kept away from light in a dark-coloured bottle.

For the measurement of starch in the roots of young plant, a 10-15 cm deep hole is dug at a distance of approximately 10 cm from the collar and any root with a minimum diameter of 5 mm is severed from the plant. A drop or two of iodine solution is applied to the smoothly cut surface of the piece of root by holding it upright. The root is kept in that position for about five minutes after which the iodine solution is shaken off and the change of colour noted. The same procedure is used for rating root starch in mature plants. In the case of mature plants, the root samples need not be drawn so close to the collar.

For comparing starch contents of different samples, the roots should be approximately of the same thickness.

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CHAPTER 10

PLUCKING

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PLUCKING TERMINOLOGY

To avoid confusion, it is necessary to define the terms used in this and other chapters in connection with plucking. These are:

Sticks: The branches left on a pruned bush are the sticks.

Primaries: The shoots growing out of the sticks are the primaries.

Laterals: The branches of the primaries are the laterals of the first order. When the first order laterals are plucked, they give rise to laterals of the second order which in turn produce laterals of the third order. In this way upto 10 orders of laterals can be produced in a year where plucking is not seasonal. In N.E. India a maximum of 8 orders of laterals are produced in a plucking season.

Stubs: The basal portions of shoots left behind on the bush after harvesting of the apical portions are known as stubs.

Maintenance leaves: All mature leaves, including fish leaves, left on the bush below the plucking surface are the maintenance leaves.

Tipping: When the primaries grow above a predetermined height, they are decapitated or tipped at that height parallel to the ground surface. Exceptions are there as in Japan, where tipping is done in the form of a hemisphere.

Plucking: Plucking in tea is synonymous with harvesting in other crops. The tender apical portions of shoots consisting of two to three leaves and the terminal buds are nipped off in plucking. The young shoots are used for the manufacture of tea.

Plucking systems: Shoots may be plucked above: (a) basal janams, (b) janams and fish leaves and (c) janams, fish leaves and a single foliage leaf. These three systems (a), (b) and (c) are respectively known as janam plucking, fish-leaf plucking and plucking to a leaf or single-leaf plucking.

Breaking back: This is an operation in which leaves and stubs which stick above the plucking table are broken back to level off the plucking surface. Some of these terms are illustrated in Fig. 23.

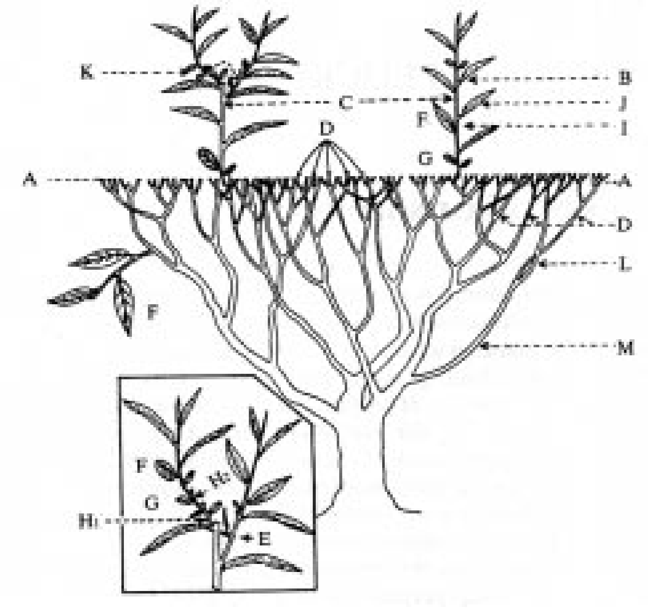

Fig. 23. Diagrammatic representation of a pruned and plucked tea bush of North East India. A-A, last pruning height, B, tipping level, C, primary shoots, D, sticks, E, stubs, F, maintenance foliage, G, cataphylls, H_1 and H_2 of the inset respectively, first and second order laterals. Levels of Deep skiff I, Medium skiff J and Light skiff K. L and M indicate the approximate positions of medium and heavy pruning (After Barua, 1961).

ROLE OF MAINTENANCE LEAVES

The capacity for photosynthesis develops gradually in young, expanding leaves of tea and a leaf does not attain full photosynthetic efficiency until it expands to more than half its maximum size (Barua, 1953; 1960 b). Even the third leaf on a growing shoot is photosynthetically less efficient than a mature leaf of equal size (Barua, *loc. cit.;* Sanderson and Sivapalan, 1966 a). Hence the young shoots on a tea bush develop at the expense of photosynthates produced by the maintenance foliage. The young, expanding leaves gradually take up the burden of manufacturing their own needs and in due course, they pass from being liabilities to becoming assets to the plant. However, the shoots are plucked at such a tender age that the young leaves do not get chance for outliving their dependence on the metabolites supplied by the maintenance foliage. It follows that plucking of the tender shoots deprives the bush of return for the material expended in their production.

Besides supplying food matter for the growth of successive crops of pluckable shoots, the maintenance leaf canopy is required to cater to the metabolic needs of other plant organs and put aside sufficient reserves to see the bush through the leafless period after pruning. The health and productivity of a tea bush, therefore, depends on the size and efficiency of the maintenance leaf canopy. Defoliation of a part of the leaf canopy reduced not only shoot yield (Barua, 1960a) but also the total amount of dry matter produced by the bush as reflected in the decrease of stem girth (TES Ann. Rep., 1983-84). Reduction of maintenance leaf area either by pests, diseases and drought or by low tipping followed by hard plucking produces a highly debilitating effect on the bush.

It has earlier been mentioned that the maximum life-span of a tea leaf on a tipped primary is 18 months. The peak photosynthetic efficiency of a leaf lasts for about six months after full expansion. Thereafter, the capacity for photosynthesis gradually declines but the aging leaf still retains some activity until its abscission (TES Ann. Rep., 1981-82). The fish leaf is photosynthetically more active than a foliage leaf (Manivel and Hussain, 1982). Despite their small size, the contribution of fish leaves to the carbohydrate pool of a tea bush could be quite substantial.

The top layer of maintenance foliage makes the maximum contribution towards the growth of new shoots (Manivel, 1980), which is consistent with the observation made by Sanderson and Sivapalan (1966 b) that an axillary shoot gets the major fraction of its nourishment from the subtending leaf. Photosynthesis declines from the top to the bottom layers of maintenance foliage due to obstruction to the passage of light through the canopy. The contribution made by the lower layers of maintenance foliage to the carbohydrate pool of the tea bush is accordingly reduced.

In Sri Lanka, Sanderson and Sivapalan (1966 b) observed only downward movement of photosynthates from the lower leaves of the maintenance canopy, while Manivel (1980) and Manivel and Hussain (1982) reported that even the fifth leaf on a primary contributed to the growth of new shoots during the main growing season of N.E. India. The direction of movement of .photosynthates reversed with the advent of the dormant season. These seemingly contradictory findings are mere reflections of two different states of production and utilisation of carbohydrates by a tea bush.

Source and Sink

The canopy of maintenance foliage is the 'source' of carbohydrates and the proliferating and expanding organs of the plant are the 'sinks' or the sites for their utilisation. The products of photosynthesis move from the source to the sinks. Radio-tracer studies have shown that the successive crops of shoots developing at the plucking table are the strongest sinks on a plucked tea bush (TES Ann. Rep., 1978-79). Within the shoot, the growing bud is the strongest sink. Sink capacity drops to 70 per cent of the bud in the first leaf below the bud, to 40 per cent in the second leaf below and 30 per cent in the third leaf (TES Ann. Rep., 1983-84). Tanton (1979) made the suggestion that sink capacity in tea could be enlarged by harvesting 3 + bud instead of 2 + bud shoots. This suggestion appears to have overlooked that the third leaf on a growing shoot is old enough to produce more than 50 per cent of the photosynthates required for its own development. Sink capacity is increased by inducing the growth of more shoots.

Carbohydrates produced by all the leaves of a maintenance canopy are primarily mobilised for the growth of shoots. If the top layers of the maintenance foliage can produce enough carbohydrates to satisfy the demand of the gowing shoots, then the photosynthates produced by the lower layers of foliage are spared to move downwards to the roots.

Thus the quantity produced by the source and their utilisation by various sinks at any particular time determine the directions of movement of photosynthates. Translocation of photosynthates simultaneously to the shoots and the roots as observed in Sri Lanka may happen elsewhere. Similarly, unidirectional movement of assimilates towards the plucking table is possible in the tea bushes of Sri Lanka and other places if the quantity produced is insufficient to meet the requirement of the growing shoots.

The products of photosynthesis do not move from one mature leaf of the maintenance canopy to another (Sanderson and Sivapalan, 1966 b). Confirming and extending these findings Manivel (1980) showed that photosynthates from the neighbouring leaves did not move into a leaf kept in complete darkness for a month. Thus, the mature leaves do not become boarders on the tea plant when they become old.

The size of the maintenance leaf canopy is expressed in terms of leaf area index (LAI) which is the ratio of total leaf area of a bush to the ground area allocated to it. A stand of tea will have an average LAI of 5, if the total area of its maintenance foliage is five times the area of the plot of land on which it grows. Maintenance leaf area is affected by the kind of plant and cultural treatments like pruning, plucking, manuring, shade etc. Dry condition of the soil and high temperature cause scorch and defoliation of leaves reducing LAI. Attacks by pests and diseases can likewise reduce LAI. Dry matter production in relation to LAI will be discussed in Chapter 11.

Plucking Systems

The most exacting system of plucking is the janam plucking which precludes the formation of any foliage leaf above the tipping level. This system of plucking in conjunction with annual light pruning was the standard practice in N.E. India since the early days of the tea industry. Large number of trials carried out on annually pruned bushes invariably proved the superiority of janam plucking and emphasised the importance of tipping height from the point of productivity of a tea bush. A tipping height of 20 cm became the norm for bushes of the Assam kind, 15 cm for hybrids and 10 cm for the China and China-hybrid bushes grown in the Darjeeling district. Detailed studies conducted later at Tocklai on a mature Assam clone growing in the open shifted the emphasis from metric tipping measures to the number of leaves left on the bush at tipping. The bush gained in health and vigour as the average number of leaves on a primary increased from 2.7 to 8.5 along with the rise of the tipping height from 5 cm to 35 cm. The number of primaries decreased and the weight of shoots harvested off each primary increased with the rise of the tipping height. The weight of crop harvested from a bush being the product of the number of primaries and yield per primary, the maximum crop was harvested at an intermediate tipping height which, under coanditions of the trial, was 15 cm above pruning level, coinciding with the model height of dormancy of the first flush. At this tipping height, each primary had an average of five foliage leaves. Thus, increased vigour associated with the rise of the tipping height is conducive to yield but only upto a point, above which yield declines due primarily to reduction in the number of primaries. As a sequel to these findings, a tipping measure of five leaves became the standard practice for all kinds of tea in N.E. India.

The trial also revealed some other important growth characteristics of the tea bush as shown in Table 39.

Top growth i.e. the combined weights of plucked shoots and prunings increased in proportion to the number of maintenance leaves on a primary, the maximum top-growth in terms of prunings being made by the unplucked bushes. The porportion of plucked shoots in top growth decreased from 66 per cent at 5 cm to 31 per cent at 35 cm tipping measures. That the bush throws up more primary shoots to make up for the deficiency of maintenance foliage is also seen from these results.

Diameter of old stems and current year's primaries and the average weight of two and a bud shoots increased along with the rise of the tipping height. The number of banjhi shoots harvested in the course of the year showed the reverse trend. Shoot weight was positively and closely correlated with stem diameter showing that thicker stems produced heavier shoots. Gradual decrease of shoot weight at increasing age from pruning and production of small shoots by light-skiffed bushes can be inferred from this relationship. The laterals get progressively thinner at each succeeding order of branching and in continuous plucking, the order of branches goes on increasing from one pruning operation to the next. In consequence, shoots of all genotypes continue to get lighter.

Increase of the order of branching is a natural process on plucked bushes. Since this process cannot be altered, some loss of shoot weight along with the progress of plucking is inevitable. However, the overall size of shoots characteristic of a genotype and their number can be maintained at high levels, if the vigour of the bush can be ensured. Despite proper cultural treatments, bushes cannot be kept in a state of vigour unless the maintenance canopy is of 'adequate' size. Unfortunately, what is an adequate canopy has not yet been satisfactorily determined in N.E. India for bushes plucked to the janam under longer pruning cycles. What follows will show that the position is no better in regions where the other two systems of plucking are in vogue.

Fish-leaf and Single-leaf Plucking

Outside N.E. India, fish-leaf and single-leaf plucking are the normal practice. In actual operation, plucking is usually a mixture of these two systems. From a recent report by Wettasinghe *et al.* (1981), it appears that the proportion of shoots plucked to fish leaf in Sri Lanka may be as high as 75 per cent, the balance being plucked to the first foliage leaf. However, this proportion is unlikely to remain constant. In fact, it may well vary from one plucking round to another even within the same field of tea. In South India shoots are generally plucked above fish leaves but the plucking table is raised two to three times in a year to add fresh foliage to the maintemmce leaf canopy.

Comparison of fish-leaf and single-leaf plucking made in Sri Lanka showed large gain in yield from fish-leaf plucking during the early years of the first three-year pruning cycle (Eden, 1949), but yield dropped by 10 to 30 per cent from the second to the fourth

Table 39. Effect of variation of tipping height on annually pruned bushes plucked to janam (After Barua and Weight, 1959; Barua, 1961)

Tipping height in cm	Average no.of leaves per primary	No of primaries plucked per bush	Fresh weight of plucked shoots per bush in kg	Fresh weight of top-growth per bush in kg	Plucking weight as per cent top growth	Average diameter of primaries at the base in mm	Per cent increase of diameter of permanent stems in 9 months	Average fresh weight of 2+ bud shoots in mg
5	2.7	219	2.24	3.40	66	4,7	4.4	387
10	3.8	178	2.46	4.20	58	5.2	4.8	389
15	5.0	162	2.91	5.78	50	5.8	6.3	436
20	5.8	138	2.48	5.48	45	5.9	6.8	429
25	6,9	136	2.66	6.42	42	6.2	6.9	467
30	7.6	118	2.53	7.25	35	6.6	8.0	477
35	8.5	88	2.08	6.64	31	6.9	9.0	507
Unplucked				9.36		6.3	9.7	

cycle. What is more striking is the large drop, by about 70 per cent, in the weight of maintenance foliage and pruned wood by the end of the fourth cycle in the plots plucked to the fish leaf (Portsmouth, 1953). Visser (1960) reviewing the same experiment for all the six cycles reported 16 and 8 per cent gain in the weight of plucked shoots from fish-leaf plucking in the fifth and the sixth cycles, respectively, following doubling of the dose of potash from 22 to 44 kg ha^{-1} and removal of heavy *Albizzia* shade. However, pruning weight did not improve and remained below 30 per cent of the single-leaf plucked plots. When fish-leaf plucking in one cycle was followed by single-leaf plucking in the next, the bush almost completely recovered from the ill-effects of the previous treatment in the production of maintenance foliage and wood but shoot yield dropped by about 40 per cent. Change over from single-leaf to fish-leaf plucking reduced the growth of prunings again by 60-70 per cent but crop yield increased by 30-40 per cent. From this and other experiments, Visser *(loc. cit.)* came to the conclusion that continuous fish-leaf plucking was harmful for the tea bushes of Sri Lanka. He advocated limited fish-leaf plucking in which bushes were to be plucked to a leaf in the early part of a pruning cycle to be followed by fish-leaf plucking. He advocated resting of such bushes for a few months before pruning.

Recently Wettasinghe *et al*. *(loc. cit.)* in Sri Lanka had advocated hard plucking for short periods. This recommendation was based on a trial conducted only for two years which obviously was too early for any recommendation. Nevertheless, the trial revealed the interesting fact that even janam plucking caused much less reduction of pruning weight of the young bushes of a vigorous clone than fish-leaf plucking did in mature seed-grown bushes of the previous trials. This indicates that vigorous bushes can withstand hard plucking for a longer period than weaker bushes.

Higher yield obtained from bushes plucked to the fish leaf was attributed by Visser mainly to two factors. In the single-leaf system, an extra leaf had to be produced by the shoot before it became ready for plucking. This delayed the plucking operation causing approximately 10 per cent loss, of crop. The other factor was more important. Only one lateral shoot developed from the axil of the foliage leaf left behind on the stub of a plucked shoot while in fish-leaf plucking, apart from the buds in the axil ofthe topmost fish leaf, some buds in the axils of lower fish leaves and janams developed into pluckable shoots. Visser estimated 80 per cent increase in the number of shoots on bushes plucked to the fish leaf in comparison with those plucked to the foliage leaf. Yield did not increase to the same extent partly due to reduction in the weight of individual shoots plucked to the fish leaf.

Plucking System and Shoot Growth

The profound effect of plucking systems on shoot multiplication is evident from the trial just cited. In single-leaf plucking, the stub of every plucked shoot carries usually three to four dormant buds, each one of which is capable of developing into a crop shoot. Out of these, only the bud in the axil of the foliage leaf just below the point of plucking develops into a pluckable shoot, the other two or more dormant buds do not usually produce any growth. This means that less than 30 per cent of the buds at the plucking table are stimulated into shoot production in the single-leaf system of plucking.

When plucking is done to the fish leaf, the stub carries usually three dormant buds out of which the bud in the axil of the topmost fish leaf and, in addition, some buds in the axils of janams below the fish leaf develop into crop shoots. The proportion of janam-axil buds that grow into pluckable shoots is, however, variable. Initially about 50 per cent of the buds may be stimulated to grow by the fish-leaf system of plucking, although their number is bound to decrease with the progress of plucking.

Janam plucking leaves normally two dormant buds on the stubs. In the experiment the results of which are partly reported in Table 39, plucking of the first order lateral stimulated the growth of both the janam-axil buds to pluckable shoots. If this rate of shoot multiplication were maintained, there ought to have been four shoots of the third order and eight of the fourth order and so on. However, the figures for relative frequency and rate of multiplication of shoots at the plucking table from successive orders of laterals, given in Table 40, show that the expected rate was far from being maiantained.

Table 40. Relative frequencies of shoots of different orders and the rate of shoot multiplication (After Barua, 1961)

Order of shoot	Average relative frequency	Rate of shoot multiplication
1st order	1.00	
2nd order	2.06	2.0
3rd order	3.03	1.5
4th order	3.49	1.2
5th order	2.70	0.8
6th order	1.17	0.4
7th order	0.23	0.2
8th order	0.02	0.1

Frequencies and multiplication rates are the average of all the seven tipping treatments tried out in the experiment. The number of buds which failed to grow went on increasing and some of the dormant buds died before the end of the plucking season. The falling rate of shoot multiplication cannot be attributed to adverse conditions of growth, at least upto the production of the 5th order lateral, since these were formed during the main growing season of N.E. India from May to September.

It is seen that non-growing buds continue to accumulate on the bush after every round of plucking. Fish-leaf plucking stimulates the growth of more dormant buds than single-leaf plucking. Janam plucking induces growth of the maximum number of buds initially but the high rate of shoot multiplication is not maintained; it declines after a time. How soon the decline sets in depends on health and vigour of the bush and climatic conditions. Experiments on janam and fish-leaf plucking just described point to increasing competition for assimilates between buds to be the cause of declining rate of shoot multiplication. Under adverse conditions, water and nutrients may not be adequate to meet the demand of more than a limited number of developing shoots, but to what extent this latter factor inhibits shoot growth under favourable growing conditions is not known.

In single-leaf plucking, insufficiency of assimilates does not appear to be the factor limiting shoot multiplication. In this system the stimulus of plucking does not extend below the leaf over which the shoot is plucked. As a result only one shoot grows out of each stub as already pointed out. Huxley (1975) in East Africa .and Tanton (1979) in Central Africa, where single-leaf plucking is followed, had also argued that shoot growth in these regions was limited by sink capacity. Since sink capacity is increased by hard plucking, a mixed system of single-leaf and fish-leaf plucking should be more productive under such situations. As mentioned earlier, continuous fish-leaf plucking under the existing methods of pruning and tipping led to inadequacy of maintenance foliage resulting in debility of tea bushes in Sri Lanka. This situation can be avoided by plucking a certain percentage of the shoots over foliage leaves but its practicability needs examination.

In the absence of objective criteria, it is not possible to correctly regulate the proportion of shoots to be plucked to fish leaf or to single leaf. Plucking to a pre-set proportion will not meet the need of bushes differing in genetical constitution, age, health and vigour. Simple, easily recognisable criteria like shoot size, stem girth, production of banjhi shoots etc. could be devised for regulating the proportion of shoots to be plucked over fish leaf and foliage leaf.

In janam plucking as followed in N.E. India on bushes pruned annually, adequacy of maintenance foliage was ensured by regulating the tipping height. After the introduction of longer pruning cycles by incorporating various forms of skiff, the position has totally changed. At present plucking is continued at the same level following light skiff and unpruned, sometimes for as long as two years, raising the plucking level by a leaf once in a year as a safeguard against depletion of maintenance foliage. We have already expressed doubt on the efficacy of this treatment. The practice of janam plucking *vis-a-vis* skiffing, particularly the lighter forms of skiff, seems to need a fresh look. Raising of the plucking level should be based on objective criteria just mentioned.

PLUCKING ROUND

Plucking round is the interval in days between successive plucking operations. It has varied from 4 to 14 days although 7-day round is the most common. Plucking should logically be adjusted to the time interval between unfolding of successive leaves on a growing shoot. This interval is known as leaf period or phyllochron. If the leaf period is four days, then a 1 + bud shoot of today will be 2 + bud within the next four days and 3+bud within eight days.

For harvesting the maximum number of 2+bud growing shoots, Wight (1932) suggested a plucking round equal to the leaf period, since all growing shoots with one unfolded leaf (1 + bud) are usually left behind on the bush at the time of plucking. During the main growing season of N.E. India, Wight observed a mean leaf period of four to five days in populations of seed-grown tea, with the mode nearer to four than to five days. Plucking at such short intervals being impracticable for most estates, he suggested as the next best alternative a plucking round of 7 days, based on the formula of a day less than twice the leaf period (2 x leaf period-I). He argued that the harvests from such a plucking round would still consist of a large majority of 2 + bud shoots which was found to be true in later experiments.

Leaf period varies from place to place as well as within the same locality at different times of the year if the climate happens to be seasonal. The mean leaf period was observed to be 9 days at St. Coombs, Sri Lanka (Portsmouth and Rajiah, 1957) and 9-10 days in Java (Harler, 1975). The variation is caused mainly by temperature differences. During the mid summer month of June when the mean maximum temperature was 32°and the minimum 25°C, the average leaf periods of 12 vegetative clones growing at Tocklai was 5.0 ± 0.4 days, which rose to 8.0 ± 0.8 days in November when the maximum and minimum temperatures dropped to 27° and 16°C, respectively (Das, 1984). Not only leaf period but the whole process of growth and development of a dormant axillary bud into a pluckable shoot is affected by temperature (Table 41).

The implication is clear that for harvesting maximum number of shoots of good quality, plucking round needs adjustment to the leaf period prevailing at any particular time since it becomes short under high and long under low ambient temperatures. However, there is another factor which affects leaf period. Under the same set

Table 41. Time taken by dormant axillary buds to develop into 2 + bud shoots

Region and elevation	Time of the year	Range of monthly mean temperature in °C		Weeks from last plucking to become 2 + bud shoots	Source
		Max.	Min.		
Brahmaputra Valley, N. E. India (70-150m)	April-September (Main growing season)	28-32	19-25	5-6	TES Ann. Rep., 1963.
Mlanje, Malawi (600-900m)	Dec.-April (Main growing season)	27-30	16-20	5-6	Tanton, 1982.
St. Coombs, Sri Lanka (1370 m)	Whole year	21-28	11-17	10-12	Portsmouth and Rajiah, 1957.
Kericho, Kenya (2200 m)	Whole year	21-26	7-12	10-14	Tanton, 1982.

of environmental conditions, leaf periods differed from clone to clone. One of the 12 clones used by Das *(loc. cit.)* in his trial had a leaf-period of 3.2 days in June as against 6.3 days of another clone. By November these values increased to 6.2 and 7.6 days, respectively. This means that the plucking round should be decided separately for each clone to avoid loss of crop. Experimental results as shown in Table 42 corroborate this

Four clones were plucked on 3, 5, 7, 9 and 14-day rounds. Shoots bigger than 2+bud were broken back above the third leaf and the broken back portions were weighed separately. Banjhi shoots with single leaf were weighed in with the 2+ bud portions and the double banjhies with the broken back portions. Results pertaining to two clones are given in the table to illustrate the significant interaction of plucking rounds on the yield pattern of different clones (TES Ann. Rep., 1970-71).

In clone A, the maximum weight of the finer fraction of shoots was harvested on 7-day rounds while 5-day rounds gave the highest crop in the other clone B. These two were among the 12 clones used by Das *(loc. cit.)* for his trial where the China clone B had the shortest leaf period.

At the optimal rounds, the coarser (larger than 2+bud) components of the crop accounted for less than 15 per cent. It went up sharply as the length of the plucking round was increased to 9 and then to 14 days. In one of the two clones, the gross weight of harvest did not increase at the longer plucking rounds. It did increase in the other clone but the difference between 9- and 14-day rounds was only 5 per cent.

Some of the 1+bud shoots left behind on the bush at the time of plucking unfold another leaf in the course of the next 24 hours and become 2+bud shoots. Some 2+bud shoots can, therefore, be plucked off a tea bush everyday. When daily plucking was tried at Tocklai, it reduced crop to less than that of the normal 7-day round (TES Ann. Rep., 1969-70). In this experiment where several plucking rounds were tried, the maximum gross weight was harvested in 10 than in 14-day rounds. A similar observation was made also in Malawi (TRFCA Ann. Rep., 1968-69)

In clonal tea, shoots of pre-set standard can be anticipated from plucking rounds based on the leaf period of individual clone. In seed-grown tea, plucking round worked out on the mean leaf period of the population will produce a coarser than the anticipated standard of leaf, because upto 50 per cent of the bushes will have leaf periods shorter than the population mean. Even so, mean leaf period would be a more sensible guide for working out plucking round of seedling tea than fixing it arbitrarily.

The limited information available on plucking rounds leads to the following interpretations :

a) The optimal plucking round differs from clone to clone and presumably between populations of seed-grown tea.

Table 42. Grams fresh weight of shoots harvested per square metre of bush surface year^{-1}

Plucking round in days	Times plucked	Clone A				Clone B			
		Wt.of 2 + bud and smaller shoots	Per cent of maximum	Gross wt. of harvest	Per cent of maximum	Wt.of 2 + bud and smaller shoots	Per cent of maximum	Gross wt. of harvest	Per cent of maximum
3	74	2133	88	2135	77	1437	90	1603	66
5	45	2009	83	2097	76	1624	100	1811	75
7	32	2409	100	2736	100	1207	74	1468	61
9	25	2075	86	2567	94	1499	92	2287	95
14	16	1575	65	2482	90	1179	72	2399	100

b) Climatic conditions of which temperature appears to be the main factor influence plucking rounds. Plucking rounds should be short under high and long under low temperature.

c) Plucking rounds of shorter duration than the optimal reduce crop.

d) Subject to an upper limit, longer plucking rounds may increase the gross weight of harvest but it will contain a high proportion of coarser shoot components.

e) Adjustment to leaf period is the only rational method for working out the most suitable plucking round. Plucking round so determined can give the maximum return in terms of both crop and quality.

It may not be practicable to switch over from one plucking round to another according to changing growth rate of shoots. In order to maintain a reasonable standard in the harvested leaf despite changing growth rates, a somewhat shorter than the optimal plucking round would be desirable.

Long plucking round is not the only cause of coarse leaf. Shoots left behind on the bush at plucking time determine the nature of the shoots that will be available for plucking at the next round. For instance 2+bud shoots left unplucked will be 3+bud within one and 4+bud within two leaf periods. Some shoots will undoubtedly go banjhi before reaching the three or four leaf stage. In that event, even a short plucking round equal to one leaf period will produce a large majority of 3+ bud shoots and a higher proportion of banjhies. The act of plucking is, therefore, required to discriminate between shoots to be plucked during the current round and those to be left for the next round to maintain overall standard of the harvested crop. Distinction between pluckable and immature shoots is a prerequisite for maintaining a good plucking standard.

PLUCKING STANDARD

Plucking standard referes to the fineness. or coarseness of the harvested shoots. Five plucking standards are recognised in N.E. India (S.K.D. and D.N.B., 1962). These are :

Plucking standard	*Types of shoots to be plucked*
Fine	All 1+bud, a1l 2+bud and single banjhies. .
Standard or Normal	Large 1+bud, a1l 2+bud and single banjhies.
Medium	A1l 2+bud and all single and double banjhies.
Coarse	All 2+bud, all shoots larger than 2+bud and double banjhies.
Very coarse	A1l 3+bud and all double banjhies.

Banjhi shoots with one and two leaves are known respectively as single and double banjhies. Breaking back will be necessary in fine, normal and medium plucking to maintain the set standards.

Grouping of plucked shoots into different standards is not inflexible in as much as it depends on the rigidity or laxity of the standards set. The extreme forms of fine and very coarse plucking are rarely adopted in practice and distinction between normal and medium plucking is seldom made.

That coarse plucking reduces the value of tea is a well-documented fact. The coarser components of the plucked shoots dilute the quality produced by the finer fractions, bringing down the overall value of the finished product. This was convincingly demonstrated by an experiment conducted at Tocklai (TES Ann. Rep., 1967-68). In this experiment shoots plucked from a section of seed-grown tea according to the normal standard were dissected into buds, first leaves, second leaves, third leaves, stems and banjhies and each one of these components was manufactured separately along with samples of whole shoots as controls. The teas were evaluated by two separate tasting panels. The results are presented in Table 43.

It can be seen that the value of tea declined from bud downwards with increasing coarseness of the shoot components.

The bud and the first leaf together made up 32 per cent of the total weight of crop but they contributed 42 per cent to the total value of the product. The remaining 53 per cent of the crop consisting of the coarser fractions (excluding the stems) contributed only 41 per cent to the total value. This means that the coarser components had a negative effect on the value of the finished product. Since it happened in normal plucking, coarser plucking can be expected to debase value even more.

Table 43. Contribution of different components of plucked shoots to total crop and value of made tea

Components	Per cent by weight of the harvested crop	Relative value of made tea	Per cent contribution of components to value of tea
Bud	11.5	100	18.1
1st leaf	20.5	79	23.8
2nd leaf	28.9	52	21.9
3rd leaf	9.8	49	7.8
Stem	15.8	64	17.4
Banjhies	13.6	55	11.1
Weighted average		65	
Control (Whole shoot)		69	

The proportion by weight of bud, first leaf and other components in any shoot varies from clone to clone (TES Ann. Rep., 1969-70). Shade and manure also affect these proportions to a certain extent (Barua *et al.*, 1957). Other cultural factors like pruning and plucking will have similar effect. Temperature, drought and atmospheric humidity too would alter the proportions of the shoot components. Owing to the influence of the cultural and environmental factors on the morphology of shoots, the quality potential of a clone is subject to fluctuation. The effect of shoot morphology on quality of tea has so far received scant attention. This aspect by itself as well as a supplement to chemical investigations on quality deserves more attention.

Banjhi shoots appearing at the plucking table should be plucked off regularly. Their presence seems to reduce yield by retarding the growth of other shoots. Banjhi shoots on the bush-frame produce similar effect. Removal of primaries which went banjhi below the tipping level and dwarf, banjhi shoots of the bush frame increased annual yield of the four clones used in a trial at Tocklai by 6.3 to 38.6 per cent (TES Ann. Rep., 1970-71). The retarding effect of banjhi shoots on shoot growth and yield appears to be linked up with the high concentration of growth retarding chemicals present in the banjhi bud.

MECHANICAL PLUCKING AIDS

Unlike in other crops, harvesting in tea is an unending operation repeated at short intervals throughout the growing season. This makes plucking the costliest operation in tea. Where the growing season is short for reasons of climate, the rush of leaf at the peak season becomes so heavy that, on occassions, upto 1.5 per cent of the annual crop has to be made on a single day. Crop intake of this magnitude puts severe strain on men and machinery since very few, if any, estate can afford to maiantain a permanent labour force large enough to cope with the crop on such peak days. The quest for mechanical plucking aids to speed up plucking and save labour has to be viewed in the above context.

Self-propelled, selective plucking machines have been developed in the U.S.S.R. and their use for harvesting the tea crop is steadily increasing. Only about 10 per cent of the crop was plucked by machine in the early seventies (Dey, 1972), the rest being plucked manually, but the proportion of machine-plucked leaf has increased in the meanwhile. The plucking action of these machines is different from that of the plucking aids used or tried elsewhere. The operative parts of the Russian plucking machine are of rubber and the shoots are not cut off. The force with which the operative rubber ‘fingers’ hit the stems of shoots is so adjusted that tender shoots are bent, very coarse stalks are left unbroken and shoots of only a certain optimum size are plucked. Gokhale (1958) observed that a certain proportion of pluckable shoots were also left behind, this being the major drawback of the machine. The machine could pluck upto 1000 kg leaf in 8 hours. Plucking round of 7-8 days is strictly maintained and the plucked leaf is sorted in green leaf sorters into different grades which are manufactured separately.

In Japan, tea is plucked only 3-4 times in a year. Motorised shears are generally used for harvesting the long shoots which are sorted out into a number of grades and manufactured separately for making green teas of different quality.

Mechanical plucking aids have been tried in many other countries of the world. In most cases trials have been confined to the use of hand-operated or motorised shears. Comparison of Tarpen Tea Plucker and Grafton Tea Plucker with hand plucking at Tocklai showed hand plucking to produce 10 to 14 per cent higher yield than mechanical plucking, there being no difference between the two machines. The percentage of fibre in the machine-plucked leaf remained high, which could not be brought down to less than 10 per cent even after various manipulations (TES Ann. Rep., 1949). Dutta (1956) did not find any difference in the total weights of shoots harvested by hand and by the mechanical harvester developed at Tocklai by Mc Tear (1956), but the coarser components constituted 45 per cent of the total harvest from mechanical plucking as against 24 per cent from hand plucking. Using a Tarpen harvester, Goodchild (1958) found more cut and broken pieces in machine-plucked than in hand-plucked leaf but bruising of the leaf was less in the former. In addition to cut pieces, Ndamugoba (1977) reported machine-plucked leaf to be coarser than leaf plucked by hand. He observed that machine plucking had to be done on longer rounds for better crop. Kulasegaram (1980) found about 60 per cent of the machine-plucked leaf to be of acceptable quality. He indicated that the percentage might increase if the plucking aid was used regularly. Othieno and Anyuka (1982) compared plucking by hand-operated and motor-operated shears with hand plucking. They sorted the plucked leaf into 10 categories, manufactured the bulked leaf from each treatment and got the teas evaluated by tea tasters for different liquor characters. TheafIavin (TF) content of the made teas was also estimated as an additional check on quality. The results obtained over a period of six months can be considered representative of the general run of experiments conducted with non-selective plucking aids. These are reproduced concisely in Table 44.

Table 44. Percentage of acceptable and unacceptable leaf and evaluation of liquor characters of teas made from bulked leaf (After Othieno and Anyuka, 1982)

Plucking method	Plucking round in days	Plucked leaf Per cent acceptable	Plucked leaf Per cent unaccep-table	Tasters' scores out of 50	TF μ mol g^{-1}
Hand	14	71.6	28.8	27	18.2
	28	70.6	28.9	29	18.5
Shear	14	52.6	46.5	23	13.2
	28	47.1	52.0	22	13.4
Motorised	14	44.7	54.6	25	13.3
machine	28	45.5	53.7	25	14.8

All shoots having upto three expanded leaves were grouped into acceptable category. Shoots with four or more leaves, cut pieces of soft and hard leaf, hard shoots, cut twigs and dry leaves fell into the unacceptable category. Tasters' scores for each of the five liquor characters ranged from 0 to 10, making 50 to be the maximum possible score for each treatment.

The motorised machine harvested at almost twice the speed of hand. Shear too was faster than hand. Plucking was faster on 28-day rounds in all the three treatments. In conformity with the results obtained by other investigators, leaf harvested with such plucking aids was of inferior quality. It is clear that plucking aids must be selective, at least to a reasonable extent. Alternatively, there should be an efficient system for sorting out the unacceptable fraction from the harvested crop.

Mention has already been made in the previous chapter of the self-propelled plucking (cum-pruning) machine designed and developed at Tocklai during the late fifties. It is a pity that further development of the machine had to be abandoned. Rapid rise of productivity throughout the world has emphasised the essentiality of an efficient plucking aid that can speed up the harvesting operation in tea.

CROP REGULATION

Heavy rush of crop sometimes throws plucking out of gear. Plucking rounds become longer and coarse components increase in the harvested crop. Leaf in excess of the manufacturing capacity flows into the factory slackening the standard of manufacture. Coarser leaf and fall in the standard of manufacture reduce the quality of the finished product. This state of affairs occurs more commonly in regions where climatic conditions restrict shoot growth to a part of the year.

The traditional method of dealing with the situation is by suspending plucking for one or two rounds and skiffing the bushes before recommencing plucking as set forth in the previous chapter. This method gives some respite to the growers but entails loss of crop. With a view to avoiding skiffing and loss of crop, various chemicals have been tested in recent years for suppressing crop during periods of heavy rush without reducing the total output of crop shoots. Results obtained at Tocklai till date are reported to be very encouraging (TES Ann. Rep., 1984-85). Single spray of anyone of Ethephon at 100 ppm (2-chloroethyl phosphonic acid), Morphactin at 50 ppm (Chlorflurenol methylester), Paclobutrazol at 200 ppm and Chlormequat at 200 ppm during the peak growing season of June to September suppressed growth for 2-3 weeks followed by vigorous growth of the bushes during the following 4-6 weeks. There was no loss of crop and the chemicals had no adverse effect on quality.

These reusults open up the possibility of regulating growth through the use of chemical growth suppressants without losing crop or quality. The chemicals deserve trial on a wide scale under commercial conditions.

PLUCKING SURFACE

With a few exceptions, tea is plucked to a flat surface throughout the world. Experiments conducted in many countries have almost invariably proved the superiority of the flat surface over plucking surface of other shapes, both in terms of plucking efficiency and yield. Exceptions are the countries like the U.S.S.R. and Japan where plucking surface is hemispherical. Two factors seem to have influenced the preference for hemispherical plucking surface in these regions. The hemispherical surface may be more convenient for plucking with the types of machines used in these countries. The second factor, which is more important, is cultivation of the shrubby China plants in single hedges spaced 1.5 m or more apart, while the plants within the hedge are planted very close. These plants have the habit of producing a large number of slender laterals low down on the bush frame which spread out to make the plant bushy. Due to stiff competition between the closely spaced bushes within the hedge row, the spread of branches along the hedge is much restricted which stimulates the branches to grow out into the vacant spaces between hedges. Under these conditions, dome-shaped plucking can better exploit the growth potential of the branches spreading on either side of a hedge than plucking to a horizontal surface. Horizontal or flat plucking can tap only the vertical growth above a certain height.

The spherical plucking surface is unlikely to have additional advantage over flat plucking at conventional spacings, particularly with plants of the Assam type having a tree-like growth habit.

HOURS OF PLUCKING

Tea shoots continue to expand throughout day and night so long as temperature remains above a critical level (See Chapter 11). However, shoots gain weight more rapidly during daytime than at night due to accumulation of the prouducts of photosynthesis faster than their utilisation for the natural processes of growth. Even during the day, shoots gain weight faster in the morning than in the afternoon hours, because the products of photosynthesis which moved into the shoots during the previous day would have been used up for growth during the hours of darkness, making room for more. Secondly, plants normally carry on photosynthesis more efficiently during morning hours than in the aftertnoon. Sakai *et al.* (1965) observed higher rate of photosysthesis of tea leaves plucked during the morning hours than those plucked at mid-day. Photosynthesis coantinued at a low rate during the afternoon hours. Such fluctuations were not observed when the leaves were stored in the dark. Radiotracer studies using leaf discs gave the same results (Aoki, 1979). This happens, because in the morning hours leaves are depleted of the products of photosynthesis. They also do not suffer from excessive heating or from high internal water stress. Water stress builds up gradually and on hot sunny days it may be so severe in the afternoon hours as to stop photosynthesis completely.

Table 45. Mean per cent dry weight of 2 + bud shoots plucked at different hours of the day (After Gogoi, 1977) .

Clone	Hour of plucking (Indian standard time)			Average
	8	11	14	
TV 9	21.5	22.7	23.4	22.5
		(5.3)	(3.0)	
TV 11	21.9	23.0	23.2	22.7
		(4.9)	(0.6)	
TV 16	20.7	22.5	22.8	22.0
		(8.9)	(1.4)	
Mean	21.4	22.8	23.1	
		(6.4)	(1.6)	

Figures in parenthesis indicate percentage increase during the interval. Add 47 min to get mean solar time at Tocklai.

Gogoi (1977) investigated the problem of changes in shoot weight at different hours of the day with a view to estimating the gain in crop that would be possible by changing the time of plucking. He started by estimating the change in weight of leaf discs cut out from the first and the second leaves of 2 + bud shoots at different hours of the day and then extended his studies to whole shoots and finally to recovery of made tea (Gogoi, 1980). Some of his data are reporduced in Table 45 to illustrate the main findings.

The rate of increase of dry matter was much higher during the morning interval from 8 hr to 11 hr than between 11 hr and 14 hr. The dry weight percentage varied significantly between clones in the morning hours but the difference narrowed down considerably as the day advanced. The clones gained in weight at different rates. The mean rate of gain when all the clones are considered together was about 2.0 per cent per hour during the first interval which dropped to about 0.5 per cent during the second.

Shoots plucked at different hours of the day were manufactured and the percentage recovery of made tea was estimated at the drier mouth. The drier mouth recovery followed the same trend. The results indicate that crop can be increased by commencing plucking late in the morning instead of starting in the early hours but whether such a time schedule would be feasible under estate practice is a matter of conjecture.

The teas made from leaf plucked at different hours were evaluated by panels of tasters. They were not very consistent and clones interacted with hours of plucking but, in general, there appeared to be a slight perference for teas manufactured from leaf plucked at 8 a.m. Tasters' preference for teas made from morning leaf finds support in chemical analysis. The results reported by Ullah (1967) of teas manufactured from morning and afternoon plucked leaves can be cited as examples. He found three to four fold increase of soluble sugars and about 15 per cent decrease of catechins in teas made from afternoon leaf.

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CHAPTER 11

PRODUCTION AND PARTITION OF DRY MATTER

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UTILISATION OF CARBOHYDRATES

The importance of maintenance foliage as the source of carbohydrates for plucked tea bushes has been pointed out in the previous chapter. The carbohydrates synthesised by the maintenance leaves are put to diverse use. The major fraction is used up in respiration which releases energy for various metabolic functions of the plant. A part of the balance is utilised for promoting growth of new tissues and organs including the shoots harvested for the manufacture of tea. Another part is utilised for the synthesis of a large number of chemicals some of which like amino acids, proteins, fats, pectins etc. directly participate in the growth processes while others like the catechins, caffeine and precursors of aromatic compounds become the primary ingredients of a cup of tea after undergoing transformation during manufacture. The balance is stored as reserve, mainly in roots, for future use.

Environmental factors profoundly affect the production of carbohydrates through the process of photosynthesis and their utilisation by the plant. The plant itself and its condition of growth modify the processes of production and utilisation. In this chapter we shall examine first the effects of environmental factors on photosynthesis and respiration and then look into the partitioning of dry matter between different organs of plucked and freely growing tea bushes.

It will be evident from what follows that the phenomenon of growth partition is a key factor in the productivity of tea.

THE PROBLEMS IN THE MEASUREMENT OF PHOTOSYNTHESIS

A clear perception of the problems associated with the measurement of photosynthesis and respiration is a prerequisite for any investigation of these metabolic functions in the tea plant.

Heterogeneity and Adaptability

Attention had already been drawn to the heterogenous nature of tea populations raised from seed. Each plant in a seed population is phenotypically and genotypically distinct from other plants. A clone being the extension of a single plant selected out of seed-grown populations, no two clones are exactly alike. Since clones are used for the study of environmental effects their reactions can be expected to differ to a greater or lesser extent. .

The China tea plants grow in the very cold climate of higher latitudes as well as in the warm tropics. Growth over such a wide range of temperature has been possible either because this race of tea has evolved ecotypes some of which are adapted to warm climate and some others to cold climate or the plants of this race possess very wide adaptability. The latter seems more probable since China plants originally imported into India and planted at about 2000 m elevation in the western Himalayas sometime during the middle of the last century thrived even better at Tocklai after transplantation. Similarly selected Japanese cultivars are growing well in the plains of N.E. India. In comparison, the Assam race is much less adaptable. Plants of this race do not thrive in places where temperature in winter drops near to the freezing point. Plants of the Cambod race appear to be somewhat less susceptible to cold than the Assam plants. Hence the plants of the three races of tea are unlikely to react to changes of temperature in the same way.

Effect of Growth Temperature

Plants which are native to and grown in cool environments generally exhibit higher photosynthetic rates at low temperature in comparison with plants that are native to and grown in warm environments. The latter plants perform better at higher temperature. Even growth temperature alone alters the temperature optimum for photosynthesis. The same plants generally exhibit higher photosynthetic rates at low temperature when grown under a cool regime and higher rates at high temperature when grown under a hot regime. The rates at the optimum temperatures may, however, be similar irrespective of the previous growth regime (Bjorkman *et al.*,1978; Berry and Bjorkman, 1980). Thus plant species exhibit 'photosynthetic acclimation' to changing temperature of growth. This is a characteristic of many species that are cultivated in habitats with large seasonal fluctuation of temperature. As pointed out in Chapter 4, temperature in certain tea-growing regions remains cool and fairly steady throughout the year while in others it fluctuates widely along with the change of season. Plants growing in cooler climate may, therefore, be expected to exhibit a low temperature optimum for photosynthesis while under fluctuating temperature, the optimum temperature for photosynthesis is likely to vary with the prevailing temperature. This is an aspect so far not studied in tea although the plant appears to be a suitable material for this study.

Effect of Carbon dioxide Concentration

Concentration of carbon dioxide (CO_2) in the photosynthetic medium is also known to alter the temperature optimum for photosynthesis. For instance, Bjorkman *et al.*, (*loc. cit.*) observed a rise in the temperature optimum for photosynthesis in the leaves of *Nerium oleander* when the CO_2 concentration was raised from atmospheric to saturating level, irrespective of whether the plants were growing previously at 20°C or 45°C. Interestingly, the temperature optima for photosynthesis both at rate-limiting and saturating CO_2 levels were higher for plants grown at 45°C than those grown at 20°C. These observations illustrate the effects of CO_2 concentration as well as the previous temperature regimes of the plants on photosynthesis.

It may be inferred from the foregoing that the China and Assam races of tea could have different temperature optima for photosynthesis under atmospheric CO_2 level, but certain genotypes environments. The latter plants perform better at higher temperature. Even growth temperature alone alters the temperature optimum for photosynthesis. The same plants generally exhibit higher photosynthetic rates at low temperature when grown under a cool regime and higher rates at high temperature when grown under a hot regime. The rates at the optimum temperatures may, however, be similar irrespective of the previous growth regime (Bjorkman *et al.*,1978; Berry and Bjorkman, 1980). Thus plant species exhibit 'photosynthetic acclimation' to changing temperature of growth. This is a characteristic of many species that are cultivated in habitats with large seasonal fluctuation of temperature. As pointed out in Chapter 4, temperature in certain tea-growing regions remains cool and fairly steady throughout the year while in others it fluctuates widely along with the change of season. Plants growing in cooler climate may, therefore, be expected to exhibit a low temperature optimum for photosynthesis while under fluctuating temperature, the optimum temperature for photosynthesis is likely to vary with the prevailing temperature. This is an aspect so far not studied in tea although the plant appears to be a suitable material for this study.

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It may be inferred from the foregoing that the China and Assam races of tea could have different temperature optima for photosynthesis under atmospheric CO_2 level, but certain genotypes where the temperature does not drop too low to stop growth of tea bushes, are the ones to benefit most from reduced rate of respiration.

Hadfield (1968) investigated the relationship between temperature and photosynthesis on tea plants referable to the Assam type. The plants were growing in a warm greenhouse at Cambridge, England. Net photosynthesis of attached leaves was measured under high light intensity in atmospheric CO_2 level. Net photosynthesis increased as the temperature of the assimilating leaves was raised, but beyond 35°C, there was a sharp decline. Between 39°C and 42°C there was no net photosynthesis but respiration continued to increase upto 48°C above which the leaf tissues were irrevocably damaged.

Net photosynthesis is the excess of photosynthetic products over that lost in respiration which, in this case, was the difference between the quantities produced and lost by the photosynthesizing leaves. However, other non-photosynthetic tissues and organs of the plant were also respiring at the same time. Loss of respiratory substrates during the hours of darkness should also enter into the calculation of the temperature optimum for photosynthesis. If the respiratory loss of carbohydrates by the whole plant during day and night was taken into account, then the temperature at which respiration overtook photosynthesis would have been less than 39°C - 42°C and the temperature optimum for net photosynthesis would also have fallen below 35°C. It is worth noting in this connection that Aoki (1979a) found 30°C to be the optimal temperature for photosynthesis by leaf discs of tea even at high bicarbonate concentration.

The meagre information available on temperature-photosynthesis relationship of the tea plant does not permit any generalisation about the range of temperatures within which the temperature optimum for net photosynthesis under high light and atmospheric CO_2, of the whole range of tea plants, will lie. It seems the optimum will not be less than 25°C and more than 30°C for most tea plants under cultivation in different parts of the world. Here temperature refers to that of the photosynthesizing leaf and not to the ambient temperature. As pointed out in Chapter 4, under certain situations temperature of an exposed tea leaf may be 10°C-12°C higher than the temperature of the surrounding air. For this reason it is necessary to take adequate precautions to keep the leaf temperature constant during measurement of photosynthesis.

Plants usually grow better when temperature at night remains lower than the optimum day temperature (Went, 1953). Nakayama *et al*. (1966) reported better growth of young, potted tea plants at 30°C day and 20°C or 25°C night temperatures than at a constant 30°C day and night temperature. In contrast 25°C day and 15°C or 20°C night temperatures reduced growth to less than that at 25°C throughout day and night. Obviously growth suffered below 20°C, although this may not be the minimum for all tea plants. Like the maximum, the range of minimum temperature for active growth of tea also needs defining.

Some information is available on the minimum temperature below which the visible growth of the tea plant completely stops. Lebedev (1961) reported stoppage of growth in Georgia when the mean air temperature fell below 13°C. Nakayama and Harada (1962) did not observe any growth of potted tea plants in Japan when kept at a constant temperature of 12.5°C. Carr (1972) reported virtual cessation of growth of tea in southern Tanzania below 14°C mean air temperature. Tanton (1982 a) in Malawi considered 12.8°C to be the base temperature for extension growth of tea shoots. Thus, there is agreement between observations made in different parts of the world that extension growth of the tea plant ceases below a minimum temperature of 13°C. However, as mentioned under optimum temperature for day and night, the possibility that certain genotypes of tea and plants adapted to low temperature regimes can grow at even lower temperatures, cannot be ruied out. In Kenya, the monthly mean maximum and minimum temperatures rarely exceed 24°C and 11°C, respectively, at any time of the year but the tea plants there flush throughout the year and produce yearly yields of the same order as plants in many warmer regions.

While extension growth stops at about 13°C, photosynthesis does not. In N.E. India, photosynthesis was observed to continue in the month of December when the mean minimum temperature was lower than 13°C and the tea bushes were completely dormant

(Manivel, 1980). ln Malawi, shoot growth does not stop completely in the winter months of May-August, but monthly yield falls drastically to less than 10 per cent of the peak summer months. In contrast, photosynthetic rate dropped only by 25 per cent (Squire, 1977). These results substantiate the arguments (Chapter 3) that temperature is not the primary cause of winter dormancy, but that it plays a complementary role to short daylength which is the major cause.

Very little information is available on the effect of soil temperature on root and top growth of tea. Carr (1972) indicated 20°C to 25°C to be the optimum range of temperature for the growth of tea roots. Between 18°C and 25°C soil temperature, Tanton (1982b) did not observe any change in the rate of shoot extension on tea bushes of Malawi. Observations made at Tocklai also suggest temperature above 25°C to be detrimental for root growth. Under field conditions, the maximum growth of new roots occurred during the winter months when temperature of the top 30 cm soil profile remained between 17° and 25°C. During summer when soil temperature was above 25°C, root growth was minimal (Barua and Dutta, 1961). However, high soil temperature might not have been the only cause of reduced root growth during the summer months. It has been shown that during the summer of N.E. India when shoots grow actively on plucked tea bushes, metabolites are mobilised almost exclusively for the growth of shoots depriving the roots of assimilates for growth (Manivel, 1980).

While studying the effects of various mulching materials on the growth of tea bushes in Kenya, Othieno (1977) observed linear increase of root growth as the soil temperature rose from 14°C to 22°C. Along with the growth of roots, he observed increment in the growth of other plant organs, apparently due to improvement in the uptake of water and nutrients from the soil by the proliferating roots. Changes in viscosity and permeability of the root protoplasm due to rise of temperature too could have contributed towards increased uptake.

These observations tend to indicate 18° to 25°C to be the optimum range of soil temperature for the growth of tea roots. However, the possibility that roots of some tea plants would grow satisfactorily even at lower temperatures cannot be excluded, although temperature above 25°C is unlikely to favour root growth.

Photorespiration

More than 99 per cent of woody angiosperms follow the tricarboxylic acid (C_3) pathway of photosynthesis and the tea plant was believed to belong to this very large group of plants. Proof in support of this belief was lacking until Roberts and Keys (1978) produced evidence to show that tea followed the C_3 or photorespiratory pathway. The photosynthetic systems of all C_3 species evolve CO_2 on exposure to light. The light or photorespiration proceeds simultaneously with metabolic or dark respiration, causing considerable loss of photo-assimilated carbon. This makes the C_3 species less efficient producers of dry matter than the small number of C_4 species that follow the dicarboxylic acid pathway of photosynthesis.

Roberts and Keys *(loc. cit.)* measured photosynthesis, photorespiration and estimated the initial products of photosynthesis by tea ieaves under strong light of 1200 μ Einstein m^{-2} sec^{-1} intensity (0.5 cal $cm^{-2}min^{-1}$) from a halogen lamp at oxygen concentrations of 21 and 55 per cent. Radio-active CO_2 at 340 ppm by volume (vpm) was fed to the photosynthesizing leaves. Leaf temperature was maintained at 26° - 27°C. Some of their results are reproduced in Table 46.

Rise of oxygen concentration in the photosynthetic medium stimulated photorespiration, reduced photosynthesis and raised the CO_2 compensation point in common with the photosynthetic behaviour of other C_3 plants. At nearly the normal level of atmospheric CO_2, photorespiration was 19 per cent of photosynthesis. Oxygen inhibition of photosynthesis in tea was reported also by Aoki (1979b).

Zelitch (1967) reported fourfold increase of photorespiration when the temperature was raised from 25° to 35°C, while dark respiration merely doubled over the 10°C rise. This presumably happens in the tea plant also. If it does, then judging from the data of Table 46, photorespiration would account for about 40 per cent of photosynthesis at 35°C.

Table 46. Photosynthesis, photorespiration and CO_2 compensation points of tea leaves under different oxygen tensions (After Roberts and Keys, 1978)

	Oxygen concentration 2%	21% (air)	55%
Photosynthesis mg CO_2 dm^{-2} hr^{-1}	10.0 ± 0.9	8.3 ± 0.7	3.6 ± 0.5
Photorespiration mg CO_2 dm^{-2} hr^{-1}	0.3 ± 0.1	1.6 ± 0.1	2.5 ± 0.4
Photorespiration as % photosynthesis	3.0	19.3	69.4
Co_2 compensation point (vpm)	39 ± 7	60 ± 4	129 ± 6

Evidence is accumulating in recent years to the effect that some species within a genus may follow the C_3 pathway of photosynthesis while a few may follow the C_4 pathway. There again are species which are neither truely C_3 nor C_4 but occupy an intermediate position, these being known as C_3 - C_4 species (Kennedy *et. al.,* 1980). Some plants within a C_3 species may also follow the C_3 - C_4 pathway. Considering the existence of an extremely wide range of genotypes in tea, including the polyploids, the chances of getting a few C_3 - C_4 plants among the vigorous strains look quite promising. Exmination of morphological characters would help in their tentative identification, which could then be confirmed by measuring the relative activities of the two carboxylating enzymes-ribulose-1, 5 diphosphate carboxylase, variously designated as RuDP, RuBP or RUP_2 and phosphoenol pyruvate carboxylase (PEP). Activity of the latter enzyme relative to that of the former is higher in C_4 than in C_3 plants.

CO_2 Concentration

The small amount of CO_2 present in air cannot saturate the photosynthetic apparatus of tea or other plants. For that reason, the rate of photosynthesis increases as the CO_2 concentration of the photosynthetic medium is artificially raised until it reaches the saturating level. Photosynthetic rates fall when the CO_2 concentration drops below the atmospheric level. At a particular concentration below the atmospheric level, photosynthetic production of carbohydrates just balances its loss through respiration. This is the CO_2 compensation point.

Few studies have so far been carried out to assess the response of the tea plant to changes in the concentration of CO_2 in the surrounding air. In an experiment reported from the TES (Ann. Rep., 1970-71), CO_2 at concentrations of 285, 350, 430 and 620 ppm were fed to attached leaves of tea kept at a temperature of 15°C and exposed to 0.02, 0.03, and 0.16 cal cm^{-2} min^{-1} active radiation. Rates of photosynthesis increased in response to increasing light intensity and CO_2 concentrations, but the effect of rising CO_2 level was more pronounced at the two lower light intensities. This is understandable since diffusive resistance of stomata increases at low light, but at any particular rate of diffusion more CO_2 molecules enter into the leaf if its concentration in the gas mixture remains high. Hence the difference in the rates of photosynthesis at high and low concentrations of CO_2 widens with increasing stomatal resistance or declining light intensity. Aoki (1979a) too observed increase in the rate of photosynthesis by leaf discs of tea when the bicarbonate concentration of the medium was raised.

The CO_2 saturation and CO_2 compensation points of tea leaves were reported to be 1300 ppm and 60 ppm, respectively, by Sakai (1977), the latter being identical with the figure quoted in Table 46. However, Barua (1953) noted some variation in the CO_2 saturation points of tea leaves from different sources under strong and weak light.

The saturation and the compensation points of CO_2 may increase with the rise of temperature. Of the six species for which data were provided by Zelitch *(loc. cit.),* the CO_2 compensation points were at least twice as high at 35°C as at 25°C.

From the point of growth of the tea bush under field conditions, the main point of interest is fluctuation of the level of atmospheric CO_2 and whether it is wide enough to make substantial difference to photosynthesis by different layers of leaf in the maintenance canopy. Decomposition of organic matter present in the soil releases CO_2 into the atmosphere. Inside a closed canopy of tea bushes, its concentration above the ground surface can be presumed to remain higher than in the outside atmosphere, enabling the lower leaves in the canopy to photosynthesize in an atmosphere enriched in CO_2. Besides, it will be shown in the next section that the leaves remaining in low light can make better use of the limited amount of energy available to them for photosynthesis than leaves which remain exposed to strong light. The combination. of CO_2 enrichment of the air and adaptation of the leaves to low light intensity must raise the contribution of the lower leaves to the carbohydrate pool of tea bushes than one would normally expect. It is worth pointing out in this connection that CO_2 enrichment of the air above the ground surface could be an additional benefit of mulching.

Stomatal Movement

Attention was drawn in the previous chapter to reduced rate of photosynthesis in the aftemoon hours and accumulation of the products of photosynthesis in leaves was cited as the causative factor. While this is so, increased resistance to the diffusion of gases into the leaf is another factor responsible for the low afternoon rate. Even in bright sunshine, stomata present on the under surface of tea leaves rarely remain fully open during the early afternoon hours. Mid-day closure of stomata to a greater or lesser extent depending on ambient conditions is a phenomenon of common occurrence in many parts of the world. The extent of closure is controlled by excess of transpiration over the supply of water to the leaves. Strong light, temperature, large vapour pressure deficit of the atmosphere and drying wind increase transpiration. Anyone or a combination of some of these factors can cause transpiration to exceed the uptake of water even by well-developed root systems from a soil at field capacity. Strong irradiance which is usually accompanied by increase of saturation deficit of the air during mid-day and early afternoon hours, is responsible for mid-day closure of stomata and reduced rates of photosynthesis at this time of the day.

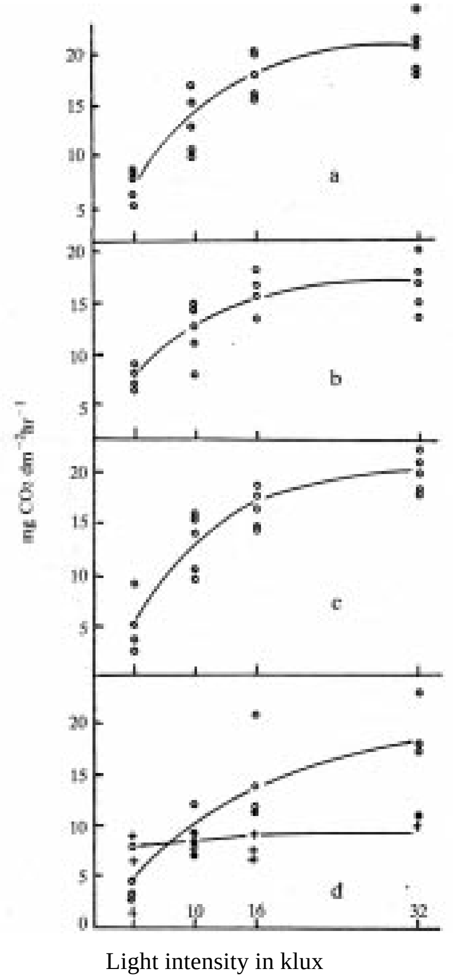
Effect of Light Intensity

The relationship between light intensity and assimilation rate was examined by Barua (1953, 1964) on mature, detached tea leaves from four sources, two (a, b) of which were nominally referable to the China race and one each to the Assam (c) and Cambod (d) races of tea. Preliminary observations showed that stomata closed on detachment of the leaf from a plant but the leaf regained full photosynthetic efficiency after storage in the dark for about 12 hr in a moist atmosphere with the petiole in water. Under those storage conditions the leaf retained full photosynthetic capacity for about 30 hours. Taking adequate precautions against these and other possible sources of error, he measured assimilation rates of full-grown, detached tea leaves in excess CO_2 and light of 4, 10, 16 and 32 kilolux intensities from an incandescent lamp, corresponding to 0.026, 0.065, 0.104 and 0.208 cal $cm^{-2}min^{-1}$ of photosynthetically active radiation. Temperature of the leaf was maintained at 25°C. Prior to detachment of the leaves, the pot-grown plants were kept in full sunshine on a bench in a hot greenhouse at Cambridge, England, with the exception of some plants of source (d) which were under the shade of a bench. The assimilation rates of the shade-grown leaves were estimated separately. The results for the sun leaves of the four sources and shade leaves of source (d) are presented graphically in Fig. 24.

The rates of apparent and real photosynthesis differed significantly between the sun leaves from the four sources in strong as well as in weak light. Neither leaf thickness nor chlorophyll concentration could account for the difference.

The maximal rates of photosynthesis in strong light (^{R}Max) and half saturating light intensities (K_1) were determined by linear transformation of the parabolic curves of Fig. 24. These are reproduced in Table 47.

The high maximum rates are notionally attainable under non-limiting light intensity and CO_2 supply but not possible under field conditions where some factors like CO_2 are always limiting. Nevertheless, the data establish the important principle that wide diversity exists in the photosynthetic capacity of tea leaves from different sources. The half-saturating light values likewise indicate differential requirement of light intensity for maximum photosynthesis by different plants.



Light intensity in klux

Fig. 24. Free-hand curves showing the rates of apparent photosynthesis of mature tea leaves from four different sources in 4, 10, 16 and 32 kilolux (Klux) light intensities. The four sources are : (a) progeny of clone 14/5/35, (b) progeny of clone 19/29/13 both referable to the China race (c) Stock 203, referable to the Assam race and (d) Indo-China stock, referable to the Southern form of tea. Sun leaves 0—0; Shade leaves +—+ (After Barua, 1953).

Table 47. Maximal rates of photosynthesis (^RMax) and half saturating light intensities (K_1) for the sun leaves of the four sources at 25°C

Source of leaf	^RMax (mg CO_2 $dm^{-2}hr^{-1}$)	K_1 (cal $cm^{-2}min^{-1}$)
(a) China	19.3	0.037
(b) China	29.8	0.072
(c) Assam	46.3	0.105
(d) Cambod	26.9	0.159

The leaves of plants growing under heavy shade exhibit lower rates of photosynthesis when transferred to strong light, in comparison with leaves which remain continuously in bright light. The shade-grown leaves of source(d) had much lower rates of photosynthesis in 0.104 and 0.208 cal $cm^{-2}min^{-1}$ light intensities than the corresponding sun leaves, but a 40 per cent higher rate at the weakest of the four light intensities (0.026 cal $cm^{-2}min^{-1}$). The heavily-shaded lower leaves on a tea bush canopy can, therefore, make more efficient use of the reduced light energy available to them for photosynthesis. How quickly tea leaves can adapt to weak or strong light is, however, not known.

In another study reported from Tocklai, photosynthetic rate of mature leaves attached to the plant was measured in a range of light intensities from very low to 0.3 cal $cm^{-2}min^{-1}$. The CO_2 concentration was kept at 360 ppm and temperature at 15°C. Leaves from pot-grown plants of only one source were taken for these measurements. The plants were grown in a hot greenhouse at Cambridge. While the CO_2 concentration was near the atmospheric level, temperature was much below the optimum for photosynthesis. Under this setup, light saturation occurred between 0.2 and 0.3 cal $cm^{-2}min^{-1}$ active radiation for leaves previously subjected to bright ligbt. Above 0.4 - 0.5 cal $cm^{-2}min^{-1}$ there was reduction of net photosynthesis which was not associated with stomatal closure (TES Ann. Rep., 1969-70).

Sakai and Aoki (1975) reported light saturation of a tea leaf to occur at 350 W m^{-2} which works out to 0.22 cal $cm^{-2}min^{-1}$ of active radiation in the 400-700 nm visible range (See Chapter 4). Square (1977) too observed light saturation at 350-400 W m^{-2} radiation. In all these studies the upper surface of the tea leaf was facing the source of light. The rate of photosynthesis decreased when the leaf was illuminated on the reverse side (Sakai *et. al.*, 1965). It seems the closely packed chlorophyllus pallisade cells below the upper epidermis of a tea leaf can trap light energy more efficiently than the loose mesophyll cells bordering the lower epidermis.

The estimates of saturating light intensity for single leaves are in fairly good agreement despite wide difference between the sources of leaf, environmental conditions and the methods of measurement. Yet it is difficult to envisage a single saturation intensity for all tea plants, nor do Fig. 24 and Table 47 suggest such a possibility. The implications of these findings and effect of high temperature on the growth of the tea bush are discussed in the next chapter.

The photosynthetic rates of single leaves under laboratory conditions provided information of fundamental value, but these cannot be extrapolated to interpret the effects of fluctuating light intensities on mature plants under field conditions. With the expectation that Net Assimilation Rate (NAR) would give a more realistic picture of the growth and shoot yielding potential of different kinds of tea plants, NAR of four clones was determined under four different light intensities. One of the clones used was typically Assam (a), one typically China (d), and the other two were intermediates. Clone (b) was nearer to the Assam end of the cline of types (Plate 2) and clone (c) was closer to the China type. Young 10-month old plants of the four clones were grown in the field at Tocklai in three replicates and were shaded by bambo-mesh screens transmitting 20, 35, 50 and 100 per cent (unshaded) of the incident radiation as measured by a Weston photocell which did not register any radiation in the infra-red beyond 750 nm. A sample of five plants was drawn from every plot on each occasion and sampling was repeated on five occasions at fortnightly intervals. NAR was calculated in the usual way. Some closely planted (30 cm spacing) bushes of the same clones were pruned and plucked from the second year.

In the absence of a significant interaction between clones and light intensities, only the mean values for clones and light intensities are shown in Tables 48 and 49 (Barua, 1957; 1970).

Table 48 has confirmed the findings that the capacity for assimilation varies with the source of leaf (i.e. phenotypes). In this trial, changes in light intensity affected NAR and LA of all the four clones in the same way. Data in Tables 48 and 49 together suggest that different phenotypes of tea including the extreme types would produce maximum weight of growth in full sunlight unless exposure to full sun reduces leaf area to a great extent. However, the weight of shoots harvested from the small, three-year old plants of the same clones as shown in Table 50 did not follow the pattern of dry weight, NAR or LA.

Clone (c) produced more weight of shoots than clone (a), although total weight of the whole one-year old plant, NAR and LA were higher in clone (a) than in clone (c). Total weight of growth and NAR were the highest in full sun, but more shoots were produced at 50 and 35 per cent light intensities. Admittedly, the plucked bushes were much too young to represent the behaviour of mature bushes. Even then the suggestion that partition of growth between the commercially important crop shoots removed from a plucked tea bush and the parts of the plant left behind has an important role in the economic productivity of different kinds of tea plants and under different illumination intensities, cannot be ignored. These observations show that the ability for accumulating dry matter can not be the sole criterion for judging the shoot-yielding capacities of tea phenotypes under different light regimes.

Growth analysis of young tea plants, therefore, proved to be an inefficient tool for measuring and comparing the productivity of different kinds of tea.

Entry of light into the maintenance leaf canopies of plucked tea bushes is affected by the pose of leaf. Hadfield (1968; 1976) who investigated this problem observed sharp drop of illumination intensity from the top to the bottom layer of leaves in the canopies of bushes having horizontal leaves while in the canopies of bushes having erect leaves, the drop was less precipitous. The

Table 48. NAR for clones and light intensities in g $dm^{-2}week^{-1}$

Clone	NAR (Mean of light intensities)	Light intensity (per cent full sun)	NAR (mean of clones)
(a) Extreme Assam	0.132	100 (Full sun)	0.156
(b)	0.116	50	0.146
(c)	0.116	35	0.128
(d) Extreme China	0.172	20	0.110
L.S.D (P=0.05)	0.039		0.032

Table 49. Leaf area (LA) in cm^2 and dry weight (DW) in g per plant

Clone	LA	DW	Light intensity (per cent)	LA	DW
(a)	242	3.08	100	142	2.24
(b)	189	2.72	50	167	2.24
(c)	116	1.64	35	153	2.02
(d)	74	1.02	20	159	1.96
L.S.D. (P=0.05)	11	0.174		11	0.164

compensation point for light was estimated at 0.02 cal cm^{-2} min^{-1}. He concluded from these observations that a much higher proportion of the lower leaves in the canopies of horizontal type bushes would be light-limited, making them photosynthetically less efficient than bushes of the erect type. However, it will be seen from what follows that such bushes did not differ from other bushes having flat or semi-erect leaves in the total net production of dry matter although growth partition in favour of crop shoots appeared to be slightly better in the erect leaf type.

Table 50. Fresh weight of shoots plucked from a bush between May and November

Clone	Shoot wt. g	Light intensity (per cent)	Shoot wt. g
(a)	59.8	100	57.0
(b)	71.4	50	72.3
(c)	78.6	35	66.8
(d)	40.8	20	54.3
L.S.D.(P=0.05)	14.5		7.1

Chlorophyll Concentration

Colour of tea leaves varies from very light yellow-green to dark blue-green with a wide range of shades in between. The dark leaves are richer in chlorophyll than the lighter ones. In a comparison made at Tocklai, the yellow-green mature leaves were found to contain 2.8 - 3.0 mg dm^{-2} of chlorophyll as against 6.9 - 8.3 mg dm^{-2} of the blue-green leaves. However, such a large difference in chlorophyll concentration had virtually no effect on the absorption of light. On a bright day both types of leaves absorbed about 98 per cent of the incoming radiation in the visible range and approximately 50 per cent of the infra-red radiation in the 700-1300 nm region (TES Ann. Rep., 1968-69). The leaves of source (b) of Fig. 24 had a chlorophyll content of 3.5 mg dm^{-2} against 5.3 mg dm^{-2} of source (a), but source (b) had the highest rate of assimilation in the weakest of the four light intensities tried. These results clearly show that chlorophyll content of the light-green mature leaves of the Assam race of tea is not a limiting factor for photosynthesis.

Effect of Drought and Waterlogging

Apart from producing other adverse effects on plants, drought and waterlogged condition of the soil reduce the rate of photosynthesis drastically. In a series of experiments conducted at Tocklai on young pot plants, conditions of drought and waterlogging were induced by withholding water or by submerging the earthenware plant pots up to the rim in water. Symptoms of drought appeared 2-3 days after ceasing to water, but no visible symptom appeared on the waterlogged plants even after 10-14 days. Another lot of normally watered plants was kept as control. Measurement of CO_2 uptake was made on single attached leaves. The photosynthetic rates of the three groups of plants under high light intensity, constant temperature and atmospheric level of CO_2 are shown in Table 51.

Table 51. Rates of CO_2 uptake of normal, droughted and waterlogged plants (Tocklai Ann. Rep., 1969-70)

Normal	21-43 ppm CO_2 min^{-1}
Droughted	1-6 ”
Waterlogged	0-5 ”

The CO_2 uptake of the droughted and waterlogged plants was greatly reduced in comparison with the control series. In case of the droughted plants, the rate of CO_2 uptake fell before the appearance of visible symptoms of wilting. The waterlogged plants did not show any marked symptom of stress. Some plants of the droughted series were watered when wilt symptoms became very marked. After 4-5 days of watering the rate of CO_2 uptake was almost identical with the control plants. In the case of the waterlogged plants, recovery was not complete even 14 days after restoration of the soil water status to field capacity, Since the experiment was discontinued at this stage, it is not known how long waterlogged plants take to recover fully. Waterlogging apparently does more lasting harm to the photosynthetic mechanism of the tea plant than drought, so long as leaves of droughted plants do not wilt permanently.

Respiration rate in the dark was almost identical for the drougted and waterlogged plants but lower than that of the controls. Totalling up the rate of CO_2 uptake over a period of 12 hours of daylight and the respiratory loss in 24 hours of day and night (assuming light and dark respiration to be equal), a net loss of CO_2 was observed in the waterlogged plants over a 24 hr period. This showed that carbohydrate reserves present in the plant were used as respiratory substrates. Obviously young plants cannot survive for long under such conditions since their carbohydrate reserves are low.

The cause of depression of photosynthesis by waterlogging has not yet been ascertained. This phenomenon deserves examination particularly in regions where waterlogging is a chronic problem. Waterlogged condition possibly produces in the plant some substances toxic to the photosynthetic apparatus of the tea plant.

NET AND GROSS PRODUCTIVITY

Net and gross productivity of tea were estimated at Tocklai on 6 out of 24 clones of a trial planted at 60 x 90 cm spacing (18500 bushes ha^{-1}). The trial was originally designed to study the interactions of plant type, manure and shade. In one treatment shade was provided by *Albizzia chinensis* trees and in another by mechanical bamboo-mesh screens, both transmitting 50-60 per cent of the incident radiation. Normal cultural practices were followed in all other respects except the initial frame-forming prune, which was done at a height of 35 cm instead of at the usual 45 cm height. Plucking weight was recorded at every round from the second till the tenth year of planting and pruning weight once in a year when the bushes were pruned. One complete repeat of the trial was uprooted at the end of the tenth year for recording the weights of stem and root.

The 24 clones used in the trial represented a very wide range of phenotypes. The clones were grouped according to leaf-pose into erect, intermediate and flat categories. The highest and the lowest yielding clones of each leaf-pose category growing under *Albizzia* shade trees were used for the estimation of net and gross productivity since total production of dry matter and yield of crop shoots of all the six clones were maximum under *Albizzia* shade (Barua and Sarma, 1982).

Respiratory loss of CO_2 from different plant organs was estimated in the laboratory for computation of gross productivity. The mean annual temperature at Tocklai being 25°C, CO_2 lost at that temperature by different plant organs in a year was computed and converted to dry matter. This quantity was added to net weight for estimating gross productivity. Dark respiration was assumed to be equal to respiration in light and there was no separate estimate for photorespiration. Due to non-inclusion of photorespiratory losses, gross productivity was underestimated. Apart from this, an accurate estimate of the respiratory loss from intact plants cannot be obtained by this method. The estimates of gross productivity can, therefore, give only an approximate idea of the huge amount of dry matter lost through respiration.

The yearly net and gross productivity as represented in the following tables are based on 10 years' average which, in this case, will be roughly equivalent to the growth made by six-year old bushes.

Only 35.4 to 37.4 per cent of the dry matter produced by a plucked tea bush in a year remained on the plant; the rest 63-66 per cent was lost in metabolic respiration (Table 52).

Respiratory loss in Malawi was estimated at 67 per cent of the total dry matter produced in the course of a year (Tanton, 1979). Close agreement between the two estimates can be attributed to similarity of ambient temperatures prevailing in Assam and Malawi. In colder climates, for example of Kenya or high elevation Sri Lanka, respiratory loss will be less with corresponding gain of net dry matter.

Partition of the net dry matter into different plant organs is summarised in Table 53. In these annually pruned bushes one year old primaries, their branches and sub-branches and the maintenance foliage borne by them constituted the prunings. The frame consisted of the above-ground portion of the bush below the level of pruning.

Weight of plucked shoots on an average accounted for 30 per cent and roots for 10 per cent of the net weight. Shoots harvested as crop was only 9 to 12 per cent of the gross weight which is somewhat higher than 7.5 per cent estimated earlier by Hadfield (1976).

Table 52. Net and gross dry matter production per year (After Barua, 1981; 1987)

Leaf-pose	Clone	Yield	Grams per bush			Quintals per hectare	
			Net	Gross	Net as % gross	Net	Gross
Erect	a	Highest	404	1141	35.4	72.7	205
<50°	b	Lowest	291	781	37.4	52.4	141
Intermediate	a	Highest	553	1581	34.9	99.5	285
50° to 80°	b	Lowest	370	1001	37.0	66.6	180
Flat	a	Highest	513	1447	35.4	92.3	260
>80°	b	Lowest	241	675	36.7	43.4	118
		Mean	395	1101	35.8	71.2	198

In Kenya, Othieno (1982) observed a different pattern of dry matter distribution in young clonal plants. In his trial, plants were spaced 1.22 x 1.22 m apart (6720 bushes ha^{-1}). Plucking weight was recorded from the third to the fifth year at the and of which bushes were uprooted for recording the weights of leaf, stem and root. The data have been recalculated and expressed on yearly basis to bring them into line with those in Tables 52 and 53 for easy comparison. The calculated figures of Table 54 represent approximately four year old bushes.

The clones of this trial and the high-yielding clones of Table 52 produced almost equal amounts of dry matter in a year but with a different pattern of partition. In Kenya, weight of plucked shoots accounted for 11 per cent and that of root, 17 per cent of the net gain in weight in a year. The corresponding figures for Assam were 30 and 8 percent. The weight of leaf and stem together made up the remaining 72 per cent while the corresponding weights of prunings and stem portions of the Assam trial were only 62 per cent. Thus, the root systems of the clonal bushes of Kenya were twice as heavy as those of Assam and the above-ground part of the plant body excluding plucking were 10 per cent heavier.

Table 53. Distribution of net dry weight into different plant organs

Leaf-pose	Clone	Per cent of total net weight				
		Plucking	Pruning	Stem	Root	Whole bush
Erect	a	31.7	46.3	13.9	8.1	100
	b	32.3	46.4	15.5	5.8	100
Intermediate	a	30.4	45.0	12.1	12.5	100
	b	24.3	49.5	16.2	10.0	100
Flat	a	27.6	49.7	13.3	9.4	100
	b	29.5	54.7	10.4	5.4	100
Mean		29.3	48.5	13.4	8.4	100

The results show that partition of growth into different organs of the plant can vary between plants and from place to place. However, little is known about the roles played by genetical, soil-environmental and cultural factors in influencing growth partition. Among the environmental factors temperature appears to exert considerable influence on the partition of net dry weight. As mentioned earlier, shoot growth diminishes as the temperature falls and ceases below 13°C, but photosynthesis accompanied by a slower rate of respiration continues even at lower temperatures. As a result, the bush gains in weight without corresponding increase of shoot weight. This seems to be the cause for the difference observed between Assam and Kenya in the apportionment of net weight into root, wood and shoot. In the colder climate of Kenya, a relatively higher fraction of the assimilates went for the production of root and wood and a lower fraction for the growth of shoots than in Assam where conditions were warmer.

Among the cultural factors plucking has been observed to produce a profound effect on growth partition. This is evident from the trials on fish-leaf and single-leaf plucking conducted in Sri Lanka (cf. Chapter 10). Fish-leaf plucking increased shoot yield but reduced growth of leaf and woody tissues of the bush frame. These effects are further magnified by janam plucking. Pruning may also change growth partition between crop shoots and other plant organs but experimental proof is lacking.

Under conditions of N.E. India, shading diverted a relatively larger fraction of the assimilates towards the production of plucked shoots. Crop shoots accounted for 32.8, 31.6 and 28.7 per cent of the total weight of whole plants, respectively under *A. chinensis* trees, bamboo-mesh screens and in full sun (TES Ann. Rep., 1972-73). Light intensity under the trees and the screens was approximately 50 per cent of full sun. Results reported earlier in Table 50 also show that more crop shoots were produced in 50 and 35 per cent light intensities under mechanical screens than in full sunlight.

Table 54. Average annual gain in net dry weight. Mean of five clones (After Othieno, 1982)

	Plucking	Leaf	Stem	Root	Whole plant
Weight gain (q ha^{-1})	10.4	21.1	44.6	15.6	91.7
Per cent whole plant	11.3	23.0	48.6	17.1	100
Range of weight (q ha^{-1})	7.6-13.1	16.5-25.8	34.8-52.1	8.7-23.8	74.6-103.5
Per cent whole plant	8.3-12.7	20.5-25.5	44.4-51.2	10.5-24.7	100

Increased yields obtained from bushes in the second and subsequent years of longer pruning cycles is attributed to partial suppression of stem growth. This finds indirect support in the observation that the weight of prunings from annually pruned bushes is higher than the yearly average pruning weight of bushes under longer pruning cycles. Suppression of stem growth is also supposed to be the cause of increased yields of closely planted fields, but contributions from contraction of bush frame resulting in high plucking point density and from reduced stem growth towards yield have not been independently assessed.

The amount of top-growth (plucking plus pruning) made in a year per unit of bush surface did not differ between 12 widely divergent *jats* of tea grown at Tocklai, but yield of crop shoots varied significantly between the *jats* (Barua, 1959) indicating strong influence of the kind of tea on growth partition. The shrubby, multi-stemmed China plants seem to convert a higher fraction of the assimilates into crop shoots than the tree-like Assam plants. The two erect-leaf clones of Table 53, which were on the borderline between Assam and China type, had a relatively higher proportion of the net weight as harvestable shoots and lighter roots, although they were not better than the other clones in the total production of dry matter. Conversion of a larger fraction of net weight into harvestable shoots is noticeable also in the extreme China clone (d) and the China-hybrid clone (c) of Tables 49 and 50. The Chinery clone (2) of Table 5 had the lowest root weight but it was not inferior to the other clones or seed progenies in yield of crop shoots or in depth and spread of the root system. This appears to be the main point in favour of the Chinery clones having erect leaf and not their superior capacity for dry matter production which, in any case, has not been proven.

Productivity of Biomass

The unplucked bushes of Table 39 produced 30 per cent more top-growth in a year than the most leniently tipped bushes and 40 per cent more than bushes tipped at the optimum height. Magambo and Cannell (1981) reported production of 263 q ha^{-1} of net dry matter in a year by seven year old, freely growing clonal bushes in Kenya as against 169 q ha^{-1} produced by plucked bushes. These results demonstrate that from the point of biomass productivity plucking is a wasteful process. The quantity of assimilates used up in the production of crop shoots can make greater contribution to the plant in the form of wood and leaf.

Dry matter production in tapped and untapped rubber trees is analogous to that of plucked and unplucked tea bushes. Rubber trees produced 260-360 q ha^{-1} dry matter in a year when untapped but tapping reduced production to 150-200 q ha^{-1} (Templeton, 1969). Tapping checked cambial activity and reduced shoot growth. Decrease of apical activity was shown to be associated with reduction of radial growth in tea, thus indicating a relationship between the two (Barua and Wight, 1959). Plucking apparently checks cambial activity in tea as tapping does in rubber.

An approximate estimate of the productivity of biomass by mature fields of plucked tea bushes in N.E. India can be made on the basis of the data presented in Table 52. In the trial under reference, yield of plucked shoots increased by 50 per cent between the 5th and the 10th year from planting. Weight of the whole plant presumably increased to the same extent, if not more, during the same interval. The biomass produced in the 10th year, therefore, could have been of the order of 150 q ha^{-1} as against 169 q ha^{-1} produced by seven-year old bushes in Kenya. Judging from the data on root and top weights of bushes in the 12th and 21st year as given in Tables 4 and 5, annual production of dry matter does not seem to have increased appreciably after the 12th year. Hence a biomass productivity of more than 200-250 q ha^{-1} $year^{-1}$ cannot usually be expected anywhere from mature well-grown fields of plucked tea. Unplucked tea plants will produce more dry matter than plucked bushes. The difference in weight between unplucked and plucked bushes may be as high as 50 per cent. In that event, the productivity of biomass by unplucked tea plants will be nearly the same as those of grassland and forest species (Cooper, 1975) growing under the same soil-environmental conditions.

Huxley (1975) estimated 240 q ha^{-1} $year^{-1}$ to be the limit of production of the tea crop corresponding to 1100-1200 q ha^{-1} $year^{-1}$ of net biomass productivity. These estimates are far too ambitious. Calculations involving net photosynthesis, leaf-area index and respiration do not indicate biomass production by plucked tea bushes to exceed 500-550 q ha^{-1} per year under optimal conditions. Out of this, the fraction utilised for the production of crop shoots can be as high as 30 per cent or 160-180 q ha^{-1} $year^{-1}$ under ideal situations. Since optimal conditions for dry matter production do not persist even throughout a single day, a more realistic estimate of the limit of productivity of the tea crop under optimal field conditions will be less than 120 - 130 q ha^{-1} per year.

High potential notwithstanding, the actual yield of tea has rarely exceeded 40 q ha^{-1} $year^{-1}$. The latex yield of rubber is also 10 to 40 q ha^{-1} $year^{-1}$ (Templeton, *loc. cit.)*. The situation is not a happy one. A leaf crop like tea can reasonably be expected to give higher economic return than rubber. The problem of unfavourable growth partition is neither new in tea nor its solution easy. But considering the immense benefit that will accrue to the tea producers throughout the world even from a fractional increase of the harvest index, the problem deserves serious consideration. Certain clues are provided by the information presented in these pages for making a start in the investigation of the problem. Growth partition is seen to vary between (a) clones (phenotypes), (b) soil-climatic conditions (e.g. Assam and Kenya), (c) plucking systems and (d) light intensities. Close planting and long pruning cycles also seem to increase the ratio of crop shoots to total gain in weight by the whole plant. Coarser plucking does not contribute towards a solution of the basic problem. Acceptance of harder and older portions of shoots increases the gross weight of harvest but at the cost of quality of the finished product.

A multi-disciplinary approach seems to be necessary for making progress towards a solution of the problem of growth partition, in which the tea research institutions of different countries can fruitfully collaborate.

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CHAPTER 12

SHADE

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SHADE-TREE TRADITION

From the early days of the tea industry in Assam, there appears to have been a feeling among a section of the planting community that a canopy of forest trees might be beneficial for the growth of tea bushes, particularly of bushes of the Assam race. Masters (1863) voiced this feeling more than a hundred years ago by stating that "the Assam plant does not appear to thrive in the inferior soils when exposed to the full influence of the sun." He recommended partial shade for tea. Some years later, one Colonel Hannay called attention to the *sau* tree, *Albizzia stipulata* (DC) = *A. chinensis* (Osbeck) Merr., and gave it the name 'tea fertilising tree' (Watt and Mann, 1898). It was, however, Buckingham (1885) who drew pointed attention to the *sau* tree in a pamphlet written for the benefit of the Indian Tea Association, recording in it his own experience and that of several other planters about the beneficial effects of the *sau* tree on the tea bush.

Watt and Mann (1903) attached importance to the shade of the trees and advocated "slight shade in the lower part of the Brahmaputra valley (Assam), except where mosquito blight is abundant." They also cautioned against general conclusions on the usefulness or otherwise of shade *per se* being drawn from observations made in one particular locality. The benefits resulting from the use of leguminous shade trees were attributed by them primarily to the fixation of nitrogen by the tree roots. Heavy shade was considered bad for quality as it induced long and stalky growth. To counter this, they suggested a regular rotation of shade trees cut down between one and three years of age for "obtaining the benefit of the *sau* tree in situations where shade would be harmful".

Thus, planting of shade-trees among tea bushes became a practice in the plains of N.E. India since the closing years of the last century. *A. chinensis* was the first tree to be used for shading tea. Other leguminous species such as *Albizzia odoratissima, Dalbergia assamica, Erythrina indica* etc. were also introduced as shade trees almost at the same time with "nearly as much, if not equal, success" (Watt and Mann, 1903). By the first quarter of the present century most planters appear to have accepted shade as a regular feature of the tea estates in N.E. India and a tradition was built up to the extent that a good stand of shade tree came to be associated with successful tea culture.

Spread of Shade-Tree Culture to Other Countries

Other tea-growing countries and regions like Sri Lanka, Indonesia and South India followed the example of N.E. India and started planting shade trees in tea plantations. The species of shade trees used and the method of their planting were, however, quite different. The non-leguminous *Grevillea robusta* was used extensively in South India and Sri Lanka along with some species of the leguminous genera *Erythrina* and *Gliricidia*. The latter species provide a lower canopy of shade and are used mainly as providers of mulch. These trees are lopped two to four times in a year while the tall *Grevilleas* may or may not be lopped.

It may be noted that the term shade as used in South India and Sri Lanka has an entirely different meaning from that of Northern India. In N.E. India shade trees are expected to provide more or less a continuous cover for the tea bushes at a height of 6-8 m above, allowing sufficient light to filter through the feathery foliage of the shade trees, while in South India and Sri Lanka one rarely, if at all, sees a continuous cover. According to Joachim (1961) the term shade tree as used in Sri lanka is a misnomer; 'green manure tree' would be a more appropriate term.

In the early years of the century shade trees were used very frequently, though not universally, in the tea estates of Indonesia (Hope, 1916). Trees commonly used were: *A. chinensis, A. moluccana, A. falcata, Erythrina* spp. and *Leucaena glauca,* the last one being a favourite for shading young tea.

When tea cultivation was started in Africa, growers followed the practice of the old tea-growing countries and started planting shade trees, particularly in the warmer belts. *Grevillea robusta* was the most common species although other species like *A. gummifera, A. adianthifolia, Gliricidia maculata* were also grown.

In the northern latitudes of the U.S.S.R., Japan, Iran and other countries where temperature drops very low during winter, shade trees were rarely grown. Shade was considered unnecessary also in the tropical and sub-tropical belts approximately above an elevation of 1300 m as the temperature remains low at such altitudes.

EARLY TRIALS WITH SHADE TREES IN NORTH EAST INDIA

After critically examining the available evidence, Cooper (1926) evaluated the advantages and disadvantages of shade trees under conditions of N.E. India. He listed addition of plant food, suppression of weed growth, root action and protection from the hot sun as the advantages of planting shade trees among tea bushes. Early mortality necessitating the renewal of shade trees every 20-30 years, competition with tea bushes for water and nutrients and depressing effect of dense shade on yield and liquor characters of made tea were considered to be the major disadvantages of shade trees. Certain shade species compete with tea bushes for water and nutrients more than others and he named *Grevillea robusta* as one such species.

Cooper *(loc. cit.)* further observed that "dark-leafed tea can do better without shade than light-leafed varieties", and that "cut-back tea, tea for any reason weak, and tea of light-leafed *jats* benefit enormously from actual shade, apart from the other benefits derived from leguminous shade trees." He arrived at the conclusion that "it is much easier to grow tea under shade than without it, but if it were necessary, tea could be grown very well, in good climate, without shade so long as cultivation and manuring and general treatment are the best, particularly if dark-leafed varieties are used." He maintained that "when very high yields (13 to 22 q ha^{-1} in those days) are produced by tea actually covering the whole ground, then there is no room for shade trees as well, but until this limit is reached, tea will generally grow better with shade than without it". Subsequent findings confirm most of these observations.

Against such a background on the use of shade trees, experiments on concentrated inorganic and organic fertilisers were started at Tocklai. Ammonium sulphate proved to be a very efficient manure for the tea bush and the industry was encouraged to use it.

Soon after the introduction of inorganic nitrogen as a fertiliser for tea, the scientists at Tocklai appear to have noticed loss of efficiency of applied nitrogen under shade. After conducting a few preliminary experiments using green crop species like *Tephrosia candida* for shading (TES Ann. Rep., 1936), large-scale field trials were laid out both at Tocklai and in a number of tea estates to study the effect of organic and inorganic nitrogen in the presence and absence of shade trees. In some of these trials phosphate and potash were also used along with nitrogen (Cooper, 1939). It may be noted in this connection that experimenting with shade trees is not as simple as trials involving cultural operations or manuring treatments in unshaded tea. Shade trees rarely grow evenly in all the plots included in a trial. No shade tree produces a uniform pattern of shade even when the trees are well-grown and spaced properly. The shadows cast by the trees in the morning and afternoon hours falling on the adjacent no-shade plots vitiate the results. If plot size is increased to avoid interference from the shadows, experimental errors increase. Because of these, some of the shade experiments failed to give clear-cut results, but others showed the effects of shade trees and their interaction with nitrogenous manuring. To illustrate these effects, results of two of the experiments are briefly presented here.

In one experiment discussed exhaustively by Wight (1959 a;b;c), 12 disparate populations *(jats)* were grown in the sun and under *A. chinensis* trees with and without inorganic nitrogen. Nitrogen was applied as ammonium sulphate at the average rate of 90 kg N ha^{-1} per year. The tea bushes were planted during 1936-37 at a triangular spacing of 1.37 m and the shade trees were planted at the same time 13.7 m apart. The average light intensity under the trees during 1951 as measured with a Weston photocell was 50-60 per cent of full sun.

The *jats* varied from wild-type *assamica* through various integrades to *jats* with some features of the *sinensis* type, covering the entire range of forms cultivated in the plains of N.E. India. As entities all *jats* could be assigned to *assamica* type, but the range of variation suggests that the observations would be applicable to most tea plants that do not show marked attributes of the China type. The manurial treatments were altered at the end of 1951. Hence the relative effects of the treatments are shown for the period from 1942 to 1951 (Table 55).

Table 55. Relative mean yields of the 12 *jats* of tea and the range of variation between *jats*

	Without nitrogen	With nitrogen	% increase due to nitrogen	% range of variation between *jats*
Shade trees absent	100	178	78	38 to 102
Shade trees present	198	236	19	— 2 to 60
% increase due to shade trees	98	32		
% range of variation between *jats*	47 to 127	12 to 98		

The effects of shade tree, nitrogen, the *jats* and the interaction of shade tree with nitrogen came out highly significant in every year of the trial. In some years, *jat* x shade and *jat* x nitrogen interactions also became marginally significant. However, the second order interaction of *jat*, shade and nitrogen was not significant in any year (Wight, 1959 b), although the range of variation from —2 to 60 per cent suggests that response to nitrogen under shade may differ with the *jat* of tea. Yield increase due to nitrogen under shade was very low, about a fourth of the increase in full sun.

After 1944 yield did not show a rising trend in any treatment which indicates that similar results can be expected from older stands of tea under comparable environmental conditions.

In Kericho and St. Coombs, nitrogen was still less effective under shade. Visser (1961 b) reported complete absence of response to nitrogen under *Grevillea robusta* trees.

Further enquiry into the cause of shade x nitrogen interaction
revealed some interesting facts as shown in Table 56.

Table 56. Mean relative yield, bush area and yield per unit area of bush surface for the 12 *jats* of tea (After Wight, 1959 b)

	No shade, no nitro-gen (Control)	Nitrogen only	Shade trees only	Nitrogen under shade trees	Effect of nitrogen and shade trees
Relative yield	100	178	198	236	Not additive
Relative bush area	100	147	144	155	Not additive
Yield per unit area	100	113	133	144	Additive

These results show that when tea bushes are spaced sufficiently apart for the differential development of their frames, the interaction of shade trees with nitrogen in respect of shoot yield is attributable to changes of bush area and not to yield per unit area of bush surface. In view of this, the nature of the interaction between shade trees and nitrogen presumably changes when expansion of bush area is restricted by closer spacing.

The total top-growth made in a year as prunings and pluckings per unit of bush surface did not differ between the 12 *jats* while yield of plucked shoots did (Barua, 1959). Attention to the significance of this observation was drawn in Chapter 11.

The other experiment illustrates the effects of very light shade (about 20 per cent) from *Albizzia chinensis* trees in the presence of 45 and 135 kg ha^{-1} nitrogen applied per year as ammonium sulphate. The experiment was conducted on a mature field of Assam bushes spaced 1.22 m apart. Yield data for the 9 year period from 1948 to 1956 are presented in Table 57.

Table 57. Total yield of made tea in kg ha^{-1} for 9 years

	Nitrogen kg ha^{-1} year^{-1}		% increase due to additional 90 kg N
	45	135	(135—45)
Shade trees absent	8,787	13,792	57
Shade trees present	11,692	16,033	37
% increase due to shade trees	33	16	

In this very lightly shaded trial the effect of shade was much less and that of nitrogen considerably higher than in the previous trial.

These and other trials conducted on shade in N.E. India during the first half of the century were mainly concerned with establishing the practical worth of shade trees vis-a-vis inorganic nitrogenous fertilisers. A light even shade was observed to benefit growth and yield of tea bushes. Effect of applied nitrogen was found to diminish under shade but the combined effects of good light shade and moderate doses of nitrogen (90-120 kg ha^{-1}) on the yield of crop shoots was observed to be superior to the individual effect of either shade or nitrogen. The possibility that all kinds of tea may not react in the same way to shade and nitrogen under shade was also indicated. Species of shade trees commonly grown in N.E. India varied in their effects on the yield of tea (Dutta, 1961).

IS SHADE NECESSARY?

From about the early fifties, there was a fresh surge of interest in the problem of shade in tea. Renewal of interest in shade can be traced to the advent of the Blister Blight disease in South

India, Sri Lanka and Indonesia in the early forties. The disease was observed to cause greater harm to shaded than to unshaded sections of tea. In the early sixties, shade trees figured prominently in the discussions at the Tea Research Institutes of South India, Sri Lanka and Africa. In East Africa, Child (1961) reviewed the historical development of the shade-tree tradition in India and Sri Lanka and compared the effects of shade trees as observed in Kenya, Malawi, Indonesia and India. He concluded that there could be no universally applicable advice on shade planting and that "from a longterm point of view, we may expect moderate shade, properly managed and controlled, to be beneficial to tea in East Africa." Subsequent studies belied this expectation. In Kenya, yield of crop shoots dropped as the percentage of bushes receiving shade from *Grevillea* trees increased (Mc Culloch *et al.*, 1966). In Malawi, shade trees depressed yield and reduced the efficiency of applied nitrogen (TRFCA Ann. Rep., 1965-66).

Joachim (1961) and Visser (1961 a; b) in Sri Lanka presented diametrically opposite views which indicated the prevailing uncertainty and inadequacy of information about shade. Joachim advocated the use of 'green manure' trees for supplying organic matter to the soil while Visser (1961 a) tried to repudiate most of the virtues attributed to shade trees. Limitation imposed by shade on the efficacy of nitrogenous fertilisers was his main argument against the use of shade trees. De Weille (1959) advocated complete removal of shade trees from the tea plantations of Indonesia. Thus, a climate of opinion deprecating the use of shade trees developed in the early sixties in many parts of the tea-growing world. In N.E. India also, where the shade tree tradition originated, some difference of opinion surfaced among scientists and tea planters alike on the question of shade.

The controversy promoted such questions as : is shade really necessary for tea? If so, under what conditions? Where shade trees have been observed to benefit tea bushes, is it not possible to provide the same benefit without going into the trouble and expense of planting trees and replacing them two-three times within the life-span of a tea population? These and allied questions led Tocklai to undertake a series of basic and field investigations, reference to some of which has been made in the previous chapters. In the following pages the shade problem in tea is examined in the light of those and such other investigations carried out at different tea research institutions.

THE SHADE PATTERN

As mentioned earlier, the concept of shade as a thin and unbroken cover of foliage over tea bushes is prevalent only in N.E. India. Such a cover of foliage was achieved to a fair extent under well-grown and properly spaced stands of *Albizzia chinensis* trees. Unlike *chinensis* other commonly used shade trees do not possess thin spreading canopies and at normal spacings, they provide patchy shade. If planted closer to provide a continuous cover, shade becomes too heavy. *A. chinensis* can no longer be used due to its extreme susceptibility to 'canker' which has killed thousands of trees during the last four decades. Effective cure of canker has not yet been discovered and a suitable substitute for *chinensis* has not so far been found. Only *Albizzia zygia,* an exotic species, resembles *A. chinensis* in canopy characteristics (Hadfield, 1963), but this species does not produce seed under N.E. Indian conditions and seed from outside sources is difficult to procure. Currently *Albizzia odoratissima* is the most popular shade tree in N.E.India but it has a thicker crown than *chinensis* which makes its shade less even at normal spacings and too heavy when the trees are planted closer. An idea of the pattern of shade cast by this tree can be had from Table 58.

The terms light, medium and heavy shade as used in the industry are purely subjective. What is medium shade to one observer may be heavy to another. Light shade may mean a thin fairly even canopy or it may refer to a virtually unshaded section of tea having a few scattered shade trees. An objective definition of shade status was first attempted by measuring light intensities with Weston photoelectric meters. Light reflected from a white board held above the tea bushes was measured with the instrument, simultaneously in the open and in shaded areas. Shade light was expressed as a percentage of the intensity recorded in the open.

The method, however, did not reveal the proportion of shaded, partly-shaded and unshaded bushes. If one half of a section of tea is covered by a black cloth leaving the other half exposed to the sun, the method would give a reading of 50 per cent light intensity for the entire section.

Hadfield (1974 a;b) re-examined the problem first by measuring with a Spectroradiometer the intensity of incident radiation at wavelengths of 380 to 1400 nm. The measurements were made under clear and cloudy sky, at different hours of the day and at different times of the year. Similar measurements were repeated in sections of tea shaded by a number of indigenous and exotic tree species. Typical examples of spectral analyses made in the open and under shade on clear days and under a uniformly overcast sky are given in Fig. 25 and Fig. 26.

Variation in the intensity of sunlight incident on a horizontal surface at a particular hour on clear days in March and May can be seen from Fig. 25. On a clear day, radiation intensity directly below the canopy of *Albizzia odoratissima* trees dropped to about a fifth of full sunlight throughout the 400—1400 nm spectral range. Fig. 26 shows that complete occlusion of the sun reduced the intensity of incoming radiations to about a sixth of a clear sky. This happened throughout the 380—1400 nm spectral region. Shading caused a further 30—40 per cent reduction in the 400—750 nm visible range, but had virtually no effect beyond 850 nm.

As a sequel to these studies, Hadfield (1974 a) looked for a simple method for characterising the light climate of shaded tea sections as well as for comparing the pattern of shade cast by different tree species. He finally adopted the ‘area survey method’ originally proposed by Evans (1956) for the study of light climate in woodlands. The method involves recording visually the area of sunflecks incident on the surface of each one of a representative sample of bushes in a section of shaded tea. A white board is used for the purpose. Large gaps in the canopies of shade trees which produce no shadows on the board are considered as large sunflecks occupying 100 per cent of the board. After some practice sunfleck area can be assessed rapidly.

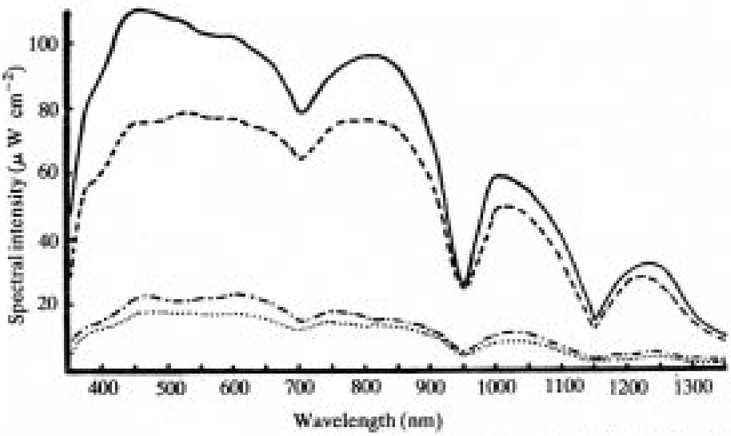

Fig. 25. Spectral analysis for the spectral region 380-1400 nm for full light in March (– – – –) and early May (———) compared to readings directly beneath a canopy of *Albizzia ordoratissima* in March (.............) and early May (–·–·–). Visible sunflecks were absent in the area where the 'beneath canopy' readings were taken. (After Hadfield, 1974a).

The bushes subjected to full solar radiation, complete shadow or a mixture of shade and sunfleck light are then sorted out. The readings are taken on a few occasions at different hours of the day. Even in the absence of spectral data, a reasonable estimate of the shade status of a section of tea can be obtained by this method. An example of the kind of information provided by the area survey method is given in Table 58. The observations were taken during cloudless periods in late May in a mature section of tea at Tocklai under a stand of *Albizzia odoratissima* planted 11 m apart.

Between 10 and 16 hours, 60 to 80 per cent of the shaded area was occupied by sunflecks which is unmodified sunlight i.e. only 20 to 40 per cent of the bushes were under 'shade light'. About 50 per cent of the bushes received almost full sunlight from mid-day till about 15 hours with a corresponding reduction in the number of bushes receiving less than 50 per cent sunlight during this part of the day.

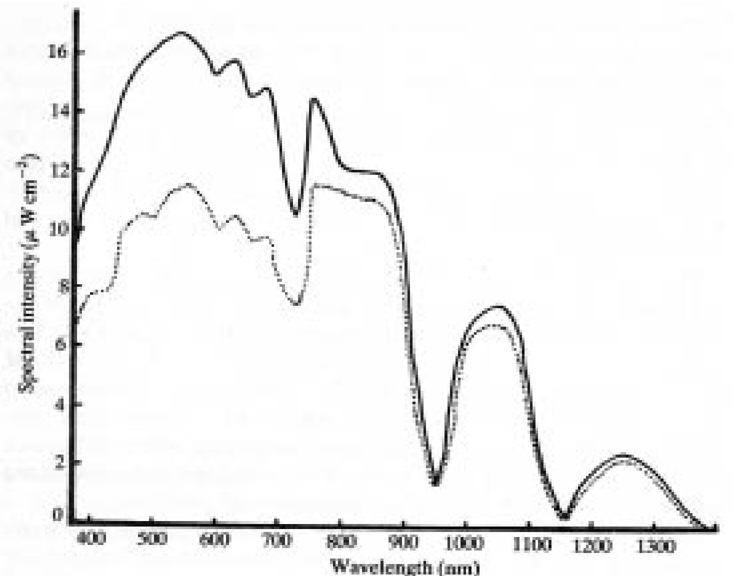

Fig. 26. Spectral analysis in the spectral region 380–1400 nm of light from a uniform overcast sky at 13.30 hours in late June (———) compared to that under a shade tree canopy when no shadow was present (.............). (After Hadfield, 1974a).

Table 58. Light pattern in a shaded section of tea at Tocklai (After Hadfield, 1974a)

	Local Tocklai time			
	10.02 hr	12.02 hr	14.02 hr	16.02 hr
Percentage area occupied by sun-flecks	68	74	80	60
Percentage unshaded bushes (i.e.- over 90% sunflecks)	28	43	53	33
Percentage bushes receiving less than 50% of full sunlight	47	29	20	50

These results show that even a shade tree like *A. odoratissima,* which is now used extensively throughout N.E. India, does not fulfil the basic requirements of light, even shade when planted at the normally accepted optimum spacing. Closer planting or better growth of the trees would have reduced the proportion of unshaded tea bushes with corresponding increase of the proportion of bushes receiving less than 50 per cent sunlight. The latter condition is undesirable since it reduces the photosynthetic efficiency of the shaded bushes.

The results reveal the actual state of shade in the tea estates of N.E. India where provision of a thin unbroken cover of foliage over tea bushes has always been the aim. The few shade trees now available to the growers are incapable of providing such a shade cover when planted in pure stands. Tocklai has recommended planting of shade trees in mixed stands, preferably using four species in intimate mixtures, but expectancy of a uniform pattern of shade under such mixed stands would be unrealistic although mixed stands are desirable from other considerations.

Despite these inadequacies, a much higher proportion of the tea bushes in N.E. India remains under shade than in other parts of the world where provision of a continuous cover over tea bushes had never been the aim. By N.E. Indian standard, tea in other regions will appear grossly undershaded. It will be of interest to compare the results obtained with the area survey method in N.E. India with those obtained by the same method in South India and other places where planting of shade trees is still favoured.

EFFECT OF SHADE *PER SE*

Reduction of Light Intensity and Temperature

Actual shade of the trees were among the benefits of shade trees mentioned by Cooper (1926). Subsequent investigations (cf. Chapter 11) have amply corroborated this foretaste. Observations made under a wide range of environmental conditions in N.E. India showed that on bright days in summer when the dry bulb temperature rose to 30°—32°C, temperature of tea leaves fully exposed to the sun reached 40°—45°C. Flat or horizontal leaves were 2° to 4°C warmer than erect leaves, but temperature of both types of leaves attained 40°C and above under such ambient conditions. Shading caused leaf temperature to remain within ± 2°C of the ambient (Hadfield, 1968). Since leaf temperature above 30°C is harmful for net photosynthesis by tea leaves (cf. Chapter 11), shade can enhance dry matter production by keeping the leaves cooler on hot days in places like N.E. India where temperature of exposed leaves rises above 30°C. In cool climate where leaf temperature remains below 30°C for a large part of the growing season, shade will depress photosynthesis by preventing temperature of leaves to rise towards the optimum.

Even in warm climate shade becomes unnecessary under overcast sky and this is a common feature in N.E. India during the main growing season. Wherefore, it amounts to balancing the benefit from shade during hot sunny weather against its depressing effect on photosynthesis in dull cloudy weather. In warm climate the gain due to the presence of moderate shade appears to be more to offset the loss. .

Permanent shade as provided by certain trees has another disadvantage. In places away from the equator, winter temperature may drop so low as to make shading unnecessary. In such locations the deciduous shade trees have some advantage over evergreen trees in as much as their leaves drop at that time of the year making shade less dense. Whether shade trees help in conserving soil moisture during dry winter will be examined later.

From a comparison of the maximum temperatures of different tea-growing countries, it is seen that the highest temperature is experienced in the plains of N. E. India during the main growing season from April to October. In the equatorial tea belt of Africa (eg. Kenya, Uganda, Tanzania etc.), high and mid elevation tea areas of Sri Lanka and high elevation tea estates of South India and Indonesia, the monthly mean maximum temperature does not rise above 30°C at any time of the year. (See Table 8). In Malawi, the monthly mean maximum temperature goes up to 31°C during the early part of the main harvesting season but air turbulence there being much more than in N.E. India, leaf temperature is less likely to remain above 30°C for long periods. The conflicting results obtained from experiments with shade trees in N.E. India, Sri Lanka, Africa and Indonesia can, therefore, be attributed primarily to differences of ambient temperature at the experimental sites (Hadfield, 1968).

The soil also remains cooler under shade. Soil temperature does not fluctuate as widely in shaded than in unshaded tea. Eden (1961) mentioned reduction of soil temperature as one of the many uses of shade trees. High soil temperature is harmful for the growth of tea roots (cf. Chapter 11). Wide fluctuation of soil temperature is also undesirable for root growth.

Shade trees intercept both infrared and visible radiations of sunlight reducing thereby the incidence of not only heat but light energy on the tea bushes underneath. Besides intercepting solar energy, shade trees add organic leaf litter to the soil, compete with tea bushes for water and nutrients and leguminous trees fix atmospheric nitrogen. These and other effects attributed to shade trees (to be discussed later) modify their role as reducers of heat and light. To study the effects of reduction of heat and light energy incident on tea bushes free from the other effects of tree shade, bamboo mesh screens were used in a number of experiments at Tocklai for shading tea bushes. Bamboo screens transmitting 50—60 per cent of the incident radiation increased shoot yield of young as well as mature bushes in some of these experiments while reducing yield in others (Barua, 1961; Barua and Sarma, 1982). An example of the negative effects of artificial shade is given in Table 59, which also includes the effects of tree shade as it was another treatment of the same experiment. *Albizzia chinensis* was the shade tree used and the shade provided by the trees was maintained approximately at 50-60 per cent of full sunlight by judicious lopping of branches from time to time. We shall first consider the effects of bamboo screens and revert to shade trees a little later. Reference to this trial was made also in Chapter 11 under dry matter production.

Yield of the experimental area as a whole was quite high, comparable to any high-yielding section of tea of the locality, but clones in each leaf-pose category varied widely in vigour and yield. Bamboo screens depressed mean yield of the clones to less than that in full sun. It is noteworthy that yields of clones belonging to all the three leaf-pose categories was depressed by screens, although in the light of the arguments advanced by Hadfield (1968), yields of flat-leaf clones should have improved and those of the erect category should have registered the maximum drop under the screens. Only three weakest clones of erect and semi-erect categories and three other below-average clones showed some yield improvement under the screens.

These apparently irreconcilable results obtained under artificial shade, in reality, follow a definite intelligible pattern. Shoot yield of all vigorously growing tea bushes with thick maintenance canopies providing complete ground coverage was depressed by overhead bamboo mesh screens transmitting approximately 50—60 per cent of the incident solar radiation, while growth and yield of young plants and weak mature bushes improved under the screens. Inherently weak clones irrespective of their leaf pose and bushes debilitated by adverse growing conditions behaved in the same way. An inherently vigorous erect-leaf clone growing poorly on impoverished soil produced more crop shoots under bamboo-mesh screens but the same type of screen depressed yield of the clone at another more fertile site within the same locality where it was growing vigorously (Barua, 1961). These results lead to the conclusion that thinness or thickness of the maintenance leaf canopy determines the reactions of all types of tea bushes to shade *per se.*, in the warm climate of N.E. India. Similar effect of shade can be envisaged in other regions where leaf temperature rises above the optimum on direct exposure to sun.

When the canopy of maintenance foliage is thin due to intrinsic lack of bush vigour, poor growing conditions or young age, direct sunlight can reach some of the lower leaves in the canopy and cause overheating. Hence in the absence of a shade/cover a large fraction, if not the entire photosynthetic system of weak and young tea bushes, suffers from the adverse effects of high temperature. Because of this,young and weak tea bushes growing in warm climate make better growth and produce higher yields under shade than in the open.

In vigorous tea bushes carrying thick maintenance canopies only the surface layer of foliage and possibly a few leaves just

Table 59. Average dry weight of plucked shoots in kg for 9 years from 9 bushes of each treatment (After Barua and Sarma, 1982)

Leaf-pose category	No. of clones	Treatment			% range of increase or decrease over full sun	
		Full sun	Bamboo screen shade	Tree shade	Under bamboo screens	Under tree shade
Erect	7	8.2	7.5	9.8	−18.8 to 3.6	0.5 to 40.2
Semi-erect	12	8.2	7.2	9.4	−28.0 to 21.9	−3.4 to 46.2
Flat	5	6.6	5.7	8.4	−33.8 to 19.0	10.1 to 60.8
Mean.		7.7	6.8	9.2	−10.1	20.4

below the top get heated up on exposure to direct light. Being shaded by the leaves above, temperature of the lower leaves does not rise above air temperature. Shade improves photosynthetic efficiency of the surface leaves by keeping them cooler. Reduction of light energy does not affect photosynthesis by the surface foliage so long as shade is not too heavy, since solar energy on bright summer days is much in excess of the requirement for maximum photosynthesis by tea leaves (cf. Chapter 11). However, the lower leaves of such bushes which do not get enough light even when the bushes are fully exposed to the sun, suffer from the imposition of shade and their photosynthetic efficiency is further reduced. The loss of photosynthetic efficiency by a very large fraction of the foliage remaining underneath the top layer appears to be the cause of yield depression of vigorous bushes under mechanical screens. The gain in photosynthetic efficiency by the surface layer of leaves cannot apparently compensate for the loss sustained by the lower foliage.

Visser (1961 b) has argued that effect of shade on tea is determined by the availability and utilisation of nutrients, mainly nitrogen, by tea bushes. Bushes respond to shade only when nitrogen and other nutrients are in short supply. In support of these arguments he quoted data from two experiments on tea and a few on cacao. In a trial at St. Coombs, Sri Lanka (Eden, 1949) and another at Kericho, Kenya (TRIEA 1956; 1957; 1958; 1959) tea bushes did not respond to *Grevillea robusta* shade nor to nitrogen under shade, but yield of unshaded tea increased linearly as the nitrogen dose was raised from 20 lb to 80 lb acre^{-1} (22 kg to 90 kg ha^{-1}), 80 lb being the maximum dose used in these trials. Yield of cacao grown on the rich soils of Ghana was depressed by *Gliricidia maculata* shade trees which also reduced drastically the response to N, P ,K and Mg applied in combination (Cunningham and Lamb, 1959). On the poor soils of Trinidad where yields were much lower than in Ghana, shade from *Enythrina poeppigiana* (Maliphant, 1959) and artificial screens transmitting 50 per cent light intensity (Murray, 1955) increased yield of cacao, although NPK nutrients had less effect under shade as in Ghana.

The foregoing observations corroborate our interpretation of the effects of shade on the growth and yield of tea. Failure of *Grevillea* shade to improve yield in the cold climates of Kericho and St. Coombs can be expected from our observations on leaf temperature. Nutrition plays only an indirect role in determining the effect of shade. Nitrogen and other nutrients improve growth and vigour which is accompanied by the production of a large number of maintenance leaves and we have already seen that yield of vigorous bushes with thick maintenance canopies was reduced and that of weak bushes with thin canopies was increased by artificial shade. Nutrition reduces the effect of shade by increasing the size of the maintenance canopy. Responses of the cacao plants of Ghana and Trinidad to shade seem to have depended on their vigour .or lack of it as in the case of tea.

Conversely, response of tea bushes to nitrogen and possibly other nutrients, both in the open and under shade, also depends on the size of the maintenance canopy. As the canopy gets thicker and denser, passage of light to the lower leaves is obstructed, carbohydrate synthesis falls and fertilisers become less effective. A stage is finally reached when further increase in the dose of fertiliser cannot induce any more growth. This light-limiting stage is reached earlier in shaded than in unshaded tea, because light is reduced in intensity while passing through the overhead shade canopy. For this reason the optimum fertiliser dose for tea under shade is lower than for bushes growing in the open.

Thus, in the final analysis, it is the maintenance leaf cover which, in warm climate, directly determines the response of plucked tea bushes to shade. Soil fertility or nutrient supply plays an indirect role by influencing growth and foliation of the bushes. Response to fertilisers is also linked with the size of the maintenance leaf canopy, both in the open and under shade.

LEAF AREA INDEX

The terms ‘thick’ and ‘thin’ cannot give any precise indication of the depth of maintenance leaf cover of tea bushes. Leaf Area Index (LAI), which is the ratio of leaf area to ground area (cf. Chapter 10), is an objective measure of canopy depth. Unfortunately, LAI was not recorded in any of the trials with artificial shade mentioned earlier, which makes it dificult to suggest at what LAI tea bushes can do without shade. Besides kind of plant, cultural treatments notably pruning and plucking, and climatic parameters apart from temperature, complicate the issue. Hadfield (1968) observed shoot yield of a flat leaf clone with LAI 3 to increase and that of on erect-leaf clone with LAI 5 to decrease under bamboo-mesh screens of 50 per cent light transmission. No generalization is possible from this single observation particularly when LAI of 8 or even higher has been recorded in vigorous fields of mature clonal tea. Although the effect of such high LAI on growth and yield of tea is not known, yet a ceiling LAI can be inferred for each situation arising out of plant type, climate and cultural treatments. Above the ceiling, yield may actually show a decline even in full sun. This is an aspect of crop shoot production which has not received much attention.

EFFECT OF SHADE TREES

Both shade trees and artificial screens reduce the intensity of heat and light energy incident on the tea bushes underneath, but their effect on growth and yield of tea could be very different as can be seen from the data presented in Table 59. In comparison with the average yield of bushes growing in the open, bushes under bamboo screens produced 10 per cent less and those under *Albizzia chinensis* trees, 20 per cent more total yield over the nine-year period of plucking, although in the first four years the clonal bushes of the area as a whole produced higher yields under the screens than in the open. The maximum yield was produced under the trees in every year of the trial (TES Ann. Rep., 1972-73). Not only the yield of crop shoots but also the total production of dry matter increased under the trees (Barua, 1981). These results led Barua and Sarma *(loc. cit.)* to the conclusion that from the response of tea bushes to artificial shade results to be obtained under natural shade cannot be predicted.

Temperature under the two types of shade was almost the same. The screens provided more uniform shade than the trees but the average light intensity was about the same under both. Some bushes in the periphery of the plots shaded by trees received direct sunlight for short periods during the morning and afternoon hours when the sun was at a low angle and this was considered to be an important cause for the favourable response of bushes to tree shade (Barua and Sarma, *loc. cit.).* However, this could not have been the sole reason. Admittedly, no serious attempt has so far been made to understand the cause/s of the differential response of tea to artificial and natural shade.

Besides giving protection from the direct rays of the sun, shade trees are assumed to benefit the growth of tea bushes in a variety of ways such as (a) addition of organic matter and nutrients to the soil through leaf-fall, (b) turnover of nutrients from the lower layers to the surface soil, (c) fixation of atmospheric nitrogen by roots of leguminous shade trees, (d) conservation of soil moisture, (e) protection from hail and storm, (f) reduction of the incidence of red spider and other mites,(g) suppression of weed growth and (h) providing comfortable working conditions to the labourers. These are important attributes, but few attempts have been made to evaluate them quantitatively. An examination of the available evidence is attempted below.

Nutritional Value of Shade Trees

The first three attributes fall under this head. Shade trees add leaf litter to the soil but the quantity varies with the species, spacing of the trees, their age and health. In N.E. India, a well-grown stand of *Albizzia chinensis* planted 12 m square (70 trees per hectare) produced 50 q of dry leaf litter per hectare in the seventh year (Dutta, 1960). Another stand of *A. chinensis* at a different site produced up to 50 q ha^{-1} leaf litter but the productivity dropped as low as 25 q in some years. The leaf litter contained 2.51 per cent N, 0.88 per cent K_2O, 0.71 per cent P_2O_5, 1.27 per cent CaO and 0.62 per cent MgO (TES Ann. Rep., 1972-73).

The underground roots of shade trees also contribute organic matter to the soil but contribution from this source has rarely been taken into cognizance. Like tea roots the young roots of shade trees die and regenerate in waves but it is extremely difficult to determine the weight of dead roots. It could be quite substantial. Besides supplying organic matter, the roots leave air spaces when they die and decompose. The air pockets are particularly useful in stiff soils where lack of aeration is often a serious problem.

In Sri Lanka, Visser (1961 a) uprooted two *Grevillea robusta* and two *Albizzi moluccana* trees aged about 10 years and determined the dry weights and N, P and K contents of different plant parts. The results were expressed in pounds per acre assuming 60 *Grevillea* and 35 *Albizzia* trees per acre planted respectively at 29 feet (8.8 m) and 35 feet (10.7 m) square spacings. The data are reproduced in Table 60 after converting the dry weights into quintals per hectare. The N, P, K contents are expressed as percentages on dry weight.

Weight of leaves and twigs amounted to 22 q ha^{-1} for each of the two species. However, the quantity of litter produced by these two species in Sri Lanka was less than the quantity provided by *Albizzia chinensis* trees in N.E. India. This happened despite the fact that the numbers of *Grevillea* and *moluccana* trees in a hectare of the Sri Lanka trial were 130 and 86 respectively, while only 70 *A. chinensis* trees were present per hectare in the N.E. Indian trial. Growing conditions for these shade trees in the two countries seem to be primarily responsible for the difference in the productivity of leaf litter. For instance *A. moluccana* grows very vigorously in N.E. India and its canopy becomes so big and dense within 3-4 years that the species is not recommended as a permanent shade tree for tea. However, addition of 20 q leaf litter per hectare every year is quite a useful contribution towards the organic matter pool of tea soil.

Despite some inevitable discrepancies between separate estimates, analytical data of leaf litters clearly show that considerable amounts of inorganic nutrients are returned to the surface soil every year by the droppings of shade trees. The leaf litters of the *Albizzia* trees were richer in nitrogen than that of the non-leguminous *Grevillea*. As a matter of interest, the highest and the lowest amounts of inorganic nutrients added to the soil every year by *A. chinensis* shade trees in N.E. India, assuming 50q and 20 q to be the maximum and minimum leaf-fall per hectare, and by the *Grevillea* and *A. moluccana* trees in Sri Lanka are computed from the data cited above and presented in Table 61.

Indication of the beneficial effects of the shade tree litter on the tea crop was obtained from the same experiment reference to which is made in Table 59. Removal of the droppings of *A. chinensis* trees reduced yield of crop shoots by 18 per cent in comparison with plots from which the droppings were not removed. Addition of equivalent amounts of leaf litter from the same shade species increased yields of plots in full sun and under bamboo mesh

Table 60. Weight of dry matter in q ha^{-1} produced by *G. robusta* and *A. moluccana* shade trees and per cent N, P, K contents of different plant parts (After Visser, 1961 a)

Plant parts	*G. robusta*				*A. moluccana*			
	Dry wt	N	P_2O_5	K_2O	Dry wt	N	P_2O_5	K_2O
Leaves and twigs	22.3	1.53	0.38	1.02	22.6	2.08	0.52	1.05
Branches	32.6	0.31	0.10	0.83	31.8	0.31	0.10	0.98
Trunks	134.4	0.31	0.13	0.60	226.2	0.32	0.08	0.38
Roots	55.6	0.31	0.12	0.81	101.0	0.31	0.13	0.66
Total	244.9				381.6			

screens by about 11 per cent above their respective controls. Similar results were obtained in Kericho, Kenya, where removal of the droppings of shade trees decreased yield of tea significantly (TRIEA Ann. Rep., 1957; 1958; 1959).

Presence of nodules in the roots of *A. chinensis* and *A. odoratissima* shade trees growing amongst plucked tea bushes of N .E. India indicates symbiotic fixation of atmospheric nitrogen by these trees. Other leguminous shade trees may also fix nitrogen. However, acidic tea soils and application of large amounts of soluble nitrogenous fertilisers retard rhizobial activity. Hence the quantity of nitrogen fixed by leguminous shade trees planted amongst tea cannot be large. Visser (1961a) was of the view that significant amounts of nitrogen would still be fixed by some of the leguminous shade trees, but no attempt has so far been made to estimate the quantity. Indirect evidence of symbiotic nitrogen fixation by leguminous shade species is obtained from an experiment reported by Dutta (1961) . Yield of tea under six leguminous species including *A. chinensis* and *A. odoratissima* increased by 20 to 36 per cent in comparison with yield of the control plots in full sun, while yield under the non-leguminous *Aleurites montana* did not differ significantly from the control. These results were obtained in the absence of any added fertiliser. However, variation in the amounts of nitrogen fixed was probably not the only cause of unequal yield increase.

Table 61. Inorganic nutrients in the leaf-fall from shade trees in kg ha^{-1} $year^{-1}$

Nutrients	N. E. India *A. chinensis*		Sri Lanka	
	Maximum	Minimum	G. *robusta*	*A. moluccana*
N	125.5	50.2	34.1	47.0
K_2O	44.0	17.6	27.7	23.7
P_2O_5	35.5	14.2	8.5	11.8
CaO	63.5	25.4		
MgO	31.0	12.4		

Data on the micronutrient contents of shade tree litter are not available under the different leguminous species. The species differed in their canopy characteristics and the pattern of shade. The average light intensity under the different species ranged from 41 to 60 per cent of full sunlight. Yield increase under *Dalbergia assamica* was the least among the leguminous species. It is a tall tree with a narrow canopy which remains leafless during whole of the dry winter and early spring.

Roots of shade trees are generally believed to penetrate deeper into the soil than the roots of plucked tea bushes, enabling them to absorb nutrients from lower strata of soil beyond the reach of tea roots and trap some of the nutrients leached down from the top soil. When leaves, pods and twigs of shade trees drop on the surface soil, the nutrients present in the dropping, in due course, become available for absorption by tea roots. In other words shade trees are assumed to enrich the top soil at the expense of deeper strata of soil which are not available to tea roots for exploration.

Adverse soil conditions like high watertable, lack of aeration, presence of hard pan etc. that limit the downward movement of tea roots, conceivably have similar effects on the roots of shade trees. However, considering that the roots of unpruned and unplucked tea seed trees go deeper than those of tea bushes under plucking (cf. Table 3), it is quite likely that shade trees produce somewhat deeper root systems than plucked tea bushes even in situations where soil conditions do not favour the growth of deep roots. The deep roots of shade trees take up water and nutrients from soil where tea roots do not exist. Some of the nutrients absorbed by these roots are brought to the surface soil by the fallen litter of leaves, thus effecting circulation of nutrients. When conditions are not favourable for the growth of deep roots, the quantity of nutrients involved in the circulation has to be small because the difference in the root depths of tea bushes and shade trees would be very narrow.

Not all shade tree roots grow deeper than tea roots; many occupy the same volume of soil where tea roots grow and compete with the latter for water and nutrients. Of the nutrients absorbed by shade trees, a part comes down on the surface soil in the leaf droppings and a fraction remains locked up in the trunks and branches of the trees and is permanently lost to the soil. Nutrients held by the thick roots of shade trees are eventually released to the soil when the roots decompose unless the trees are removed with the roots. The quantities of NPK nutrients locked up in the trunks and branches of the two shade trees *G. robusta* and A. *moluccana* and the amounts returned to the soil by the litter of fallen leaves and twigs are shown in Table 62, the calculations being based on the data of Table 60. It is assumed that the roots decay *in situ.*

The figures for nutrients removed by shade trees according to Visser (1961 a) were underestimates due to the fact that larger offtakes were observed by Lamb *et al*. (1955) by young *Aibizzia sumatrana* trees during the first three years after planting. Such differences between trees, their age and errors in nutrient determinations notwithstanding, it is apparent that quantities of nutrients returned to the soil by the leaf litter are much in excess of the amounts locked up in the permanent parts of shade trees. Although this is likely to be the pattern for all shade trees, the actual quantities of nutrients removed from and returned to the soil will depend on the species of trees, their planting density, location etc.

The gaps in our knowledge regarding the contribution of shade trees towards nutrition of tea will be apparent from the foregoing account. The amounts of nitrogen fixed by leguminous trees and the extent of nutrient turnover from lower to the surface layers of soil are still matters of speculation. Estimates of return and removal of nutrients are also extremely few. Need for more information on all these aspects is obvious, at least in those regions where shade trees are going to remain as permanent features of tea plantations. The existing evidence, however, demonstrates the importance of shade trees as suppliers of large amounts of organic matter. Where shade is necessary for keeping tea leaves cooler, the leaf litter comes as a bonus. The value of the leaf litter for maintaining the soil in good physical condition cannot be ignored. It also helps in raising the nitrogen status of the soil. Gokhale (1960) investigated the nitrogen contents of the top soil profile in unshaded tea and tea shaded lightly by *Albizzia chinensis,* both the treatments receiving NPK fertilisers. After 15 years of continuous treatment, the nitrogen content of the unshaded tea soil was 5.5 per cent lower than that of the shaded. These exploratory studies suggest the

Table 62. The quantities of NPK nutrients removed in the trunks and branches of *G. robusta* and *A. moluccana* and returned to the soil by their leaf droppings in kg ha^{-1} $year^{-1}$

	G. robusta			*A. moluccana*		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Quantity returned	34.1	8.5	22.7	47.0	11.8	23.7
Quantity removed	5.2	2.1	11.6	8.2	2.1	11.7

importance of shade tree droppings in the nutrition of tea, but thorough investigation is needed on the changes of physical and chemical properties of soil in shaded and unshaded tea as well as on the feeding zones of tea and shade tree roots in different types of soil. The latter study has been made possible by the development of radio-tracer techniques.

Moisture Status of Soil Under Shade

Uneven distribution of the annual rainfall is characteristic of all but very few of the tea areas of the world. Inadequacy or complete cessation of rain for long periods creates condition of water stress which limits productivity and, in extreme situations, kills tea bushes. One of the reasons for interplanting shade trees in the tea plantations of North and South India is to provide some relief to tea bushes in periods of drought, since it is believed that certain shade trees help in conserving moisture in the soil. At first sight such an assumption appears unjustified because transpiration by the shade trees adds up to the loss of moisture from the soil but, at the same time, the leaf litter of the trees and the cooling effect of shade reduce evaporation from soil and transpiration by tea. The saving of water by mulching and cooling may, under appropriate conditions, exceed the water lost by the shade trees in transpiration.

According to some reports from North and South India, the presense of certain shade trees had helped in the conservation of water during dry spells. Although such reports are not many, a table has been compiled with data from different sources of N.E. India to illustrate the effects of a number of tree species on the moisture status of tea soils. The observations presented in Table 63 were made during the driest part of the year on sandy loam soils where mature leaves of tea wilt permanently below a moisture content of about 7 per cent.

The significant effect of shade *per se* can be seen from the difference in the moisture content of unshaded soil and soil shaded by artificial screens. The young *chinensis* trees providing hardly any shade and drawing water apparently from the root zone of tea bushes caused greater depletion of soil moisture than in unshaded tea but trees of the same species, when mature, helped to conserve moisture as shown by the data in B. *A. procera,* another leguminous species commonly grown for shading tea in N.E. India, failed to conserve any moisture. Of the five leguminous species shown in C, soil moisture under *A. odoratissima* and two others was significantly higher than under the remaining two. *A. zygia* was one of these two species although, as pointed out earlier, it has desirable canopy characteristics. Soil moisture data under two non-leguminous forest species are included under D as a matter of

Table 63. Per cent soil moisture in the presence and absence of shade trees and artificial shade

Type of shade	Age of tea and shade trees	Time of sampling	Sampling depth in cm	% moisture	Source
A. No shade	2-3 years	January	0-23	10.5	TES
Bamboo screens				12.0	Ann. Rep.,
A. chinensis				9.4	1962
		L.S.D. at 5%		0.9	
B. No shade	10 years	March	0-23	9.4	
A.procera				9.2	Dutta,
A. chinensis				11.5	1961
		L.S.D at5%		1.4	
C. *A. odoratissima*	7 years	March	2.5-45	11.6	TES Ann. Rep.,
A. gummifera				8.6	1963.
A. zygia				9.4	
Adenanthe-era pavonina				11.0	
Milletia dura				11.6	
		L.S.D. at 5%		1.8	
D. No shade	10 years	March	0-30	8.5	
Premna bengalensis				8.8	
Melia				8.9	
azedarach				N.S.	

interest. These estimates were made during an unusually dry spell. Interestingly, the presence of the trees did not have adverse effect on the moisture content of the top soil.

Venkataramani (1961) determined soil moisture at 0-23 cm and 23-46 cm depths at Davershola, South India, in unshaded tea and tea shaded by *Erythrina lithosperma.* The moistme content at both depths was higher in the shaded than in the unshaded areas.

Moisture status of soil under shade trees is only of academic interest to tea growers in those regions where shade trees are unwanted. Confining observations to areas where shade has been found useful, it appears that fully-grown stands of certain shade trees can assist conservation of moisture during dry spells. Suitability of a species for this purpose can be ascertained only by field trials extending over a number of years to enable the trees to grow to full size. No selection criterion has yet been found to dispense with or shorten the field trials. Desirable canopy characteristics have not proved to be suitable selection criteria for shade trees from the point of moisture relations.

Shade trees may serve another useful purpose. When the trees are in full leaf and their roots have access to ample supply of water, the amount of water transpired by the trees must be quite high. The main growing phase of the shade trees in N.E. India coincides with the wettest and warmest part of the year when, due to inefficient drainage, the ground watertabtle rises near to the surface in a large part of the plains. Under these conditions it is possible that the trees assist in drying up the soil by transpiring more water than they help to conserve. This aspect of the water relation under shade trees deserves attention in N.E. India and elsewhere where high watertable is a big problem.

Shade Trees in Relation to Diseases and Pests

Shade trees are known to influence the incidence of many diseases and pests. Blister Blight is a glaring example, the incidence of which increases remarkably under shade. As pointed out earlier, the whole question of shade in tea came up for review only after the appearance of the disease in Sri Lanka, South India and Indonesia.

Shade trees are prone to attacks by various pests and diseases; some of which are common enemies of tea. Again, each species exhibits specificity for certain pests and diseases although similar pest and disease spectrum can be seen in a number of species. Since many shade tree pests and diseases are common to tea, the fear that shade trees can act as hosts for some of them is not unfounded. *A.chinensis*, the most popular shade tree of N.E. India, is attacked by a large number of leaf eating caterpillars, root borers, Mambracids etc. and is highly susceptible to canker. Many root-rot fungi of tea parasitise on this tree. *A. odoratissima* likewise is prone to the attack of caterpillars, root borers and root diseases. A caterpillar *Boradesa omissa* does great harm to another shade tree, *Derris robusta*, grown in many parts of N.E. India. *Indigofera teysmanii*, used extensively in N.E. India as a temporary shade, hosts Black beetle *(Xylotrupes gideon)* and hairy caterpillar *(Diacrisia oblique)*. *Grevillea robusta* which is widely used in South India, Sri Lanka and until recently in Africa is susceptible to attack by Scarlet mite, Red spider mite, Red borer *(Zeuzera coffeae)* and Tea Tortrix. It is also prone to a number of root diseases. These few examples should suffice to show that none of the commonly used shade trees is free from the attack of many pests and diseases some of which infest tea. Therefore, the risk of certain pests and diseases migrating from shade trees to tea bushes is quite real. The reverse is also true i.e. tea can act as the host for some diseases and pests of shade trees.

Contrariwise, shade helps in the control of certain pests of tea. The whole spectrum of mites falls into this category. Red spider, which is the most damaging of the mites under N.E. Indian conditions, remains under check in shaded tea. Das (1959) recorded progressive decrease of Red spider infestation as shade became denser. Removal of shade trees as a measure for the control of Blister Blight in Indonesia increased the incidence of Orange mite (De Weille, 1959). Other casual observations indicate the value of shade in the control of some other pests. Othieno (1983) mentioned gradual but long-lasting increase of pests, particularly Thrips, in the tea-growing countries of Africa such as Malawi, following the removal of shade trees. In an observation made on hot (south) and cold (north) slopes of *teelas* in the Cachar district of Assam, tea bushes suffered less from the depredations of termites on the sheltered north slope. On the hot south slope, shaded tea bushes suffered less from the attacks of termites and *Poria hypobrunnea*. (TES Ann. Rep., 1982-83). There also is the interesting observation that *Indigofera teysmanii*, widely used as a temporary shade tree in N.E. India, is a better host of the root-knot nematode *Meloidogyne incognita* than tea bushes. *Indigofera* trees attract the nematodes leaving the tea bushes relatively free (TES Ann. Rep., 1979-80).

The few observations just mentioned suggest the possibility of shade trees exercising a check on some other pests and diseases of tea. This can be ascertained only through systematic studies.

Protective Action of Shade Trees

Shaded tea suffers less from hail damage but the degree of protection given by shade trees is almost impossible to quantify due to the involvement of a large number of factors such as intensity, time of occurrence and direction of hail, species of shade trees, their age, planting density and planting pattern. While shade trees may give some protection to tea bushes from strong wind, the damage caused to tea by broken branches and whole trees uprooted by storm cannot be ignored.

In hot climate shade improves the working condition for labourers on sunny days.

EFFECT OF SHADE REMOVAL

Thinning out of heavy shade has always been a normal practice in N.E. I.ndia. Yield increases following thinning but complete removal of trees is entirely a different matter. Yield of crop shoots normally increases immediately following shade removal, although the effect is short-lived. After complete removal of a mixed stand of *Albizzia falcata* and *Leucaena* trees giving medium to heavy shade, Vink (1953) in Indonesia observed nearly 70 per cent increase of crop shoots for about a year. Thereafter the shaded plots outyielded the deshaded plots and the yield difference was widening with the passage of time. Visser (196lb) argued that the initial increase observed by Vink could have been maintained if the deshaded plots were manured liberally. This argument was not borne out by a large-scale trial conducted at Tocklai (Barua and Gogoi, 1979). In the trial, a 4.8 ha section of 10- year old Assam tea shaded by a uniform stand of *Albizzia odoratissima* trees was divided into two equal parts. After recording pretreatment yields, shade trees in one half of the section were cut down at the ground level during 1965-66 cold weather and three manurial treatments were imposed from 1966 on each half of the trial.

The manurial treatments were: nitrogen alone at the rates of (a) 112 kg ha^{-1} (b) 224 kg ha^{-1} and (c) a combination of 224 kg nitrogen, 45 kg phosphate (P_2O_5) and 90 kg potash (K_2O) per hectare. The yields of crop shoots for the years 1966 to 1970 are given in Table 64.

Except in the year 1966 immediately following shade removal, the yields of the shaded plots were consistently higher than those of the deshaded plots. Yield of the deshaded plots dropped gradually from 1966 to 1969 and very sharply in 1970 while those of the shaded plots did not fall but increased markedly in 1970. The 1970 yields of the plots from which shade trees were removed were nearly half of those of the shaded plots. There was very little yield difference between the two nitrogen doses, but NPK combination produced significantly higher yields, both with and without shade. The NPK combination reduced but could not arrest yield decline of the plots without shade. The highest yield was produced by the shaded plots receiving NPK nutrients.

Shade gave maximum benefit during the hottest part of the year when the ambient day temperature exceeded 30°C on 90 per cent of the days.

The results clearly show that in places like N.E. India where tea bushes require protection from the hot sun, fertilisers cannot replace shade. Where leaf temperature remains below 30°C for a large part of the year and removal of shade trees improves yield, fertilisers cannot respond under shade.

Table 64. Mean kg dry weight of shoots plucked per 100 bushes

Shade trees	Manure	1966	1967	1968	1969	1970
Removed	N_{112}	10.5	9.8	8.2	7.9	6.7
	N_{224}	10.9	10.2	8.4	8.2	5.0
	N_{224} P_{45} K_{90}	11.2	12.3	11.1	10.8	7.9
Treatment	mean	10.9	10.8	9.2	9.0	6.5
Not removed	N_{112}	9.5	11.0	11.2	10.5	11.6
	N_{224}	9.6	12.1	11.5	10.6.	11.5
	N_{224} P_{45} K_{90}	10.8	13.0	12.8	12.6	13.6
Treatment	mean	10.0	12.0	11.8	11.2	12.2

EFFECT OF SHADE ON MOISTURE CONTENT AND LIQUOR CHARACTERS

Moisture Content

Clones, plucking seasons and hours of plucking influence moisture content of plucked shoots when soil moisture is non-limiting. For comparing moisture contents of shoots produced under shade and in the open, adequate precaution against these variables becomes necessary. Results of one of the observations made in N.E. India with due regard to the above sources of error are quoted in Table 65. Assam type bushes were uniformly shaded by bamboo mesh screens transmitting 50 and 40 per cent of the incident light. Shoots for moisture estimation were drawn from the plucking baskets on 26 plucking rounds spread over the entire harvesting season. Dry matter content of shoots did not deviate by more than 1.5 per cent from the respective means except on two wet plucking rounds when the deviation was as high as 3 per cent.

Shade caused significant reduction of the dry matter content of plucked shoots but there was no difference between the two shade densities. On an average the dry matter content of shoots dropped by 5 per cent under shade. This has to be taken into account while comparing green leaf yields of shaded and unshaded tea. In another observation, the average fresh weight of assorted shoots growing under *A. chinensis* trees (50 per cent shade) was found to be 5 to 6.5 per cent higher than shoots growing without shade.

Dry weight percentage did not differ between the two doses of nitrogen. In a more detailed investigation, Barua *et al.* (1958) observed, besides low dry weight percentage of shoots growing under shade, a shade x nitrogen interaction in shoot dry weight. The weight of the finer components of plucked shoots e.g. bud, first leaf and the soft piece of stem above the second leaf was raised or lowered by different forms of organic or inorganic nitrogenous fertilisers and their amounts, depending on whether the fertilisers were applied to bushes in sun or under shade. The magnitude of the interactions in relation to shoot morphology was rather small; nevertheless this aspect deserves study for better understanding of the effects of shade and nitrogen on quality of made tea.

Liquor Characters

From the early days of the tea industry, a very large number of trials have been carried out in N.E. India and elsewhere to study the effect of shade on the liquor characters of teas made by orthodox and cut-leaf methods. Although there are a few exceptions, moderate shade has generally been found to improve colour and strength of liquor. Quality, briskness and colour of infused leaf decline under shade (Gogoi, 1976 ; Rahman *et al.* 1978). The overall value of tea made from shoots produced under moderate shade is usually slightly lower than tea made from unshaded bushes. Heavy shade produces worse effect on liquor characters. This was the conclusion drawn from experiments conducted at Tocklai between the two World Wars (Cooper, 1939). Despite some loss of value, monetary gain from moderately shaded tea under North Indian conditions was shown to be much higher than from tea without shade, because increase in yield more than compensated for the slight loss of value of the made tea (TES Ann. Rep., 1974-75).

Hilton (1971) reported increase of epigallocatechin gallate (EGCG), epicatechin gallate (ECG), level of polyphenol oxidase

(PPO) and decrease of epigallocatechin (EGC) and gallocatechin (GC) in shaded tea shoots. Removal of shade even for 24 hr was sufficient to reduce PPO activity. These chemical changes are in conformity with the findings of tea tasters that colour and strength

Table 65. Per cent dry weight of crop shoots produced under three light intensities (Barua, 1957)

Nitrogen kg ha^{-1}	Light intensity 100% (Unshaded)	50%	40%
84	21.65	20.78	20.62
168	21.75	20.59	20.72
Mean	21.70	20.66	20.67
	L.S.D. at 5% = 0.16		

of liquors increase and quality and briskness decrease in teas made from shaded bushes.

SYLVICULTURE AND MAINTENANCE OF SHADE

In this section attention is drawn to a few important factors relating to the choice of shade tree species, collection of seed, raising of nurseries, transplanting and maintenance of shade in tea areas. This is not an exhaustive account. The readers may refer to other sources (e.g. W.J.G, 1970 a; b; c) for more complete information.

Choice of Shade Species

Shade species should be selected with due regard to the following criteria :

a) Suitability to the soil and climate of the area
b) Economic life
c) Size and shape of canopy
d) Leaflet size and duration of foliation
e) Root depth
f) Disease and pest resistance
g) Resistance to storm damage

As mentioned earlier no known species of shade trees fulfills all these required criteria.

It is a wrong policy to plant any shade species on a commercial scale without first ascertaining its adaptability to the local soil and climate. Longevity is an equally important consideration while introducing a new species, for which one has to be guided by the experience of others cultivating the species in the same locality. In the absence of such guidance planting of a new species without prolonged trial will be a calculated risk, although it may do well in the initial years. Depth of the root system is another very important consideration in the choice of a species. The shade trees must have deeper root systems than plucked tea bushes. A tree that produces a very thick canopy is undesirable, more so if the leaflet size is also big. Similarly, deciduous species remaining leafless for long periods, particularly when shade is most needed, cannot be efficient as shade trees. Almost all shade species are prone to the attacks of different pests and diseases, although proneness to diseases and pests differs between species. A good shade species must be reasonably free from pests and diseases as their control on tall trees is a formidable task.

Temporary Shade

In a fresh clearing, permanent shade trees are usually planted at the same time as the tea bushes. The young shade trees take a few years to provide effective shade to the newly planted tea although this is the time when shade is most needed. In the early days of the tea industry in India and many other places, tea was planted between lines of green crops like *Tephrosia, Crotalaria, Priotropis; Desmodium, Sesbania* etc. for protecting the young tea plants from the direct rays of the sun. This practice is still followed to some extent in N.E. India and a few other places, although experimental findings do not support it. Uncut green crop *(Tephrosia candida)* depressed the growth of young tea plants although lopping of the crop effected some improvement. The loppings hoed into the soil had a highly beneficial effect on the growth of tea, after removal of the green crop. The results demonstrated the harmful effect of standing green crops on the growth of young tea but burial of the green crops before planting of tea had the opposite effect (Cooper, 1939).

Another practice which is gaining favour in N.E. India during recent years is the planting of short-duration, quick-growing tree species amongst young tea to provide shade during the early years of a plantation. *Indigofera teysmanii* is the species now extensively used. Other species like *Gliricidia sepium, Leucaena glauca* are also sometimes grown as temporary shade. These short duration species are initially planted at close spacings and then gradually thinned out. These are finally removed when the permanent shade species take over. Like the green crops, the temporary shade trees also need careful control, particularly during periods of water stress. The temporary species like *Indigofera* appears to benefit tea but proper assessment is lacking.

Temporary shade trees should not be grown in low and marginal rainfall areas as they will intensify the problem of water scarcity. Mechanical shade is the only alternative for protecting young tea plants in such areas.

Shade Tree Nursery

Only reliable seed should be used for raising nurseries. Seeds from pest-free, healthy trees of the locality are usually the best and the safest for planting nurseries. Shade tree seedlings are raised either in ordinary nursery beds or in polythene sleeves.

Nursery seedlings of permanent shade trees can be transplanted with *bheties* when they grow to a height of not less than one metre but for transplanting into mature tea, seedlings have to be taller than the tea bushes. Shade tree seedlings can be transplanted successfully also as stumps, provided they are well-grown with a minimum diameter of 2.0 cm at the collar. Better success has been obtained with sturdier plants. The seedlings are cut back at a height of 1.5 to 2 m above ground level and the cut end is protected with some suitable material.

The polythene sleeves for raising shade tree seedlings should be of sufficient size and strength. The minimum size for sleeves is suggested to be 30 cm lay flat cut into 60 cm lengths of 300 gauge polythene (W.J.G., 1970 a). The same author recommends a mixture consisting of 4 parts of good friable soil, 1 part of dry well-rotted cattle manure together with 1 kg super phosphate and 0.5 kg slaked lime per cubic metre of soil-cattle manure mixture for filling the sleeves. However, the most suitable soil-nutrient mixture will depend on the kind of soil available for filling sleeves. Where the soil lacks cohesion, the bottom end of the sleeve may have to be closed as in the case of sleeve nursery for tea plants. If the sleeve-grown plants are held back in the nursery for long, the tap roots grow into the soil upon which the sleeves rest. It is, therefore, necessary to move the sleeves from time to time, if necessary by cutting the projecting roots flush with the bottom end of the sleeve with a sharp knife. It is a wise precaution to sow two or three seeds in each sleeve at the appropriate time and when the seedlings are 15-20 cm tall, the weaker seedlings can be pulled out and thrown away, leaving only one seedling per sleeve. Time of planting seeds will depend on local conditions.

Like tea nurseries shade tree nurseries should be well-drained. Care should be taken to protect the plants from attacks by diseases and pests.

Transplanting

The size of the planting pit for permanent shade trees, both in young and mature tea, should be fairly big irrespective of whether transplanting is done in sleeves, with *bheties* or as stumps. The actual size of the planting pit will depend on the type of soil. The recommendation for the sandy loam soils of N.E. India is that the pit should be 75 cm wide and 90 cm deep. Loosening of the soil at the bottom of the pit to a further depth of 15 cm is suggested for stiff soils. The manures recommended for mixing with the excavated soil are : 10-15 kg dry well-rotted cattle manure or 1.0-1.5 kg oil cake, 0.5 kg superphosphate, 2.5 kg wood ash and 0.5 kg slaked lime (W.J.G., 1970a). However, suitable planting mixtures for other locations will have to be worked out by trial.

Shade tree seedlings, like young tea plants, should not be transplanted when the soil is dry. The soil should remain moist from the time of transplanting until the seedlings are fully established in their new surrounding.

In properly manured tea fields, extra manure for shade trees is not normally necessary. If the manure mixture for tea is deficient of potash and phosphate, then application of these nutrients will be desirable for better growth of the shade trees. Application of lime will be helpful in very acid soils.

Species of Shade Trees

No tree species can be considered ideal for shading tea. *Albizzia chinensis* was the nearest approach to an ideal shade tree for North India but, as mentioned earlier, this species is fast dying out throughout N.E. India. The primary cause of death of this species has been attributed to monoculture. Tocklai now recommends mixed stands of shade trees for tea, with a minimum of four species planted in intimate mixture (W.J.G., 1970c).The species of shade trees selected for mixed stands will naturally depend upon the adaptability of the species to the locality.

A very large number of tree species have been tried in different parts of the world for shading tea. In N.E. India alone, not less than 50 indigenous and exotic species have so far been investigated. The results have not been encouraging. Trials lasting for decades have merely shown that two indigenous species, *Acacia lenticularis* and *Dalbergia sericea*, can also be used for shading tea. These trees were not used in the past. *Albizzia lebbek*, another shade tree currently recommended, cannot be considered to be a new discovery. It was used earlier on a very limited scale.

At present *Albizzia odoratissima* is the most widely used shade species of N.E. India. So is *Grevillea robusta* in South India and Sri Lanka. The possibility of these species going the way of *A. chinensis* in N.E. India should always be kept in view and search for new species should be intensified.

Wide tree to tree variation observed in any stand of shade trees belonging to a particular species indicates the possibility of isolating vigorous trees having better canopy characteristics and greater resistance to pests and diseases. Development of an easy method for vegetative multiplication of the selected trees as clones will resolve some of the problems now being faced in the sylviculture of shade, improving at the same time the quality of shade cast by the trees. The tissue culture technique may prove useful in the vegetative propagation on shade trees as the recent results show (Phukan and Mitra, 1983).

Indications of interspecific hybridisation among leguminous shade species already exist. The possibility of breeding improved strains of shade trees by hybridisation and selection also deserves serious consideration.

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CHAPTER 13

MINERAL NUTRITION AND WATER MANAGEMENT

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DEVELOPMENT OF MANURING PRACTICE IN TEA CULTURE

Until about the last quarter of the past century, manures were rarely applied to tea in the countries of South-East Asia which took up tea cultivation on a commercial scale during the last century. The native fertility of the virgin forest clearings in which tea was first planted could sustain the low crop harvested in those early years. With the passage of time, the fertility of the soil gradually fell but the demand for crop went on increasing. This situation induced the planters to make use of any organic manure which was readily available to them. Green manure raised locally was naturally the first choice, followed by the application of cattle manure collected from the neighbourhood. Bulkiness of cattle manure and its scarcity led to the use of more concentrated forms of organic manures like animal carcass meals and oil cakes. Regular use of such concentrated organic manures either alone or in conjunction with cattle manure and green manure became more or less a standard practice in the tea areas of India., Sri Lanka and Indonesia. Field trials were carried out subsequently in India and elsewhere to evaluate the efficacies of the various forms of organic manure.

Except for a few isolated attempts, inorganic fertilisers were not tried in tea until the First World War. After the War, a few enterprising planters of these countries started manuring tea bushes with small quantities of ammonium sulphate. Results being encouraging, the use of this form of nitrogen gradually spread. Meanwhile the scientists at Tocklai and other tea research centres of the region started field trials with inorganic nitrogen and other chemical fertilisers. The trials demonstrated within a short time the suitability of inorganic fertilisers for tea. The fertiliser doses used in those early experiments were, however, very small in comparison with the quantities being tried in more recent years.

Ammonium sulphate was the main nitrogenous fertiliser tried in those early years along with others like calcium ammonium nitrate, calcium nitrate, calcium cynamide, ammonium sulphate nitrate and sodium nitrate. Investigations with different forms of nitrogen are still continuing and we shall refer to some of these a little later.

Ammonium sulphate did not find ready acceptance by a large body of tea growers (cf. Chapter 5). They feared that its continued use would make the soil too acidic and hasten the loss of bases like potassium, calcium and magnesium. Some planters firmly believed that use of inorganic nitrogen would adversely affect the quality of tea. It took many years of sustained investigation to convince the planters that the benefits to be gained from the use of inorganic nitrogenous fertilisers would more than compensate for the possible harm.

Next to nitrogen, potassium and calcium are the most abundant elements found in tea. Trials with inorganic nitrogen and potash fertilisers began almost simultaneously in India, Sri Lanka and Indonesia, but benefit from the application of potassic fertilisers was not detected anywhere yet for some more years. Long-term trials conducted in Sri Lanka revealed the danger of omitting potash from the fertiliser mixture used in tea. Omission of potash fertilisers caused deterioration of health and productivity of certain tea fields in Sri Lanka, leading finally to the death of a large number of bushes (Portsmouth, 1951). Similar results were soon obtained in South India and other countries but potassic fertilisers took much longer, nearly forty years, to show beneficial effect on health and productivity of mature tea bushes of N.E. India. From about the early fifties, potash became an essential ingredient of the fertiliser mixtures for tea in all countries except N.E. India where it was not applied to mature tea for another twenty years, although young tea was manured liberally with potash (and phosphate).

Small but significiant and consistent gain in crop from phosphate was first reported in the early forties. Despite relatively small response, low doses of phosphatic fertilisers had generally been applied to tea in most countries as a precautionary measure.

Attention was drawn in Chapter 5 to the inclusion of magnesium in the fertiliser mixtures for tea in many parts of the world and to foliar application of zinc. Application of lime has also been favoured in certain situations not so much for its value as a fertiliser but as a measure against the build up of excessive soil acidity.

MINERAL COMPOSITION

Before considering nutrient requirement of tea, it is worth having a look at the mineral composition of the plant. A few reports on the mineral composition of tea are available in the literature, but these are confined mainly to the young shoots. Chemical analyses of other plant parts for minerals are very scarce. Information on the mineral composition of tea roots is virtually unavailable.

Small discrepancy is observed between the analytical results reported by different workers, but this is inevitable. Kind of plant, climate, nutrient status of the soil, time and method of sampling and the analytical procedure used contribute towards these discrepancies. Nevenheless, the results reported by different workers (Gokhale and Bhattacharyya, 1960; Hasselo, 1965; Ranganathan, 1973; Hilton, 1974), to quote only a few, fall into the same general pattern. Two sets of results, one pertaining to young plucked shoots and the other to pruned branches, are reporduced in Tables 66 and 67 as examples of the mineral composition of young and old organs of the tea plant.

Gokhale and Bhattacharyya *(loc. cit.)* divided plucked, two and a bud shoots of four clones into bud, first leaf, second leaf and stem and analysed them separately, repeating the analysis on three dates. Analytical results for two clones on two sampling dates are presented in Table 66.

The authors concluded. that chemical composition varied markedly with physiological age of the tissue, date of sampling as also between the four clones. Nitrogen, phosphorus and sulphur decreased and other constituents, notably potassium, calcium and aluminium increased as the leaf matured. The maximum concentration of the mono and divident cations (K, Ca andMg) occurred in the stem portion. Nitrogen, sulphur, phosphorus and potassium increased during the period July to September, whereas calcium and manganese showed definite decrease. Of the two clones shown in the table, 3/77 had substantially less calcium, sulphur, aluminium and managanese than 19/29/13. These results show that leaf age, climatic conditions at the time of drawing samples and the kind of plant influence mineral composition. It may be mentioned in this connection that clone 3/77 is a broad, light leaf Assam plant while clone 19/29/13 is a complex hybrid having prominent features of the China race of tea.

Table 67 shows the mineral contents of prunings (Ranganathan, 1972). For the purpose of analysis, five-year old prunings from each one of 11 clones were divided into :

A. Foliage at the time of pruning

B. Twigs and branches carrying foliage

C. Secondary and tertiary wood of 0.6 to 1.6 cm diam. (mean 0.9 cm)

D. Primary wood of 1.3 to 8 cm diam. (mean 4 cm)

Separate analyses were carried out for each clone.

Wide variation in the mineral composition of clones is the most striking feature of Table 67. As expected, the contents of various elements are less in the woody parts than in the maintenance foliage.

Hasselo (1965) examined the mineral contents of tea leaves primarily from the angle of sampling. Mineral content was determined in (a) two and a bud plucked shoots (F), (b) the third leaf of a plucked shoot (F + 1) , (c) the topmost maintenance leaf (M), (d) the maintenance leaf just below (M + 1) and a leaf low down on the bush frame (Mt). The leaves were sampled from the same clone grown at two different elevations, viz. at 1370 m and 30 m. It was observed that N and P contents and, to a lesser extent, K content dropped as the leaf increased in age. In every case the drop was very sharp between flush shoot (F) and the first maintenance leaf (M) and very gentle between M and the oldest leaf Mt. Calcium (Ca) and manganese (Mn) contents increased steeply between F and M and slowly between M and Mt. Aluminium

Table 66. Chemical analysis of different parts of two and a bud tea shoot on two dates

		Date of Sampling							
		7 July				6 September			
Per cent on dry wt.	Clone number	Bud	1st leaf	2nd leaf	Stem	Bud	1st leaf	2nd leaf	Stem
Total ash	19/29/13	5.3	5.8	6.1	7.6	5.1	5.6	5.7	7.7
	3/77	4.4	5.5	5.7	6.9	4.7	5.6	5.7	7.0
Nitrogen	19/29/13	4.54	3.88	3.48	3.34	5.20	5.00	4.42	3.88
	3/77	5.12	4.42	3.84	3.49	5.81	5.77	4.98	4.59
Potassium	19/29/13	2.14	2.40	2.54	2.93	2.29	2.41	2.55	3.37
(K_2O)	3/77	2.07	2.21	2.46	2.91	2.30	2.41	2.68	3.20
Phosphorus	19/29/13	1.30	1.04	0.90	0.97	1.47	1.24	1.08	1.10
(P_2O_5)	3/77	1.16	1.01	0.93	0.95	1.38	1.26	1.13	1.10
Calcium	19/29/13	0.45	0.71	0.80	1.25	0.34	0.45	0.56	1.05
(CaO)	3/77	0.32	0.55	0.74	0.90	0.20	0.32	0.52	0.66
Magnesium	19/29/13	0.30	0.31	0.30	0.42	0.30	0.32	0.29	0.46
(MgO)	3/77	0.28	0.30	0.29	0.37	0.31	0.32	0.30	0.41
Aluminium	19/29/13	0.04	0.06	0.10	0.03	0.04	0.07	0.09	0.04
(Al_2O_3)	3/77	0.03	0.04	0.06	0.02	0.31	0.04	0.06	0.02
Manganese (a)	19/29/13	483	786	782	641	234	408	394	361
(Mn_2O_3)	3/77	296	575	644	553	234	386	584	486
Iron (a)	19/29/13	85	99	88	67	94	96	100	59
(Fe_2O_3)	3/77	90	104	100	78	90	92	110	72
Sulphur	19/29/13	0.79	0.71	0.66	0.64	0.88	0.79	0.79	0.71
(SO_3)	3/77	0.66	0.64	0.63	0.52	0.77	0.71	0.71	0.60
Clorine	19/29/13	0.03	0.04	0.06	0.05	0.03	0.05	0.06	0.07
(Cl)	3/77	0.03	0.04	0.05	0.06	0.02	0.03	0.06	0.07
Sand and	19/29/13	0.04	0.08	0.07	0.05	0.08	0.07	0.07	0.04
Silicate (SiO_2)	3/77	0.04	0.08	0.09	0.05	0.06	0.10	0.10	0.10

(a) Parts per million on dry weght. Sodium (Na_2O) varied from trace to 0.03%

too fell into the same pattern. At the higher elevation, zinc (Zn) content did not change much with the age of the leaf but at the lower elevation, there was an appreciable decline from F to M. The same was the trend with copper (Cu). Boron (B) content increased from F to M but beyond M, age of the leaf did not have any effect. Molybdenum (Mo) content of F and F + 1 was about 2 ppm which rose to about 5 ppm in the older leaves.

Elevation had a marked effect on mineral composition. In general leaves on low-grown plants, both young and mature, had more N, K and Mn than those on high-grown plants, while reverse was the case with Ca, iron (Fe) and Zn, particularly the last one.

Elevation effect could be attributed primarily to temperature but rainfall also played a part. The lack of proportionality between the nutrient contents of young and old leaves, at least in the case of some nutrients, poses sampling problems for nutrient analysis.

An idea of the mineral composition of young and old tea leaves and prunings can be formed from the above. It would be clear that the mineral composition of any organ of the tea plant does not remain stable for long and the instability is influenced by genetical, environmental as wll as cultural factors. Others too had arrived at similar conclusions (TES Ann. Rep., 1977-78). The implications of these findings are discussed below.

Nutrient Removal

Except for estimating the quantities of the three major nutrients N, P and K removed by the harvested crop and prunings, the problem of circulation of nutrients in tea fields has not been thoroughly studied. The nutrients locked up in the body of the plant including the roots, lost in leaching, added to the soil by the fallen litter of leaves and the dead roots—must all enter into any computation of nutrient balance. Biological fixation of atmospheric nitrogen and its loss in the gaseous form have also to be taken into account.

Willson (1969) examined the problem in a field of mature tea in East Africa over a pruning cycle of three years. Besides calculating the quantities of N, P_2O_5 and K_2O removed by crop and prunings in the three year period, he made some estimates of

Table 67. Chemical analysis of prunings from 11 clones. Maximum and minimum values are shown in the table.

Per cent on dry weight	A	B	C	D	Weighted average of A, B. C, D
Moisture	58-68	62-75	49-64	41-57	61.0
Nitrogen (N)	3.76-3.15	2.19-1.49	2.10-0.79	1.14-0.35	1.80
Potassium (K)	0.94-0.57	0.78-0.44	0.26-0.16	0.29-0.10	0.43
Phosphorus (P)	0.42-0.28	0.36-0.25	0.37-0.18	0.30-0.18	0.30
Calcium (Ca)	1.37-1.02	0.69-0.48	0.30-0.24	0.22-0.18	0.64
Magnesium (Mg)	0.32-0.24	0.22-0.18	0.19-0.15	0.14-0.11	0.21
Copper (Cu) (a)	93-40	93-35	53-13	25-8	40
Manganese (Mn) (a)	3045-840	525-158	525-113	293-118	667
Sodium (Na) (a)					85

(a) Parts per million (ppm)
Nutient content is expressed in elemental form i.e. as P, K etc. and not as P_2O_5, CaO etc.

the leaching loss of these nutrients and their addition through leaf-fall. He also made an estimate of the amount of N fixed from the atmosphere and its loss in the gaseous form. However, the nutrients locked up in the plant and their release to the soil by the decomposed roots were not accounted for. A summary of the results reported by Willson is presented in Table 68.

Table 68. Loss of nutrients in kg ha^{-1} over a three year period (After Willson, 1969)

		Nutrients		
		N	P_2O_5	K_2O
A Loss	In plucked shoots (5,050 kg)	252	40	108
	In prunings (22,400 kg)	785	135	570
	Leached	52	1	16
	Lost as gas	150		
	Total	1239	176	694
B Gain	Fertilisers applied	510	102	102
	Nutrients in leaf-fall	56	9	22
	Stored in mulch	100	62	2
	Total	666	173	126
Net loss (A-B)		573	3	568

The loss of nitrogen and potassium far exceeded the quantities added as fertiliser and mulch.The loss was caused primarily by the removal of prunings since about 63% N, 77% P_2O_5 and 82% K_2O were removed only by the prunings. In comparison, nutrient removal by the crop was very small and less than the quantities supplied as fertilisers.

Attention has already been drawn to the few gaps present in the above analysis. Loss of nutrients would probably have been higher if the factors mentioned above were taken into account.

Secondly, estimates of leaching loss made under East African conditions will not apply to regions experiencing high and intensive rainfall. In N.E. India leaching loss of N was 38-40 per cent when ammonium sulphate was applied at the rate of 100 to 200 kg N ha^{-1}. The gaseous loss was 9 to 20 per cent (TES Ann. Rep., 1974-75). Recovery of nitrogen by plant when applied as urea was even less, only about 30 per cent (TES Ann. Rep., 1977-78). Nonetheless, the results given in Table 68 are highly instructive and deserve serious consideration by scientists and tea planters alike. Attention has already been drawn in Chapter 5 to the highly detrimental effects of removal of the pruning litter from tea fields. It was suggested that chopping up the pruned branches and scattering the cut particles among tea bushes would be more effective in retarding the loss of soil fertility than trying to replenish the nutrients lost with the prunings by applying them from the fertiliser bag. The latter will be a very expensive proposition.

MINERAL DEFICIENCY AND EXCESS

Reference was made in Chapter 5 to the increasing incidence of magnesium and zinc deficiency throughout the tea areas of the world. In this context stress was laid on taking effective steps for the control of soil erosion and loss of organic matter from the soil.

A deficient mineral produces characteristic symptoms on the plant. When a few bushes in a section of tea exhibit these symptoms, it is a warning that the whole section may be suffering from a shortage of that particular nutrient.

The deficiency symptoms occurring on different plant species are not exactly the same, for which it becomes necessary to indentify the symptoms on the species under investigation. The work on indentification of the mineral deficiency symptoms produced on the tea plant was first undertaken at the Tea Research Institute of Indonesia just before the Second World War. Deficiency symptoms were induced artificially by growing plants in sand culture and withholding the supply of one nutrinet at a time from the culture medium to create deficiency of that particular nutrinet. By following this standard procedure, symptoms produced on the plant due to the deficiency of potassium, calcium, magnesium, sulphur and phosphorus were recorded and illustrated with coloured drawings (de Haan and Schoorel, 1940; de Haan, 1941). In the late sixties similar studies were carried out at the Tea Research Institute of Sri Lanka. The Sri Lanka workers could indentify, in addition to the above, deficiency symptoms produced by manganese and boron. The symptoms were recorded and illustrated with coloured photographs (TRIC Ann. Rep., 1967; Pethiyagoda and Krishnapillai, 1971 a,b). Deficiency symptoms as recorded in these and some other publications (Tolhurst, 1954; Mukasa and Kawai, 1956; Chu, 1978) are briefly described below. Readers requiring more complete information should refer to the original publications.

Deficient element	**Deficiency symptoms**
Nitrogen	Stunted growth of the plant; leaves pale yellow; defoliation begins with the lower leaves and extends to upper leaves.
Potassium	Very distinctive foliar symptoms of marginal scorch; thin stem; internodes usually longer.
Calcium	Downward curving of mature leaf, followed by marginal scorch starting from the leaf tip; apical activity much reduced; the later-formed leaves drop and growth virtually ceases; translucent patches on the lower surface of some leaves, the patches gradually coalesce and develop into brown necrotic areas.
Magnesium	Distinctive interveinal chlorosis on mature leaves but intensity of symptoms varies from clone to clone; defoliation of young plants starting from the lower leaves.
Phosphorus	Surface of mature leaves smooth which darkens and occasionally becomes slightly purple; leaves yellow at the tip.
Sulphur	Very distinctive chlorotic symptoms; younger leaves appear pale-green to

	yellow; veins stand out clearly as a green network against a pale-yellow background.
Boron	Shoot apices die; axillary buds abort and clusters of small shoots appear in the axils; leaves become dark-green and thick; cork formation as excrescences on the upper side of leaf stalk, spreading to main veins and laterals.
Manganese	Interveinal cholorosis of old and young leaves; irregular mottling, veins and surrounding areas remaining green; necrotic spots develop within the chlorotic patches, mainly close to leaf margin; severe deformation of young leaves and buds.
Zinc	Leaves smaller, darker and sickle shaped due to unequal development of the lamina on either side of the mid-rib; internodes shorter.

No specific deficiency symptoms associated with copper, iron, zinc, molybdenum, aluminium, fluorine and chlorine were noted in the investigations carried out by Pethiyagoda and Krishnapillai *(loc. cit.)*.

Deficiency can be corrected by supplying the plant with the deficient element. Proneness to deficiency of one or the other element differs between plants. Plants of the Cambod race of tea, in general, appear to be more sensitive to deficiency of magnesium than plants of the other two races. It is possible that similar variation may occur in respect of other nutrients also. This aspect needs further study, which may lead to the isolation of clones having low requirement of certain nutrients or of clones which can make better use of the nutrients present in the soil.

Mineral Excess

Excess of certain minerals is equally harmful to plant as their deficiency. Pethiyagoda and Krishnapillai *(loc. cit.)* reported toxic effects of excess boron and fluorine on young tea plants grown in sand culture. Boron toxicity symptoms were irregular, brown patches of dead tissue in the interveinal region with a greater concentration towards the leaf margin. The affected leaves subsequently dropped. Similar toxic symptoms were reported from N.E. India when boric acid at 0.6 per cent concentration was applied to eighteen-month old clonal plants as foliar spray. The leaves exhibiting toxicity had 1l0-120 ppm of boron. No adverse effect of soil or foliar application of manganese was, however, observed when applied to young plants even at as high a rate as 40 kg Mn per hectare (Prasad and Dey, 1979). Zinc too did not produce any apparent adverse effect on tea plants when applied as foliar spray continuously for three years. However, copper sprayed at a concentration of 12 kg copper sulphate per hectare for one season was observed to depress yield of mature tea. These observations, though limited, argue against indiscriminate application of micronutrients to tea.

As regrads the major nutrients, it will be shown later that excess of one in soil can interfere with the uptake of another.

USE OF FERTILISERS

Starting with the trials of organic manures at Tocklai in the early years of the century, a very large number of fertiliser trials have been carried out by the tea research institutes in different parts of the world. Until the mid-sixties, these trials were designed to assess the response of tea bushes to the three major nutrients, nitrogen (N), potassium (K) and phoshporus (P) and their various combinations. Since the mid-sixties, effects of calcium, magnesium and micro nutrients zinc (Zn), boron (B) and manganese (Mn) on the tea plants have also been evaluated by field trials as well as by laboratory studies. Trials with major and minor nutrients are continuing at many tea research institutes. In most cases the agronomic trials were not confined only to the precincts of the experimental stations but were extended to different soil-climatic zones where tea is cultivated.

Fertiliser combinations, their rates and methods of application recommended in different countries on the basis of agronomic trials have many points of difference, these being the consequences of wide diversity that exists in the soil-climatic enviroments of different countries (cf. Chapter 5). However, there are some points of agreement in the research findings of different countries on the reactions of the tea bush to the application of fertilisers. For instance, response to N and K fertilisers differs everywhere between clones and seed populations *(jats)*. The plant absorbs a nutrient in large quantities, much in excess of its requirment for growth, when its supply is plentiful. The efficiency of a nutrient is limited on the shortage of another. For example shortage of K rerduces response to nitrogen. Nutrition (and irrigation) does not overcome seasonal dormancy (cf. Chapter 3). Other salient points of agreement and discord will be discussed under each nutrient.

NITROGEN

Organic and Inorganic Nitrogen

Nitrogen is the most important fertiliser for tea and, in that role, it has been extensively studied. Attention has already been drawn to the initial resistance to the introduction of ammonium sulphate as a fertiliser for tea. Preference for organic manures shown in those days stemmed from the belief that organics released nitrogen slowly, had longer residual effect and, unlike ammonium sulphate, reduced the loss of basic nutrients from the soil. The initial experiments on nitrogen manuring were, therefore, designed to compare the effects of organic and inorganic fertilisers. On the basis of evidence collected through a series of experiments, Cooper (1939) in N.E. India arrived at a number of important conclusions which are generally valid even today. He concluded that from the point of growth and yield of the tea bush, organic manures like cowdung, oil cakes, animal meals and composts were less efficient than inorganic fertilisers like ammonium sulphate. In terms of yield of plucked shoots, one unit of N in cattle manure was only 30 to 40 per cent as effcient as that of ammonium sulphate. Efficiency of animal meals were somewhat better but still much below that of inorganic nitrogen. Composts were the least efficient.

Cooper *(loc. cit.)* observed that, “The organics proved to be slower in action even in the early weeks after application." Eden (1976) too holds the same view. The bulk manures had longer residual effects than inorganic nitrogen but the difference was much less where tea prunings decomposed *in situ*.

Calcium cynamide and nitrate of soda, two other inorganic nitrogenous fertilisers tried in those early experiments, proved inferior to ammonium sulphate. Calcium cynamide reduced soil acidity very rapidly and nitrate of soda produced harmful effects on the soil by reducing its tilth. Of late, other inorganic nitrogen sources like ammonium nitrate, ammonium sulphate nitrate, calcium ammonium nitrate and urea have been tried as fertilisers for tea. Ammonium nitrate is not considered suitable on account of its high hygroscopicity and leaching loss and ammonium sulphate nitrate is neither more efficient nor less acid-forming than ammonium sulphate. Calcium ammoinum nitrate and urea need some comments as these fertlisers, particularly the latter is replacing ammonium sulphate in some countries and its use is gradually expanding.

Urea

Urea is the most concentrated nitrogenous fertiliser with an N content of 46 per cent against 21 per cent of ammonium sulphate. It can be prepared from natural gas found in oil fields at relatively cheaper cost. Sulphur needed for the manufacture of ammonium sulphate is a rare commodity in many countries. For these reasons, the Governments of certain countries are encouraging the use of urea in place of ammonium sulphate in tea as well as in other crops. However, scientists of some countries have not favoured urea as a substitute for ammonium sulphate for a number of reasons.

A certain percentage of nitrogen of all nitrogenous fertilisers volatilizes into the atomosphere as ammonia, when soil micro-organisms act on the fertilisers. The loss of nitrogen is small in acid soil but in the case of urea, it may still be quite high due to temporary fall in acidity around the urea particles when it breaks down to ammonium carbonate and then, at least a fraction of it, to ammonium bicarbonate with the release of ammonia gas. Fernando and Bhavanandan (1971) in Sri Lanka estimated the loss of nitrogen as ammonia under laboratory and simulated field conditions following the application of urea, ammonium sulphate and calcium ammonium nitrate to soil. The loss of nitrogen from urea was found to be quite high, 10 to 40 per cent, as against 0.2 to 4.7 per cent loss from ammonium sulphate. Volatilization loss of nitrogen from urea was negligible during the first 48 hours after application while maximum loss occurred during the third and fourth days. There was no loss after about three weeks. Nitrogen loss was not affected when urea was mixed with potassium chloride and superphosphate, but burial of urea a few centimeteres below soil level reduced loss very considerably. Watering after broadcasting of the fertiliser also reduced loss. Hence a little rain after application can arrest loss of nitrogen to a great extent. Presence of organic matter in the soil increased loss of ammonia.

High volatilization loss of ammonia from urea than from ammonium sulphate was reported also from Tocklai, but the difference between the two fertlisers was not as striking as in Sri Lanka, possibly due to the indirect method of assesment adopted at Tocklai (TES Ann. Rep., 1974-75; 1977-78). Despite the shortcoming of the latter method, loss of nitrogen from urea was found to be at least 50 per cent higher than from ammonium sulphate.

Contamination of some commercial urea with biuret is another argument against its use as a fertiliser, since biuret is supposed to produce toxic effects on tea if its proportion in the urea exceeds 1.5 to 2.0 per cent. However, experimental spraying of urea solution deliberately contaminated with 1, 2, 5 and 10 per cent biuret did not have any adverse effect on growth or nitrogen uptake by young tea plants (TES Ann. Rep., 1972-73). This shows that the ill effects of commercial urea on the tea plant could be due to some factors or contaminants in the urea other than biuret. However, this question deserves a fresh look.

High hygroscopicity is a disadvantage with crystalline urea but this can be got over to a large extent by using granulated (prilled) urea.

Urea coated with sulphur, lac and Neem were tried on young plants at Tocklai. Sulphur and Neem-coated urea reduced leaching loss remarkably and increased residual build up of soil nitrogen, particularly by the former. Plant uptake showed some improvement with Neem-coated urea. Isobutylidene di-urea, another form of urea tried in the same experiment, proved more effective in reducing loss, increasing plant uptake and building up soil reserve (Barua and Dey, 1984).

Ammonia generated in the soil following the application of urea is supposed to harm young feeding roots of tea. No such effect had been noticed in N.E. India where application rate of nitrogen rarely exceeded 120 kg ha^{-1} at a time.

Lower nitrogen efficiency in comparison with ammonium sulphate is another argument against urea, efficiency being measured in terms of crop return per unit of applied nitrogen. Since volatilization loss of ammonia is higher with urea than with ammonium sulphate, decline in efficiency is bound to occur due to reduction in the quantity of nitrogen available to the plant for absorption unless steps are taken to arrest the loss of ammonia.

Greater loss of ammonium nitrogen from soil applied urea than from ammonium sulphate can explain to a large extent the variable results obtained in different countries in experiments designed to compare the efficiencies of urea, ammonium sulphate and other forms of nitrogen, because the factors that control volatile loss of nitrogen could not have remained the same in all these experiments. From field experiments carried out in different parts of N.E. India, on an average, urea was found to be 5 per cent less efficient than ammonium sulphate (TES Ann. Rep., 1966). In an experiment in Kericho, urea proved less efficient than ammonium sulphate while in another experiment carried out in the Kyawge district of Uganda, the two fertilisers gave the same response (Willson, 1967). The nitrogen dose used in these trials was 90 kg ha^{-1} $year^{-1}$. Urea and five other nitrogenous fertilisers were compared in a trial conducted over a period of eight years in the Nilgiri-Wynaad district of South India. Nitrogen was applied at the rate of 157 kg ha^{-1} $year^{-1}$ along with basic dressings of potash and phosphate. Urea gave 8 per cent less yield in the course of the experiment than ammonium sulphate, although yield differences reached the level of significance only in one or two years (UPASI Ann. Rep., 1968). Calcium ammonium nitrate (CAN) proved to be less efficient than ammonium sulphate. Yield depression following prolonged use of CAN was reported also by Tocklai (TES Ann. Rep., 1969-70).

Relative efficiency of urea, ammonium sulphate and calcuim ammonium nitrate was tested in a trial in Sri Lanka over a period of nine years. Nitrogen was applied at two rates of 168 kg and 336 kg ha^{-1} $year^{-1}$ along with basic dressings of potash, phosphate and zinc. At the lower rate of nitrogen application, yield from urea was slightly (2%) higher than from ammonium sulphate but at the higher rate, ammonium sulphate was distinctly (10%) superior. A summary of the results of this experiment is reproduced in Table 69 (Bhavanandan and Sunderalingam, 1971)

Table 69. Effect of three forms of nitrogen at two levels of application on yield of made tea. Total yield in kg ha^{-1} for 9 years from 1961-62 to 1969-70

Nitrogen level kg $ha^{-1}year^{-1}$	Ammonium sulphate	Urea	Calcium ammonium nitrate (a)
168	15052	15335	14168
Difference from ammonium sulphate		+238	—884
336	19489	17523	18162
Difference from ammonium sulphate		—1966	—1327

(a) Granular fertilisers were used during the first three years.

The 10 per cent loss of efficiency by urea at the higher rate of application is unlikely to exceed the difference in the gaseous loss of nitrogen between urea and ammonium sulphate. It means that if the loss of nitrogen from urea could have been reduced to the extent of the loss from ammonium sulphate, then its efficiency would not have fallen even at the higher rate of application. Yields obtained with the lower dose justify this assumption.

Urea has some additional advantages not found in ammonium sulphate. It does not cause as rapid a rise of soil acidity as ammonium sulphate. At low concentrations (upto 12% in low volume spraying), it can be applied as foliar spray.

Calcium ammonium nitrate

Next to urea, calcium ammonium nitrate is receiving wider attention of the tea growers. Chenery (1966) strongly advocated its use as a substitute for ammonium sulphate to counteract to some extent the harmful effects of the latter on tea soils. Calcium ammonium nitrate also raises soil acidity but at a much slower rate than ammonium sulphate (Bhavanandan and Sunderalingam, *loc. cit.)*. However, this nitrogen source has not proved as efficient as ammonium sulphate even in soils having a pH around 4.0, as is evident from Table 69. Further long-term studies are needed to prove its efficiency in acid soils. It is also worth examining whether usefulness of calcium ammonium nitrate would enhance if it is used in conjunction with ammonium sulphate and urea. It may be noted in this connection that calcium ammonium nitrate is even more hygroscopic than urea.

Ammonia and Nitrate Nitrogen

The tea plant can take up nitrogen either as ammonia (NH_4^+) or as nitrate ($N0_3^-$), although the plant may have preference for one of the two. In their sand culture experiments, Pethiyagoda and Krishnapillai (1971) found that the plants made better growth when 60 to 80 per cent of the nitrogen was supplied as nitrate. On the other hand, Kularatne and Bhavanandan (1971) of the same laboratory working with nitrogen isotopes observed that the nitrogen assimilated by plants supplied with ammonia N was twice as much as that assimilated by nitrate treated plants. Xun and Guomin (1986) also found that the tea plant showed a preference for the ammonium than for the nitrate ion. These studies indicate a preference of the tea plant for ammonia N.

When ammonium sulphate is applied to tea fields, a part of its nitrogen gets converted to nitrate through the action of soil micro-organisms. This happens also with urea. Some ammonia is generated in the process of nitrification of organic matter. The tea plant, therefore, has access to both ammonia and nitrate ions when it is supplied with any of these fertilisers or calcium ammonium nitrate. If the plant needs some nitrate for better growth, these fertilisers automatically take care of it. A nitrate fertiliser like calcium or sodium nitrate cannot satisfy the need of the tea plant for ammonium ions although the plant can still get some ammonia from the decomposed organic matter.

The process of nitrification starts immediately after fertiliser application and under favourable soil-climatic conditions, the process is completed within weeks. With the object of slowing down nitrification rate and reducing leaching loss of nitrogen, two nitrification inhibitors, N-Serve (2-chloro-6-trichloromethyl pyridine) and A.M. (2-amino-4 chloro-6 methyl pyridine), were tried along with urea on young pot-grown plants at Tocklai. As expected, leaching loss of nitrogen increased as the dose of urea was raised from 0 to 200 kg N ha^{-1} in steps of 50 kilograms. The inhibitors were highly effective in reducing leaching loss (TES Ann. Rep., 1979-80). Although the effect of the inhibitors was not reflected in yield when tried out in field in conjunction with urea (TES Ann. Rep., 1983-84), it is yet too early to draw firm conclusions regarding their usefulness. Nitrification inhibitors deserve further trials particularly in soils where the nitrification rate is very high.

Rate of Application

The manuring strategy of most tea-producing countries had undergone drastic changes in course of the last 20 years or so. Current trends augur more changes in the coming years. Introduction of high-yielding planting materials ushered in these changes. Better planting material and improvement in crop husbandry raised the demand for nitrogen and other fertilisers. More nitrogen and other complementary fertilisers are used now by the tea industry in different parts of the world than at any time in the past. However, fertiliser doses and their methods of application differ considerably between tea areas. Upto 500 kg N ha^{-1} $year^{-1}$ is being used in some tea plantations of the U.S.S.R. (Antiya, 1975). In the lowlands of Sri Lanka, clonal tea had responded to the application of 538 kg N ha^{-1} per year (Wettasinghe, 1973). At the other extreme, nitrogen rate recommended by Tocklai for the tea estates of N.E. India does not exceed 135 kg ha^{-1} (Anon, 1970). Response of clonal tea upto 200 kg N ha^{-1} was reported for the first time from this region only in 1972 (TES Ann. Rep., 1972-73).

The above examples should suffice to show that a fertiliser policy considered suitable for one country cannot satisfy the requirements of another country. In fact, even within a country a uniform manuring policy cannot cater to the needs of different soil-climatic zones.

The case of N.E. India needs some comment. Despite lack of response to high doses of nitrogenous fertilisers, the average yield of tea in N.E. India is not low in comparison with many other producing countries. Productivity of a few districts of this area are among the highest in the world. High productivity cannot be attributed to native fertility of the soil, since tea soils of this area are relatively poorer in plant food than those of many other countries (cf. Chapter 5). Plants failed to respond to high doses of nitrogen even when supplemented with adequate quantities of potash, phosphate and other nutrients. No satisfactory explanation is forthcoming for this baffling behaviour of the tea plant.

Mention has already been made of the fact that a certain fraction of the nitrogen applied in the form of ammonium sulphate or urea is lost as ammonia and another fraction is lost in leaching. Both these losses will vary from place to place depending on temperature, rainfall and soil characteristics. How much nitrogen is lost under different situations is not known. In the absence of this basic information, satisfactory explanation for the anomalous behaviour of the tea plant cannot be found. However, the explanation could be very simple. In order to produce a certain amount of crop, plants are to be supplied with more fertiliser nitrogen in areas where the loss of nitrogen is high than in other areas where it is low.

The effect of increasing doses of nitrogen on yield of tea follows everywhere the same pattern. Yield increases as the dose of nitrogen is raised but after reaching a maximum corresponding to a certain level of application, it starts declining if the nitrogen level is further raised. The level of nitrogen corresponding to the point of inflexion differs, depending on whether the plant under a particular situation is responsive to high or low doses of nitrogen.

Going back to the two experiments referred to earlier, it will be observed that in the experiment reported from Sri Lanka yield was showing an increasing trend even at 538 kg dose of nitrogen. A still bigger dose of nitrogen will be required there to reach the point of inflexion. In the other experiment reported from Tocklai, the point of inflexion occurred at 232 kg ha^{-1} nitrogen.

A consequence of the dose-response relationship just mentioned, is the fall in crop return per unit of nitrogen as its level of application is gradually raised. Any increase in the dose of nitrogen above a certain limit ceases to be remunerative. This factor has to be constantly kept in view while working out the requirement of nitrogen (and other fertilisers) for a given situation. In the Sri Lanka experiment mentioned above as well as in other experiments (Bhavanandan and Manipura, 1969), return was usually less than a kilogram of crop per kg of applied nitrogen when the nitrogen level was above 240 kg per hectare. Although response to very high doses of nitrogen has been reported from different countries in recent times, the optimal does in terms of return per unit N has rarely been found to exceed 300 kg ha^{-1} per year.

It may be noted in the above context that yield increases due to increase in the number of shoots. Nitrogen or any other fertiliser has little effect on the weight of individual shoots.

Ratio Manuring

No method so far devised to estimate the nitrogen requirement of a tea estate can be regarded as fully satisfactory. Until some years ago, manuring on replacement basis was very popular in many countries. The changing fertiliser recommendations show that it is no longer so. Sri Lanka would serve as a good example to illustrate this point. Early recommendation in Sri Lanka was to apply 10 kg N for every 100 kg of crop harvested. Gunn and Kanapathipillai (1962) pointed out that the response of the tea plant was not as high. They suggested a yield-trend method for determining the nitrogen responsiveness of tea areas. This too did not prove adequate and a few years later Fernando *et al.* (1969) resorted to yield responses obtained from field experiments carried out in different parts of Sri Lanka for assessing fertiliser requirements. Replacement method was virtually abandoned.

Removal of nutrients by prunings does not generally enter into calculations of fertiliser requirements of tea fields. This introduces a huge error into assessment of fertiliser requirment as will be evident from the data presented in Table 68. Fertiliser requirements based on crop response which automatically allows for the loss of fertilisers from tea fields, is the only sound method of computation.

Fertiliser Balance

Nitrogen alone cannot support healthy growth of the tea plant. In the absence of other nutrients needed by the plant or if their supply is inadequate, growth of the plant suffers. Hence a balance has to be maintained in the supply of nitrogen, potassium and phosphorus as well as of magnesium, calcium and minor elements like zinc, where these are needed.

To obtain the best response, it has been suggested that the nutrients should be made available to the plant in a definite proportion. Foliar analysis of nutrients occasionally supplemented by soil analyis is the basis of this view. However, application of fertilisers at the computed rates does not assure that the nutrients will be available to the plant in the same ratio, since the plant draws some nutrients from the soil reserve and some applied nutrients are lost. Hence for the purpose of fertiliser application, the ratio worked out from chemical analysis can serve merely as a guide.

Nitrogen and Quality

As mentionel earlier, the controversy on the effect of nitrogenous manuring on quality of made tea started with the introduction of inorganic nitrogenous fertiliser and it has not ended even today. The accumulated evidence clearly shows that heavy application of nitrogenous fertiliser produces adverse effect on quality of made tea, quality being taken in the broader sense of overall value. Heavy and light or high and low are vague terms which donot convey any precise information. As we have already seen, what is a high dose of nitrogen in one area may be considered only an average dose in another.

Harrison (1970) attempted to be more specific. After conducting a large number of experiments he concluded that, “There is a slight decrease in the value of tea from nitrogenous manuring, with any kind of nitrogenous manure, provided it is sufficient enough to cause an increase in crop. The drop in value is proportional to crop increase, not to the quantity or kind of manure. Any nitrogenous manure, organic or inorganic, however, if aplied in sufficient quantity to double this crop increase, produces a detectable drop in the value of the made tea.” These conclusions have not yet been challenged.

On the contrary, adverse effect of high nitrogen on quality has been reported by a large number of investigators. To quote a few, Hilton (1971) observed significant depression of theaflavins when the dose of nitrogen was raised from 45 kg to 224 kg per hectare. Guseinov (1973) reported better leaf quality at 90 kg than at 180 kg or 360 kg ha^{-1} of nitrogen application. Utnelishvili (1974) found that in the podzolic soils of the U.S.S.R., nitrogen above 200 kg ha^{-1} had adverse effect on leaf quality.

PHOSPHORUS

Phosphorus requirement of tea is much less than that of nitrogen and potsassium and the response of the plant to phosphatic fertiliser is also more erratic. Among the countries of South East Asia, Sri Lanka was the first to observe positive response of tea bushes to the application of phosphatic fertilisers. Eden (1944) reported significant improvement in yield when old-established tea was supplied with 34 kg phosphate per hectare. Increase of the fertiliser dose to 64 kg did not have additional effect. In two experiments reported from N. E. India in 1954, application of 22 kg P_2O_5 per hactare to mature tea bushes caused significant and consistent increase in yield over a period of 13 years, the average increase being 100 kg ha^{-1} per year, while 180 kg ha^{-1} was the increase at 67 kg ha^{-1} dose. Yield increase was significant every year at both rates of application (TES Ann. Rep.,1954). Subsequently, response to phosphatic fertilisers was reported from South India also (UPASI Ann. Rep., 1971; Ranganathan, 1973). It appears that response to phosphatic fertilisers is gradually becoming more widespread.

Compared to nitrogen and potassium, response of the tea plant to phosphate is small, except in isolated cases where it may be quite substantial. Low return cannot be an argument for neglecting the use of phosphatic fertilisers as incipient shortage in the supply of phosphate will have very adverse effect on the growth and yield of tea.

Supply of 30 to 80 kg ha^{-1} of phosphate appears to meet the requirement of most soils. In soils where the phosphate level has fallen very low or where availablity of the nutrient is a problem, application of the nutrient may have to be increased. A report from the U.S.S.R. shows that over a four year period, yield increased by 77 per cent when the basal dose of NK fertilisers was supplemented by 150 kg phosphate per hectare. Yield nearly doubled at 300 kg dose of phosphate (Putkardze, 1964). Ready fixation of phosphate is a problem in all acid tea soils, but in the tea soils of the U.S.S.R. it appears to be particularly serious.

A number of phosphatic fertilisers are used in tea of which a few are water soluble. These are :

Single superphosphate contains 15-16% P_2O_5 in water soluble form. It also contains 50% calcium sulphate (Gypsum), about 8% silicon, 2% calcium fluoride and 4% iron and aluminium phosphate.

Triple superphosphate contains 45-50% water soluble phosphate and 17-20% lime.

Dicalcium phosphate with 44-44% total P_2O_5 contains 35-40% soluble in neutral ammonium citrate solution.

Ammonium and diammonium phosphate, the former containing 62% P_2O_5 and 12% N and the latter, 54% P_2O_5 and 21% N. Both these are water soluble.

Saphosphophate contains 27-28% P_2O_5.

Rock phosphate : The phosphate content differs between sources of supply. The rock phosphate available in India contains 15 to 32 per cent P_2O_5. P_2O_5 contents of foreign rock phosphates vary from 30 to 34 per cent. These phosphates contain large amounts of calcium (upto 40% CaO) and smaller amounts of magnesium.

In the preparation of NPK mixtures, use of ammonium phosphate is advocated by Tocklai (Anon, 1970). Superphosphate has not been found to be more efficient than ground mineral phosphate. For quick action, ammonium phosphate can be used as a foliar spray.

POTASSIUM

The base-exchange capacity of acidic tea soils is usually low. Application of acid forming fertilisers like ammonium sulphate hastened the loss of bases and the process was further aggravated by the removal of prunings. The capacity of the soil to meet the demand of tea bushes for various nutrients gradually fell, finally reaching a stage when plants started showing signs of hunger. It happened first with potassium, this being the nutrient used by the plant in large quantities. Potash deficiency did not occur simultaneously everywhere since the store of labile potash was not the same in all soils nor were agronomic practices similar in different countries. At present application of potassic fertilisers has become a necessity throughout the tea-growing world. Even then there are some pockets of soil where tea bushes do not respond to the application of potash, although they respond even to very high doses of nitrogen. In the experiment in the low country of Sri Lanka referred to earlier, the bushes did not respond to potash application even when the nitrogen level exceeded 500 kg ha^{-1} per year.

Like nitrogen the requirement of potash when used in conjunction with N, P and other nutrients like Zn, has to be determined ultimately from plant response. Soil and tissue analysis have also been carried out extensively for estimating the potash requirement of tea. We shall have more to say on tissue analysis but may point out in passing that information provided by soil and leaf analysis cannot be made the basis of fertiliser recommendation without their authentication by field trials.

Nitrogen being the major nutrient for tea, potash and phosphate are tagged on to it for enhancing its efficiency. The three nutrients are usually applied in fixed proportions, although the proportions differ from country to country. As pointed out earlier, the replacement method of manuring is no longer strictly followed anywhere, but yield is still the major consideration in the allotment of fertilisers for different sections of tea in a tea estate. A section giving low yield almost invariably gets less fertiliser than a high-yielding section. Since the fertilisers are applied in a fixed proportion, a low yielding field not only gets less nitrogen but less of the other two nutrients as well, although one of the factors responsible for low yield may be deficiency of potassium.

This is one sphere where soil analysis can assist. The available level of potassium gives an indication of the potash status of soil. If it is low, corrective measures can be initiated.

For the purpose of potash application, a similar approach has been adopted in N.E. India, where crop increase has been spectacular in many localities following the application of potash in recent years. Soils of this region have been classified according to their available potash status into four groups. The minimum quantity of potash fertiliser required by each soil group has been worked out in such a way that after meeting the immediate requirement of the plant, something is left for building up soil reserve, which has dropped very low in certain soils. After the base saturation of the soil is sufficiently raised, maintenance doses of potash are expected to suffice (TES Ann. Rep., 1970-71). While the idea appears attractive, improvement of base status of the tea soils of N.E. India or elsewhere would be a difficult task unless the huge drain of nutrients from tea fields could be effectively checked.

Potash fertilisers have been observed to increase the tolerance of the tea plant to water stress. Water use efficiency increased when the plant was supplied with potash, more so under conditions of water stress than when the soil was at field capacity (Dey, 1977 b).

Alternate wetting and drying of the soil increase fixation of potash. This has a bearing on the time of potash application.

Opinion differs on the effect of potash on tea quality. It seems potash may affect quality indirectly by increasing the fibre content of tea shoots.

Sulphate and chloride (muriate) are the two forms in which potash is applied to tea. Commercial brands of the former contain about 50% K_2O and of the latter, 50 to 60 per cent. Both are water soluble salts.

CALCIUM AND MAGNESIUM

Deficiency of magnesium, first detected in Sri Lanka (Tolhurst, 1954), became widespread within two decades and regular application of magnesium fertiliser to tea came to be a standard practice in many tea-growing areas. Although the need for calcium to counteract the harmful effects of acidic fertilisers was recognised for years, it was only recently that judicious use of lime in tea had been advocated by research institutions in some parts of the world. Application of lime is intended to serve the dual purpose of reducing soil acidity and meeting the calcium requirement of the tea plant (cf. Chapter 5).

Although calcium was not applied in the past as a fertiliser yet tea soils received some amount of calcium along with phosphorus, since most phosphatic fertilisers with the exception of ammonium phosphate contain large amounts of calcium.

In applying calcium to tea areas, some factors other than soil acidity will also have to be taken into account. Calcium depresses the uptake of potassium. This is likely to cause shortage of potassium in the plant unless the level of fertiliser potassium is sufficiently raised. Secondly, liming can increase the leaching loss of nitrogen by stimulating nitrification of fertilisers like ammonium sulphate and urea.

Some observations made at Tocklai on the effect of lime on the release of soil phosphorus is of interest (Bhattacharyya and Dey, 1978). Liming was observed to increase the water soluble and aluminium phosphate fractions of tea soils. The authors considered this to be a useful contribution of liming since, according to them, aluminium phosphate is a major source of phosphorus for tea bushes.

Dolomite limestone is the main magnesium fertiliser for tea although it contains more calcium than magnesium (28% CaO and 14% MgO, approximately). To that extent dolomite contributes towards the calcium requirement of tea. It may, therefore, prove advantageous to work out first the contributions made jointly by dolomite and calcium phosphate towards calcium requirement of a tea field, before resorting to the application of lime.

Magnesium sulphate is another source of magnesium. In this form, the fertiliser is easily soluble and can be applied as foliar spray, where necessary. Epsom salt which contains 17-18% MgO and Kieserite with 24% MgO are both known by the broad term "magnesium sulphate".

SULPHUR

Sulphur is essential for the growth of tea and other plants. Most tea soils can supply adequate amounts of this nutrient, but there are areas in some parts of Africa where soils are deficient in sulphur. Tea bushes growing on those soils suffer from sulphur deficiency. Storey and Leach (1933) were the first to draw attention to sulphur deficiency of tea. Subsequent investigations in Africa identified sulphur deficient soils and showed that application of ammonium sulphate could keep the available sulphur content of the soil at a sufficiently high level to meet the entire demand of the crop (TRFCA Ann. Rep., 1967-68). Periodic application of sulphur or ammonium sulphate will be necessary if nitrogenous fertilisers like urea or calcium ammonium nitrate are used in areas susceptible to sulphur deficiency.

MICRONUTRIENTS

Zinc

Following the discovery of zinc deficiency symptoms in the tea areas of Sri Lanka (Tolhurst, 1962), deficiency of the element was observed in other tea-growing areas and, within a span of two decades, zinc became an indispensible fertiliser for tea throughout the world. This has happened despite the fact that the zinc level of tea soils, perhaps with a few minor exceptions, is considerably higher than the critical level which is placed at 0.3 to 2.3 ppm of available zinc (Cox and Kampratt, 1972). The reason is not known. It is possible that the capacity of the soil to release zinc had not been able to cope with the large crops of tea harvested in recent years or that the high rate of application of the other nutrients is interfering with the uptake of zinc.

Zinc is applied mostly as foliar spray and rarely as soil dressing. Studies conducted at Tocklai (Sultana *et aI.*, 1978) showed foliar-applied zinc to be at least 10 times more efficient than zinc applied to soil. Zinc sprayed on the foliage was absorbed within 24 hours but it took three weeks for complete absorption of soil-applied zinc. Tissue concentration of zinc at 0.5 kg ha^{-1} rate of foliar application was equivalent to 20 kg ha^{-1} of soil-applied zinc. In young plants, roots mobilised the maximum amount of zinc followed by stem and leaf in that order. Organic matter and finer soil fractions like clay and silt were observed to have a positive effect on the uptake of zinc.

Application of zinc varies between tea areas from about 2 kg to 20 kg Zn ha^{-1} per year. Still higher rates of application are also reported. Uptake of zinc differs between clones. For equal response, broad-leaf Assam plants seem to require less of the nutrient than small-leaf China plants. No adverse effect of zinc on quality of made tea has been reported.

Zinc sulphate ($ZnSO_4$) and zinc oxide (ZnO) are the two forms in which the nutrient is applied to tea. Commercial zinc chelate was reported to be 30-40% more efficient, when uptake by plant was taken as the criterion (Sultana *et al., loc. cit.).*

Manganese

Manganese deficiency symptoms were reported from Sri Lanka (Tolhurst, 1954) earlier to the discovery of zinc deficiency, but deficiency of this element has so far been highly localised.

As in the case of other nutrients, manganese content of plant tissues increases with increasing rates of application. In a pot experiment carried out at Tocklai on young plants, manganese content of leaf, stem and root increased as the level of the nutrient was raised in steps from 0 to 40 kg Mn per hectare. The maximum concentration of manganese occurred in leaf and the minimum in root, stem concentration occupying an intermediate position. Phosphate produced a synergistic effect on manganese uptake

(Prasad and Dey, 1979).

Manganese can be used either as sulphate or as chloride.

Boron

This micronutrient is now receiving increasing attention although serious cases of boron deficiency have not so far been reported. In experiments reported by Prasad and Dey (1979), boron uptake by young tea plants increased as the dose of boric acid was gradually raised from 0 to 6 kg B per hectare. Foliar application was about 10 times more effective than soil application. Boron concentration in the plant decreased in the order leaf>stem>root. Severe toxic symptoms were produced at the highest (0. 6%) rate of foliar application.

Copper

Copper deficiency has been reported in certain highly organic soils of Malawi. Tea bushes growing on those soils have low polyphenol oxidase (PPO) activity, this being the enzyme largely reponsible for oxidation of the catechins present in tea shoots. The enzyme contains copper. Long-lasting improvement of PPO activity could be effected by spraying bushes with dilute (1 to 2%) copper sulphate solution. Spraying of copper had only a temporary effect on bushes which already had a reasonably high PPO activity (TRFCA Ann. Rep., 1968-69).

Copper sulphate sprayed at high concentration (12%) suppressed growth of tea bushes in N.E. India.

Aluminium

The tea plant accumulates abnormally large amounts of aluminium (cf. Chapter 5), without any apparently adverse effect on the plant. The role of this element in the nutrition of tea has not yet been elucidated. Jones (1961) proposed the hypothesis that aluminium tolerant plants contain or excrete organic acids that form soluble chelated complexes with aluminium, thereby reducing its chemical activity and toxicity. The tea plant produces a large amount of oxalic acid which combines with calcium to form calcium oxalate. Large number of calcium oxalate crystals are found in leaves and other organs of the plant. Hence it is questionable if aluminium plays the role of a neutralizer of organic acids formed in tea.

Molybdenum

This element is involved in the reduction of nitrate to ammonia but its deficiency in tea has not so far been reported. Foliar and soil application of molybdenum on tea bushes failed to produce any effect.

In addition to the above micronutrients, iron and silicon are also essential for growth, but deficiency of these elements has not yet been reported in tea.

NUTRIENT ABSORPTION

Nutrient absorption by plant is an extremely intricate phenomenon involving the plant, soil, climate and the treatments given to the plant and soil. It is largely an active process where energy is expended. Carbohydrates synthesized by leaves are translocated to roots where these are oxidised during the process of respiration with the release of energy. Respiration cannot take place in the absence of oxygen present in the air. Hence the prime requirement for nutrient absorption by root is a soil which permits ingress of air in sufficient quantity for sustaining root respiration. Roots cannot get enough oxygen for respiration in compacted soil, soil having an impervious crust on the surface or in soil that is waterlogged. Nutrient uptake and growth of plant suffer unless the soil is open, well aerated and freely drained.

Closely linked with nutrient uptake is the base exchange capacity of a soil i.e. the capacity of soil to hold on to bases like calcium, potassium etc. (Cation Exchange Capacity). Acidic tea soils possess lower base exchange capacity than many other arable soils. Methods of crop husbandry followed in the past coupled with the use of acidic fertilisers hastended the depletion of bases from tea soils, which were already low in bases. Organic matter too can hold bases, but systematic efforts to conserve organic matter in soils appear to have been lacking in a large part of the tea-growing world. In consequence, the base status of many tea soils have failen so low that growth of the tea bush can no longer be sustained without supplying the bases to the soils although, in the past, the soil itself could meet the modest need of the plant for most of these nutrients from its reserve.

It may be economically feasible to feed the tea bush with all the nutrients it needs, but their indiscriminate supply will create serious problems of nutrient balance in the soil, a condition necessary for the smooth uptake of nutrients by plant roots. It is known that an excess of one nutrient in the soil can depress the uptake of another, a phenomenon known as ion-antagonism. Much remains to be learnt about ion-antagonism in tea, but a few facts are known which we shall cite to illustrate the hazards of undirected application of nutrients to tea fields.

Calcium-potassium antagonism is a well-documented case not only in tea but in other crops also. Excess of available calcium in the soil depresses the uptake of potassium. However, what constitutes an excess is not well-defined in the case of tea. Crop depression was reported from N.E. India when the available K : Ca ratio of the soil was 2 : 1 but at 4 : 1 ratio, there was no depression (TES Ann. Rep., 1969-70). This finding remains to be confirmed under different soil climatic conditions.

High concentration of potassium is known to interfere with the uptake of magnesium. When tissue concentration of magnesium is low, application of heavy doses of potassic fertlisers can cause deficiency of magnesium.

These two examples will clearly show how difficult it will be to work out the requirements of potassium, calcium and magnesium when all three are to be applied to a tea field. Further complications will arise from the fact that some of the applied nutrients will get fixed in the soil, some lost in leaching and a certain amount will be released from the soil reserve.

Some more cases of ion-antagonism in tea have come to light. With increased supply of nitrogen, potash percentage in leaf decreased. Nitrate reduced the uptake of phosphate (Krishnapillai, 1981). Boron depressed the uptake of calcium (TES Ann. Rep., 1979-80). Manganese depressed the uptake of iron (Takayangi and Ishigaki, 1976). Contradictory results were reported on the influence of phosphorus on the uptake of zinc. A negative correlation between P and Zn was observed at Tocklai (TES Ann. Rep., 1977-78) while Shuvalov *et al.* (1986) working with radio-active isotopes, found the correlation to be positive. Manganese had a synergistic effect on the absorption of phosphorus (Prasad and Dey, *loc. cit.).*

Cation Exchange Capacity (C.E.C.) of roots plays an important role in nutrient uptake. Any treatment given to the tea plant, irrespective of whether it is cultural, nutritional or hormonal, that increases the growth of feeder roots also raises the C.E.C. of roots. When the C.E.C. is high, the plant can absorb more nutrients, with a preference for the divalent cations Ca^{++}, Mg^{++} etc. to the monovalent K^{+} (Chamua, 1975). Preferential uptake of Ca^{++} and Mg^{++} at the expense of K^{+} can cause potash deficiency, particularly of young plants. This can be countered by stepping up the rate of potash application. This situation is likely to occur more frequently in predominetly Chinery type clones since the proportion of white to red roots is generally high in the China kind of tea.

Available evidence suggests that under favourable growing conditions, a tea bush with a good cover of foliage starts absorbing nitrogen and potassium within a few days from fertliser application. The position regarding the uptake of phosphours is not clear. All foliar-applied fertlisers are absorded very quickly and stomata present on the undersurfrace of tea leaves appear to be the points of entry of the nutrients into leaf. Foliar-sprayed urea was observed to enter into the treated leaves through the stomata (Barua, *et at.*, 1967).

Uptake of nutrients by tea plants from mulched soil is higher than from unmulched soil. Mulching controls weed growth and increases the production of feeder roots in the surface layer of soil (TES Ann. Rep., 1982-83). When the organic mulch decomposes, nutrients are released to the soil. Manipura *et al.* (1969) observed increase of available phosphorus and exchangeable potassium in the top 7.5 cm soil under Guatemala mulch. Control of weeds reduces competition between tea and weeds for nutrients. Thus by controlling weeds, inducing the growth of feeder roots and contributing nutrients, mulching increases nutrient absorption by tea plants. In the cold climate of Kericho, Kenya, increase of soil temperature under mulch was considered to be an important factor for enhancement of nutrient uptake from mulched than from bare soil (Othieno, 1976; 1977). Similar results were reported by Shyu and Wu (1968) from Taiwan, where mulching with paddy straw raised soil temperature and improved growth of tea.

The maximum concentration of feeder roots of tea occurs in the top few centimetres of soil (cf. Chapter 3). These delicate roots are liable to damage and destruction during cultivation of the soil for the control of weeds or for incorporation of fertlisers. Due care has to be exercised in these operations to avoid destruction of the feeder roots.

Until about 30 years ago, response of the tea plant to phosphate was very rare in S.E. Asia where the maximum amount of tea is produced, but significant response to phosphatic fertilisers has been reported from a few areas in recent years. Although phosphorus requirement of tea is small in comparison with its need for nitrogen and potassium yet it is remarkable that the low-phosphatic acid tea soils of this region, where phosphate gets readily fixed, could meet the demand of the crop for decades with little or no application of phosphatic fertlisers.

Association of endotrophic mycorrhiza with tea roots was mentioned in Chapter 3 and attention was drawn to its probable role in the phosphate metabolism of tea. Recently Neog (1986) has shown that tea plants grown in sterilised soil accumulated much less phosphate than plants grown in normal, unsterilised soil. The latter plants produced better growth than the former. This is a fairly conclusive evidence of the positive role that mycorrhiza plays in the phosphate nutrition of tea. Further investigation may throw more light on this and other aspects of mycorrhizal association in tea.

TIME AND METHOD OF FERTILISER APPLICATION

Time

Common sense dictates and experimental evidence confirms that fertilisers should not be applied when the plant remains leafless. This means that no fertiliser should be applied to pruned bushes until the bushes have produced a 'good' cover of leaves. What consitutes a good cover cannot, however, be easily defined without taking into consideration the age of bushes and the severity of the pruning operation. A minimum of three leaves on each newly grown primary may be taken as a working standard, leaving enough scope for adjustment according to each situation. Furthermore, pruning reduces root growth (cf. Chapter 3), so that the capacity of plants for absorption of nutrients also declines after pruning.

Application of pre-pruning fertliser mixtures with the idea of hastening recovery of bushes from pruning was a common practice in the past. Since pruned bushes are virtually incapable of taking up nutrients from the soil, application of fertlisers before pruning will be a wastage. Large amounts of fertlisers are leached out of the area or sink below the root zone before the pruned bushes have produced enough foliage to make use of them. However, there can be no harm if fertlisers are applied sufficiently ahead of pruning, allowing enough time to the bushes for their utilisation.

It has generally been found that tea bushes are less responsive to fertiliser nitrogen in the year of pruning, but this does not seem to be the experience everywhere (Willson, 1969; Anon, *loc. cit.)*. The argument is advanced that a pruned tea bush needs better nourishment than an unpruned one to enable it to produce a new crop of shoots (primaries), the number and vigour of which determine its productivity in the subsequent years of the pruning cycle. However, this argument appears to be tenuous. A bush in the pruned year remaining virtually leafless for a part of the year cannot be expected to utilise as much nutrients as it does in the following years when it is fully foliated.

Fertilisers should be applied to moist soil. On dry soil, nutrients remain unavoidable to plants and volatilization loss of nitrogen as ammonia increases. Fertilisers should not be applied when heavy rain is expected. Heavy rain following fertiliser application increases leaching loss. Moist soil and light showers afterwards is a condition ideal for fertiliser application.

In areas where tea grows throughout the year, fertilisers can be applied to unpruned tea at any time of the year, provided the conditions mentioned above are satisfied. The same cannot be said of areas where growth is seasonal. In N.E. India shoot production slows down from about mid-October and shoot growth completely ceases by December. Under these conditions, fertilisers applied after June could not make the same impact on yield as that of earlier application although some residual effect of July-applied fertilisers was observed in the following year (Cooper, 1939). These results were confirmed by subsequent studies. Hence, in areas where shoot production either stops completely or remains very negligible for a part of the year, beginning of the growing season after the soil has been wetted by rain, is the most appropriate time for fertiliser application.

Method

Fertiliser application is normally a manual operation in tea. In suitable terrain, mechanical application may ensure uniform distribution of fertilisers, but if done conscientiously under proper supervision, manual application can also be very efficient.

Nutrients absorbed by one limb of the tea root system are translocated only to particular branches of the plant. Radio-active calcium, phosphorus and sulphur fed to about 12 per cent of the root system of a tea bush were translocated to a restricted number of branches (Ajdinjan, 1956), showing that certain roots supply nutrients to certain branches. This fact has to be kept in view while applying fertilisers, both to young and mature tea.

Even distribution of fertilisers over the entire area of a mature tea field including the inter-row spaces ensures access of all roots to the applied nutrients. In hedge-planted tea, application of fertilisers only on the sides of hedges leaving the spaces inside hedges unmanured deprives a part of the branch system of bushes from getting full benefits of the fertilisers.

Various practical methods have been devised for the application of fertilisers. Whatever method is used, uniform distribution of fertilisers should be the aim. Uniform distribution over a large area becomes difficult if the quantity of fertiliser is small. One way of getting over the difficulty is by increasing the bulk by mixing the fertilisers with some inert material like sand or powdered soil. If fertilisers are applied in divided doses, application to alternate rows at a time could be another solution.

Some adjustments become necessary in applying fertilisers to young tea although principles are the same. The roots of young plants spread over a small area which is generally wider than the spread of the branch system. Yet large spaces between plants remain inaccessible to the roots. Fertilisers are wasted if application is done on those vacant spaces. To avoid wastage as well as to give attention to each plant in the early stages of development, young plants are manured on individual basis. The normal practice is to apply a measured quantity of fertiliser in an annular strip around each plant, taking care to leave a gap between the plant and the fertiliser strip to avoid contact of the plant with the fertiliser. The soft stems of young plants get scorched when they come into contact with soluble salts like ammonium sulphate and potassium chloride.

The annular strip on which fertilisers are applied should extend beyond the perimeter of the branch system since, as mentioned earlier, roots spread over a wider area than the top. The width of the fertiliser strip extends at each successive application as the plants increase in size, ultimately making contact with the neighbouring strips. After this stage is reached, fertilisers can be applied over the entire area as in the case of mature tea. The time taken to reach this stage depends on the rate of growth of the young plants which, in turn, is controlled by genetical, enviromental and cultural factors. As such, there cannot be a definite time limit applicable to all situations beyond which, for the purpose of fertiliser application, young tea can be treated at par with mature tea.

Fertiliser placement

Fertiliser placement has been a controversial issue in tea. One school is of the opinion that there is no advantage in placing or incorporating fertilisers with the soil after their application on the surface, while the other school holds contrary views. However, neither surface application nor placement can satisfy the requirements of diverse soil-climatic and topographical conditions under which tea is grown. Of the three methods of fertiliser application, placement is the most expensive while surface application is cheap and the most convenient. Surface application is, therefore, preferable unless local conditions demand placement or soil incorporation.

Tea plantations located on steep slopes in high rainfall areas experience heavy loss of soluble fertilisers due to leaching. In such areas, placement or soil incorporation of fertilisers would be advantageous. Again in areas where temperature remains very low, sub-surface placement gets the advantage of a higher rate of nitrification as the temperature inside the soil remains higher than at the surface. Fertilisers will require forking into a soil having a hard surface or a crust. Surface application should suffice under most other situations, if fertilisers are applied under favourable conditions.

Advantage of placement of phosphatic fertlisers has been reported from many areas. For instance, Ranganathan (1973) observed increased uptake of phosphorus in South India when fertilisers were placed at 15-25 cm depth. Surface broadcasting had no effect. Shuvalov *et al.* (1986) reported highest translocation of radioactive phosphorus to aerial mass when tagged fertilisers were placed at 30-40 cm depth. In contrast, no improvement from placement of phosphatic fertiliser below the soil surface was observed in N.E. India, either in the past or at present (TES Ann. Rep., 1981-82). In Japan too broadcasting between rows followed by surface incorporation was found to be the most effective method (Ikegaya, 1975). The observed differences can be attributed to rapid fixation of P in the acidic tea soils. The small amount of available P also gets fixed at other sites during its movement in solution through the soil. When the depth of placement of phosphate coincides with the zone of maximum root activity, the available fraction or a part of it is absorbed by tea roots before its refixation. This was clearly brought out in the investigations of the Russian workers. In N.E. India the maximum concentration of white, feeding roots of tea occurs near the soil surface (Barua and Dutta,1961). Hence placement of phosphatic fertiliser in the lower layers of soil confers no benefit over surface application. The same considerations apply to other areas.

When sprayed on the foliage of tea bushes in diluted solution, nutrients get promptly absorbed, apparently through the stomata present on the undersurface of leaves (Barua *et al., loc. cit.).* Foliar application is, therefore, the most efficient method of curing plants suffering from deficiency of one or more nutrients. This can also be an effective method of supplying nutrients to tea bushes when root aeration is impeded by flooding or waterlogging.

Single and split application of fertilisers

Much larger quantities of fertilisers are applied to tea now throughout the world than at any time in the past although, as pointed out earlier, the rates of application differ widely between different areas. Volatilization loss of nitrogen and leaching loss of other soluble fertilisers, particularly in high rainfall areas, increase if the quantity of fertilisers applied at anyone time is large. The danger to the damage of feeding roots from concentrated salt solution also increases at high levels of fertiliser application. On these considerations as well as on the strength of experimental evidence, many Tea Research Institutes favour application of fertilisers in divided doses. For instance, Fernando *et al.* (1969) in Sri Lanka recomended application of 134 kg ha^{-1} nitrogen in three split doses. More splits were advised for higher rates. Split application of even the basal dose of fertiliser mixture (NPKMg) was suggested where the application rate was high.

Strangely, however, split application of fertilisers in N.E. India has not proved superior to application in a single dose (TES Ann. Rep., 1969-70). Similar results have been obtained in Central Africa (TRFCA Ann. Rep., 1967-68) and East Africa (TRIEA Ann. Rep., 1979), although the nitrogen doses used in all these experiments were quite high, upto 250 kg per hectare. No satisfactory explanation is forthcoming for the anomalous behaviour of tea in these areas, but the suggestion has been advanced that loss of fertilisers does not result from single application since the tea plant can absorb large amounts of nutrients and store them for future use. This, however, does not explain why tea bushes in other areas respond to split application. Examination of soil properties and rooting pattern of bushes in different areas is likely to provide a more satisfactory explanation. Whatever may be the final explanation, the arguments in favour of split application of large quantities of fertilisers cannot be ignored, simply because tea bushes of certain areas have so far failed to respond to this method of application.

Roots of young tea plants have limited foraging capacity, which makes split application all the more necessary for young tea.

LEAF ANALYSIS

Mineral analysis of leaves (or any other plant organ) can be a useful tool for assessing the nutrient status of tea bushes. Nutrient composition can be utilised for recognising deficiencies and can serve as a preliminary source of information for fertiliser use. To be useful the results of chemical analysis must, however, be reproducible. If the results cannot be reproduced, interpretation of data becomes faulty. This means that the procedure for sampling leaves and the techniques of chemical analysis have to be standardised first to make leaf analysis a meaningful exercise.

The mineral composition of plants remains in a state of unstable equilibrium under the influence of a large number of internal and external factors. We have already indicated that age, leaf position and genetical make up of the plant influence nutrient composition of leaves. Soil, fertiliser application, drought, waterlogging, weed competition, shade, rainfall and temperature are the predominant external factors which can influence nutrient composition of a plant by affecting uptake.

Sampling should first aim at identifying the leaf that is least susceptible to unpredictable behaviour under the influence of the internal and external factors and then find out the most appropriate time for collecting the leaf samples. Although the task is formidable, attempts have been made from time to time to identify a suitable leaf for nutrient analysis and standardise the conditions for its collection.

Hasselo (1965) working at TRI Sri Lanka came to the conclusion that the topmost maintenance leaf at the time of sampling (i.e. the leaf from the axil of which the topmost pluckable shoot has emerged) was the best choice for the purpose of mineral analysis. Mineral contents of this leaf gave a fair indication of the K, Na, Mn, Fe, Zn and Mo content of leaves in the plucking table under up country and low country conditions of Sri Lanka, but not of N, P, Ca, Mg and B contents. For studying climatic effects on nutrient uptake by the tea bush and/or changes in nutrient availability in soil and for investigations on the relation between nutrition and weather-induced changes in quality, he considered the plucked shoot (2 + bud) or the third leaf to be preferable. Large monthly fluctuations in leaf nutrient contents indicated that several samples would have to be taken in consecutive months. If one particular period had to be chosen then just after the main flush seasons i.e. June-July or Novenber-December was considered to be most suitable under Sri Lanka conditions.

Hilton (1971) working at TRFCA in Malawi observed that the greatest increase of N and K occurred in the third (from top) leaf of four-leaf shoots, when the plants were supplied with increasing quantities of these nutrients. In the case of P, the first leaf was a little more sensitive than the third leaf. He concluded that for demonstrating the effects of N and K, the third leaf would be the best choice. For P also, analysis of this leaf would give fairly satisfactory results, without having to carry out separate analysis of the first leaf. Like Hasselo, Hilton also found the first maintenance leaf to be more sensitive to changes in nutrient status than the third leaf, but the sampling error associated with this leaf being high, he preferred the third leaf. The highest cropping months of January-February under Malawi conditions were considered to be the best time of the year for drawing leaf samples for nutrient analysis.

Studies conducted at Tocklai in N.E. India (TES Ann. Rep., 1979-80) had shown the third leaf of growing shoots to be the most sensitive indicator of N, K, Mg and Zn status of tea bushes. In case of P, the second leaf appeared to be slightly better than the third, since seasonal fluctuation of P was the least in the second leaf, but to avoid duplication of work, the third leaf was suggested for nutrient analysis. In case of Ca, each one of first, second and third leaf was equally satisfactory. Wide seasonal variation in the nutrient content of leaves was observed at Tocklai as elsewhere. The highest cropping period of July-September under N.E. Indian conditions was considered to be the best time for drawing leaf samples.

These observations suggest that the nutrient composition of the third leaf of growing shoots is the best representation of the nutrient status of a tea bush. If sampling errors could be minimised, the topmost maintenance leaf at the time of sampling would be even better. However, no criterion has been devised to determine the number of leaves that will be required to make the sample representative of a tea population. For seedling tea, the sample size will necessarily be much bigger than for clonal population. Soil heterogeneity within the sampled area will also increase sample size. This important aspect of sampling has not received much attention.

There is a general consensus that sampling should be done during the highest cropping months, but opinion differs on the number of samples to be drawn for analysis. It would, however, be necessary to leave a wide gap between sampling and fertiliser application.

The foregoing account will show that despite some progress, much remains to be done towards standardising the procedure for sampling leaves for nutrient analysis. Unless this is done, leaf analysis data cannot be relied upon to serve as a supplement to fertiliser trials.

Notwithstanding the limitations imposed on leaf analysis by the absence of a standard procedure for drawing samples from plant populations, many other facets of nutrition of the tea plant have been studied successfully on individual plants where sampling is not a serious problem. In some of these experiments, plants were grown in sand culture while in others field-grown plants were used. Reference has already been made to many of the important contributions emanating from these studies. Briefly, the rates of uptake of soil and foliar applied nutrients by the tea plant, interactions between nutrients in the uptake phenomenon, variation in mineral composition of plant tissues, uptake of nutrients by different clones, pathways of translocation of nutrients from roots to the aerial parts are some of the important findings that have advanced our knowledge of tea nutrition to a great extent. Attempts at direct and indirect correlation of leaf nutrient composition with quality of made tea have also met with partial success. Correlation of soil and plant nutrient contents has also been investigated. All in all, mineral analysis of leaf has proved to be an important tool for the study of tea nutrition. Standardisation of a technique for drawing leaf samples from tea populations will widen its scope considerably.

WATER MANAGEMENT

Plants take up nutrients from the soil in aqueous solution. In a dry soil, nutrients applied as fertilisers as well as those present in the soil remain unavailable to plants. Water itself is essential for plant growth, but its excess in soil interferes with the absorption of nutrients by plant roots. Manuring becomes ineffective if plants donot get the right amount of water. However, supply of water to the tea plant in keeping with its need at all phases of its growth is beset with practical difficulties in many tea areas.

Rainfall in the tea areas varies from 650 mm to 6000 mm (cf. Chapter 1) and its distribution in a large majority of the areas is very uneven (cf. Chapter 4). In practice, water management in tea involves dealing with situations arising out of too little, too much and uneven distribution of rain.

A brief account of soil water relationship is given in Cahpter 8. Some theoretical aspects of water relations in tea have been discussed by Squire and Callander (1981) with special reference to the conditions prevailing in East and Central Africa. In this chapter our observations will be confined to a few practical problems of water management in tea areas.

Drainage

Laying of drains in sloping terrain cleared for planting tea has been dealt with under soil erosion and catchment planning (cf. Chapter 8). But drains are necessary also in old tea not planted on the contour. Steepness of slope, depth and texture of soil, total quantity of rain, intensity of rain storms and weed flora are factors that determine drainage designs. These factors differ from place to place and sometimes between sections of tea within a tea estate. Hence there cannot be a standard drainage design formula applicable under all situations. Each section of tea will have to be treated on its own merit. Expert guidance is required for laying out drains in old sections of tea. Haphazard cutting of earth may cause serious problems of soil erosion. Drains should be laid on the contour, their size and frequency matching with the volume of water to be discharged at peak flow. Where the soil is easily erodable, it may be necessary to protect banks of the main drains with rivetments of stone, brick, plastic tiles etc. In East Africa the bottom and sides of main drains are grassed, usually with *Eragrostis curvula*, to check erosion (Kilavuka, 1982). It is a commendable practice for areas where rainfall is not high, but is unlikely to work in high rainfall areas. Even in the latter areas grasses and weeds growing on drain banks should not be disturbed as these provide some protection to drain sides and check erosion.

North-East India is the largest tea belt where the plant is cultivated on flat and gently sloping land at elevations of less than 300 metres. A brief account of the deteriorating drainage situation of this region was given in Chapter 8, but some more details of the investigations carried out at Tocklai in recent years for controlling watertable could be useful to other areas facing similar difficulties.

Drainage of the flat and gently sloping lands of the Assam Valley and Cachar is getting increasingly difficult due to siltation of the two main rivers, the Brahmaputra and the Borak, as well as their numerous tributaries. The bed of the Brahmaputra rose at the alarming rate of 6 to 8.25 cm per annum during the period 1910 to 1960 (Dey, 1981). Floods have become recurrent features of these valleys and their intensity and frequency are on the increase. During the months of heavy rainfall from July to September, drainage of water from tea estates is impeded by high water level of the natural outfalls like streams, rivers, land depressions *(hullah)* etc, resulting in stagnation of water in the tea areas and submergence of roots. The old existing shallow drainage systems of most tea estates are inadequate under the changing conditions. A recent survey has shown that 5-6 per cent of the tea estates cannot be drained economically, 46 per cent can be drained with difficulty by adopting new technology while the remaining 48 per cent can still be drained by conventional methods despite changes in outfall characteristics. The estates which fall into the last category require an improved net-work of bigger, deeper and, at places, closer drains under the changed circumstances. Depth, width and spacing of the new network of drains are worked out for each situation by taking into account rainfall pattern, soil texture, hydraulic conductivity of soil and nature of outfall.

Pumping combined with gravity flow is the strategy adopted for drainage of those estates where gravity flow alone cannot keep the groundwater level below the effective root zone, which is about 90 cm under conditions of N.E. India. The catchment selected for drainage is first level-surveyed. Depth and spacing of drains are then worked out to maintain groundwater level at the desired depth, by following the procedure mentioned above. The network of drains is laid and watertable depth is occasionally checked. The drains discharge into a main channel along which water flows out of the catchment into the nearest natural outfall, when drainage conditions are favourable for gravity flow. During periods of heavy and continuous rainfall when gravity flow ceases, water from the channel is diverted to an artificial reservoir constructed at the lowest part of the catchment. Water is pumped out from the reservoir into an outlet channel provided with a sluice gate. The duration for which pumping becomes necessary can vary widely under the same rainfall conditions depending on the volume of water that flows out of the catchment under the action of gravity which, in turn, is determined by the depth of the natural outfall. Some tea estates have tried this system successfully.

Open drains, if properly designed and laid out, occupy a large amount of space which reduces the area available for tea bushes. Drain banks get eroded, particularly in loose-textured soils, and drain maintenance is costly. To avoid wastage of space, Tocklai conducted experiments on sub-surface drainage (Dey, 1977a; 1981). A waterlogged section of tea was selected for the trial. After working out depth and spacing of drains, PVC slotted pipes were laid at site and enveloped by graded gravels. The pipes discharged water into a collector drain which carried the water to the natural outfall. When gravity flow stopped due to the rise of water level in the natural outfall, pumping out of water was resorted to as in the case of the open-drain system mentioned above. Yield of the badly waterlogged section where this system was tried increased by 22-25 per cent during the first three years, demonstrating thereby the efficacy of the system.

The initial cost of the pipe drainage system is high. In the experiment just described, it took 8-9 years to recover the cost of installing this system. However, sub-surface pipe drainage has a number of advantages over open drains, of which elimination of the recurring cost of drain maintenance and release of land for accommodating more tea bushes are the main. If these and other ancillary benefits like unhampered passage of pluckers and other field workers, reduction in the number of culverts and bridges etc., are taken into account, sub-surface drainage may prove to be more profitable than open drains in a long-duriation crop like tea. This drainage system deserves trial on a wider scale to prove its worth under different situations as well as to provide additional data for cost-benefit analysis.

The tea areas of Bangladesh adjoining the Cachar district of Assam face similar drainage problems. According to Van der Laan (1971) drainage would be a very sound investment in many parts of Bangladesh which would be repaid in the course of one to two years.

Irrigation

The expectation that supply of water during periods of water stress will increase growth and yield of tea is not realised when some other factor essential for growth is limiting. It has been shown in Chapter 4 that the expected increase of crop was not obtained from the irrigated bushes in Malawi during the hot dry months of the year when the atmospheric humidity was very low. However, water is the major factor limiting yield of tea either throughout or at certain times of the year in a majority of the tea areas.

Only a few major tea-growing countries like Indonesia and Sri Lanka are fortunate in getting some rain throughout the year in their tea areas. Even there, certain regions like Uva in Sri Lanka suffer from deficit of water at certain times of the year (cf. Chapter 4). Due to seasonal pattern of rainfall, tea areas in most other countries, comprising 60-65 per cent of the global total, are exposed to periods of drought, which lasts from two-three weeks in some places to five months or more in others. In the sub-tropical belt, the dry period starts early in the cold season and continues until spring and, at times, extends into early summer. In a large majority of the areas falling under this pattern of rainfall, tea bushes remain dormant during the cold weather under the influence of short days and cold nights (cf. Chapter 3). Irrigation of such areas during the cold season does not reflect immediately on yield. Besides, the soil charged with water from previous rains retains some moisture at this time of the year when loss due to evapotranspiration is also small. On these considerations and in view of the fact that irrigation is a costly operation, beginning of the growing phase after the dormant season appears to be the correct time for starting irrigation. Experimental evidence from different countires also shows very little benefit from cold weather irrigation.

Irrigation has been tried almost in all areas exposed to long dry spells. Results of irrigation experiments and commercial field trials conducted in different parts of Africa and in a few other regions, viz. Assam, East Pakistan (Bangladesh) and Taiwan were discussed in a symposium held at the Tea Research Institute of East Africa. The proceedings of the symposium were edited by Carr and Carr (1971) and published in a monograph. It emerged from the deliberations that irrigation would increase crop in areas subjected to long, dry spells, but that economics of irrigation depended on many other factors. The general consensus was that irrigation on a commercial scale would not pay in areas where the dry spell is of short duration or where the expectancy of intermittent rains during the long, dry spell is high. Importance of root depth in any scheme of irrigation was stressed. Deep-rooting tea bushes could withstand large soil water deficit without showing any adverse effect on yield. Ch'ang and Wu (1971) at the same symposium presented experimental data to show that yield actually was depressed when the soil moisture was at 75 per cent field capacity. They observed maximum response to fertilisers in plots maintained at 50 per cent field capacity. These latter results are in contrast to those obtained in N.E. India where irrigation induced maximum crop production when the soil was maintained at field capacity throughout the dry season from November to end April (Biswas and Sanyal, 1983). These differences seem to be the consequence of rooting habits. The shallow-rooted tea bushes of N.E. India reacted adversely to slight deficit of water in the top soil where most of the absorbing roots are concentrated. The tea bushes of

Taiwan presumably have deeper roots. These bushes did not suffer from a deficit of water in the top 40 cm of soil, that being the depth of soil-water measurement, since the deep roots could draw water from lower depths.

Biswas and Sanyal *(loc. cit.)* made use of long-term meteorological data and crop records of tea estates to compute the benefits of irrigating tea during the dry part of the year in different soil-climatic zones of N.E. India. They worked out for each zone the quantity of irrigation water that would be needed to produce the expected benefit. These statistical computations showed that dry weather irrigation followed by efficient drainage of excess water during the wet season would cause 9 to 53 per cent increase over the current yields in different parts of the region. The quantity of irrigation water required to produce yield increase of the same order would, however, be variable. For instance, 120 mm irrigation water increased yield by 44 per cent in one location in the Dooars while at another location in the same area, 240 mm of water caused only 25 per cent increase, although the yields of irrigated tea at both sites were virtually the same. Two irrigation trials, one in Assam and other in the Dooars, lent support to these statistical findings. The importance of prior assessment of economic viability of irrigation projects is implicit in these findings.

A suitable source of water at a convenient place near the irrigation site is a pre-requisite for any irrigation project. If water has to be conveyed over a long distance or raised to the site by pumping in several stages, then the project becomes expensive. Such projects may still pay under certain situations, but the cost-benefit aspects should be examined carefully before undertaking such schemes.

Suitable sources of water are not easily available during the dry months even in areas of excessive rainfall during the wet season. Non-availability of water at convenient locations has been a deterrent for undertaking irrigation projects in some parts of N.E. India where irrigation would have been profitable. Catchmentwise storage of water for irrigating tea during the dry weather within each estate or a group of contiguous estates is under active consideration.

Among the clones selected in different countries some have proved to be more resistant to drought than others. The value of drought resistant cultivars for dry areas is indisputable, but suitable field selection criteria for drought resistance have not yet been identified. Such criteria as shoot-water potential (Carr, 1977) can be useful only after the preliminary stages of selection. Surprisingly, not much attention has so far been paid to the selection of drought-resistant clones.

Water Conservation

In areas of low and marginal rainfall, more importance attaches to conservation of water in tea fields than to supply of water through irrigation. In any case, irrigation is not a feasible proposition for many tea growers because of practical difficulties or financial constraints. Surface run-off is admittedly small in areas of low rainfall but after heavy rainstorms, it may be quite considerable. Run-off is accompained by soil erosion.

Catchment planning which includes contour planting and contour drainage is designed to check soil erosion (cf. Chapter 8). This system can be adapted to great advantage for the conservation of water in tea fields. This has been done in Malawi and the method followed there was described by Shaxson (1971). In this method rainwater is detained in small, shallow basins or 'microcatchments' which are formed by erecting cross-ties between contour ridges. The contour ridges and the cross-ties are spaced 80 cm apart which makes each microcatchment 80 cm x 80 cm square. The walls of the cross-ties are two thirds the height of the contour ridges that run across the slope on a slight gradient from the crest to the natural drainage channel. Tea is planted in the micro catchments at a spacing of 80 cm within and 160 cm between microcatchment rows. At times water may overflow the cross-ties, but because of its slow movement towards the outlet channel, it can do no harm.

Great importance is attached to covering bare soil including the contour ridges and the cross-ties with mulch until tea bushes completely cover the ground. Mulch protects the soil from the beating action of rain that makes the soil impervious to water by forming a thin crust on the surface. Splash from rain drops displaces soil particles which get washed out by rain.

The method just described can be used in all areas of low and marginal rainfall with such modifications as may be required to suit local conditions.

Soil should not be kept bare either in young or in mature tea. Since mulching material is difficult to get in sufficient quantity, stress was laid on cultivation of mulch crops on any spare land. In the year of pruning when the soil is exposed to rain and sun, the pruned area should be mulched with the pruning litter which makes as good a mulch as any grass, cover crop or weed. Attention was drawn in the foregoing pages to the damage caused to soil and the monetary loss resulting from the removal of prunings from tea fields.

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CHAPTER 14

PESTS AND DISEASES

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PESTS

OCCURRENCE AND DISTRIBUTION

More than 300 species of pests have been observed to attack the tea plant. All these species cannot be found in any one country or a region within the country. The pest spectrum varies from place to place. Fortunately only a small fraction of these pests are known to cause serious harm to health and productivity of the tea plant in their places of occurrence.

The number of pest species found in the old tea growing countries of Asia viz. China, India, Bangladesh, Sri Lanka, Indonesia, is much higher than those in Africa and other countries which started growing tea in more recent times. Banerjee (1981) attributes age of tea plantations to be the factor responsible for large abundance of pest species in the above countries.

Low temperature reduces but does not eliminate incidence of pests on tea. The tea bushes of Russia, Japan, Turkey, Persia etc. located at high latitudes remain dormant during the winter months on account of short daylength and low temperature, which occasionally drops below freezing . Even under such conditions unpruned and skiffed tea bushes carry enough leaves, providing food and shelter to a number of pests, until growing conditions improve in the spring and summer for their multiplication and depredation. Alternative host plants which are many can also provide shelter to some of the tea pests.

Muraleedharan (1992) has published a comprehensive list of the major and the minor pests attacking the tea plant, indicating therein the countries where they occur. Our observations in the subsequent pages will be confined only to the major pests of tea.

Tea pests can be grouped into two broad categories, seasonal and perennial. Seasonal pests are more widespread but their impact on tea economy is of a temporary nature. The perennial pests debilitate tea bushes gradually but a few of them do so in a short period of time, producing serious adverse impact on tea economy.

PEST CONTROL

The history of pest control in tea (also in other crops) can be divided into three distinct phases. These are :

(a) upto 1940	- Pre-pesticide period
(b) 1940 to Circa 1970	- Absolute dependence on pesticide
(c) After 1970	- Curtailment of pesticide use

Utilization of other plant protection chemicals follows the same time sequence.

(a) Upto 1940

Until the use of vegetatively propagated clones from 1950 onwards, tea areas were planted with seedlings raised from mixed seeds of hybrid origin. In North East India (and elsewhere) planting was done at wide spacings of 135-150 cm, accommodating about 5000 bushes per hectare. Yields obtained from such tea fields were low which, in North East India, was about 400 kg/ha made tea in the year 1900. However, bushes of diverse genetic constitution planted at such wide spacings must have provided some protection from infestation by pests and their dispersal from one area to another.

In the absence of pesticides, the tea growers had to rely mostly on the enemies of the pests, viz. predators, parasites and microbes to keep the pest populations under reasonable check. Adjustment of cultural operations like pruning and occasionally some traditional measures were also tried to mitigate the damage caused by pests.

During this period the tea growers had the use of the element sulphur which was an accepted pesticide from the bygone days. Sulphur alone or in combination with lime as ‘lime-sulphur’ was effectively used primarily for the control of red spider and other mites.

(b) 1940 - Circa 1970

DDT is the first organic pesticide synthesized by a German chemist Othmur Zeidler as early as 1874 but its value as pesticide was not known until demonstrated by the investigations of Paul Muller of Switzerland in 1939 (Goel & Gutpa, 1989). Discovery of DDT is a highly significant event in the history of plant sciences. The pesticide was produced in bulk and used extensively during World War II, particularly in the war zones, for effective control of malarial mosquitoes. DDT was soon recognized as a broad spectrum pesticide and it became very popular amongst growers of various crops who used it for protecting their crops from pest damage.

Discovery of DDT acted as a stimulant and many chemical firms started synthesizing and marketing varieties of agrochemicals for the protection of different crops from the ravages of pests, diseases and weeds. In the context of increasing demand for food, fodder and other agroproducts by the rapidly expanding world population, availability of these chemicals for reducing crop loss was regarded as a blessing. The agrochemical industry grew rapidly to its present size with an estimated market value of 26 billion dollars in 1992 (Stetter, 1993).

During this period yield of tea in India increased from 600 kg/ha in 1950 to 1200 kg/ha in 1970. This was primarily due to introduction of superior clonal cultivars for replanting and extension of tea areas and improvement of agrotechniques, but contribution of pesticides in reducing crop loss cannot be ignored.

c) After 1970

While pesticides were freely used for immediate gain which was backed by aggressive marketing policy of the producers, the wisdom of absolute dependence on pesticide for crop protection began to be questioned. Pesticides are intrinsically toxic chemicals. They are toxic not only to the target pests but also to their natural enemies and, in fact, to all living organisms. Pesticides also pollute air, water, soil and the entire environment. Food products are contaminated by pesticides through mechanical contact or **via** the food chain. In his book the **Silent-Spring**, R. Carson (1962) brought these facts to the notice of the general public. The book and press reports on the same theme received wide publicity, pressurising the Governments of different countries to take prompt action against indiscriminate use of pesticides.

Meanwhile FAO, UNDP, WHO and other agencies of the United Nations had taken note of the various problems associated with the use of pesticides, besides poisoning of the environment and food stuffs. Here the term pesticide has been used in a broad sense comprising all plant protection chemicals including herbicide (Oudejans, 1991). Intensified cropping with high-yielding but non-resistant varieties aided by massive chemical inputs initially produced high yields but often caused build up of resistance to pest, fungi and weeds (Davies, 1992) and outbreak of secondary pests followed by diminishing yields. These developments led FAO and UNDP in 1975 to ban the use of DDT, Heptachlor and BHC for crop protection and to draw up a comprehensive set of rules for production, distribution and utilization of pesticides (FAO, 1986). These rules directed Governments and pesticide industries to "Develop and promote **Integrated Pest Management systems (IPM)** and the use of safer, efficient, cost-effective methods" and advised public sector groups and international organizations to "actively support such activities".

INTEGRATED PEST MANAGEMENT (IPM)

IPM is defined as "a pest management system that in the context of the associated environment and population dynamics of pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury." Essentially it is a system of crop protection combining cultural, biological, genetical and chemical methods aiming at maximum productivity with minimum adverse effect on the environment. The basic idea is to minimize application of chemical pesticides and explore all other eco-friendly avenues for crop production and protection. Hence as the first step IPM dissuades application of chemical pesticide below Economic Threshold (ET) level of a crop. At this level crop protection measures should be initiated to prevent pest population from reaching the Economic Injury Level (EIL).

Tea being a long duration perennial crop, it harbours certain pests all the year round. Besides most pest species have alternate host plants either within or in the vicinity of tea fields. These situations pose problems for cultural and biological control of tea pests. Even then, in the absence of alternatives, cultural methods were employed from the early days of the tea industry for the control of a number of destructive pests with varying degrees of success.

Cultural Method

In tea, the normal cultural operations like pruning, plucking, provision of shade (where necessary) composition and quantity of nutrients applied, control of weeds, preparation of land for planting etc. influence pest outbreak, their intensity and distribution. Pruning removes a large part of the bush frame and, along with it, a large fraction of the pests feeding on maintenance foliage and stem. The luscious shoots produced by the bush while recovering from pruning attract flushworms, leaf rollers, tea tortrix, thrips and aphids. The plucking operation can take care of these pests to a certain extent if carried out timely. Maintenance of bush hygiene by cleaning dead wood, snags and removing dying branches at the time of pruning and protection of the large pruning cuts with protective paint help in eliminating/reducing the incidence of termite and infection by stem canker (*Poria hypobrunnea*). In Sri Lanka infection of shot-hole borer is hardly observed in tea stems during the first year of pruning.

Plant population per unit area has vastly increased, particularly during the last three decades, everywhere in the tea-growing world. Supported by better nutrition and more efficient control of pests, diseases and weeds, these densely planted areas are producing very high yields and along with it, more branches and maintenance foliage below the plucking level. The thick and congested top hamper of the bushes is raising the cost of control measures.

Tea pests are designated major or minor depending on the extent of damage caused. Climate has a profound influence on the occurrence and distribution of pest species. *Helopeltis theivora* Waterhouse is a major pest of tea in India while the corresponding species in Kenya and Malawi are *H. antonii* Kirby and *H. schoutedeni Reuter*, respectively. The thrip *Scirtothrips dorsalis* Hood is a major pest in North East India, Japan and China while the major thrips respectively of Kenya and Malawi are *S. kenyesis* Mound and *S. aurantii* Faure. Such examples are many. These instances indicate high degree of sensitivity of the pest species to the climatic environments.

The pests are also highly selective of the host plant. Among rows of a number of clones growing at the Tocklai Experimental Station, flush worms invariably infested only one clone every year during spring, without touching the others.

The chinary bushes are more susceptible to attack by red spider and scarlet mites than bushes of the Assam type in N. E. India. The red spider mite prefers the early part of the year when the weather conditions are dry and sunny. The other most destructive pest, tea mosquito bug (*Helopeltis theivora* Waterhouse), on the other hand, prefers cool and shady conditions. Overhead tree shade is necessary in N.E. India for increasing productivity of tea (See Chap 12), which also reduces the intensity of red spider attack. In area prone to attack by tea mosquito bug, overhead shade should be thinned. Live wood eating termite has now become a major pest in some parts of N.E. India. This pest became a problem only after discontinuation of hoeing of the tea areas. The pest can still be controlled to a large extent by forking the soil around tea bushes as the small nests of this type of termite remain within 8 to 20 cm of the soil surface (Das, 1994).

Relative abundance of nitrogen in the fertilizer mixture for tea has been observed to increase the infestation of phytophagous insects and mites (Muraleedharan, 1991). Heavy build up of mite population also followed continuous application of copper fungicides for the control of the blister blight disease (*Exobasium vexans* Massee) of tea (Cranham, 1966). In Sri Lanka, Gadd (1944) recorded increase in the incidence of shot hole borer (*Xyleborus fornicatus* Eichh) following the use of nitrogenous fertilizer. Application of DDT for the control of mosquito bug also increased the incidence of mites.

Light trapping of moths of caterpillar pests like looper caterpillar, which is an occasional but major pest of tea in N.E. India, by using suitable devices at night is a useful practice. Light trapping also helps in the control of termites. *Dalbergia assamica,* a leguminous shade tree, is a very favourite host of looper caterpillar. This shade species should not be planted in tea. Hand collection of caterpillar pests like looper is a standard practice in N.E. India.

Among the cultural operations, proper timing of pesticide application should receive top proirity. In the harvesting season, pesticides should be applied soon after plucking to reduce the chance of their presence in made tea.

Biological control

Biological control mainly involves preservation of the enemies of the pests and, where possible, augmenting their numbers by artificial production and release. Among the natural enemies of tea pests, predators and parasites predominate, although pathogens also play some part. A large number of natural enemies of tea pests have been identified in different countries. A few of these, if properly utilised, can be expected to effectively control such very harmful pests as red spider and other mites, caterpillar pests and scale insects as pointed out by Hazarika *et al*. (1994), Das and Barua (1990).

Survey of conventional tea areas where chemical fertilizers and chemical pest, disease and weed control methods are followed and organic tea areas where no chemical is used, not even chemical fertilizer, revealed the presence of a much wider range of pest population and their enemies in the latter areas than in the former (Borthakur *et al.,* 1993). This clearly indicates the difficulty of preserving the natural enemies of the pests in conventional tea fields. Because of this, scientists particularly in countries like Japan, are paying more attention towards bacterial and viral control of tea pests than control by predators and parasites. In fact certain *Bacillus thuringiensis* (Bt) preparations have already been registered in Japan for the control of tea leaf rollers (Tortricids) and looper caterpillar (Kariya, 1977). Two granulosis viruses (GV) isolated from a tortrix species effectively controlled tortrix pests, some of which like *Homona magnanima* Diakonoff causes serious harm to tea in Japan (Kodomari, 1993). Work on bacterial and viral pest control agents is in progress in other countries besides Japan (Zhen *et al.*, 1985; Barthakur and Raghunathan, 1987). For instance certain strains of BT have been successfully used for the control of caterpillar pests. However, in countries like India where silk worms are also reared in some tea growings areas, the possibility of introducing viral and bacterial pest control agents will need serious thought.

So far no predator/parasite of any major tea pest has been produced on a large scale to supplement their naturally occurring populations under field conditions. Susceptibility of the predators/parasites to the commonly used pesticides, as already mentioned, is the main problem. However efforts to find solution to this problem should not be abandoned since, if successful, this will be the least objectionable method of pest control in tea.

Antibiotics, which are fungal metabolites, have already been introduced for crop protection. Streptomycin sulphate sprays under the names Agromycin and Phytomycin have been used in the USA for the control of fireblight and walnut blight

A number of other avenues have been identified for biological control of tea pests, of which a few have already been explored. Pheromones are volatile compounds which can be utilized in disrupting mating of harmful insects for reducing their pest populations. Certain pheromones have been field tested in Japan against some species of tea tortrix. (Muraleedharan, 1992; Sarmah *et al.,* 2005)). Certain entomopathogenic nematode species are being tried for the control of live-wood eating tea termites. Inhibition of sterol and fatty acid metabolism appears to be another promising line of study for controlling such very harmful pest as the shot-hole borer (Sivapalan, 1999).

Genetical Method

Selection of tea cultivars resistant to the major pests (and diseases) is the ideal solution of the pest (and disease) problem in tea. It eliminates the risk of environmental pollution and the presence of harmful residues in made tea. However, no tea plant fully resistant to any of the major pests of tea has so far been discovered in any tea growing country although plants displaying partial resistance have been found everywhere.

Breeding of pest (or disease) resistant plant is a very difficult problem even in an annual or short-duration crop. In a perennial, long-duration crop like tea, the problem is really formidable. For instance a plant currently resistant to a particular pest may, at a later date, prove susceptible to a mutant form of the same pest or an allied species. Secondly, while breeding for pest resistance, its possible adverse effect on yield and quality of the crop cannot be ignored. Despite such and other difficulties, plant breeders should persist in their efforts to produce tea cultivars resistant to some of the more harmful pests (and diseases) of tea by utilizing modern tools like identification of pest (and disease) causing genes and their replacement by healthy ones. Breeding for the introduction of physiological changes in the plant leading to production of repellant metabolites for certain pests appears to be another line of study worth pursuing.

Meanwhile work on the production of vigorous hybrid progenies and the search for pest resistant clones in these populations have to be continued.

Chemical method

Plant protection chemicals have received maximum adverse publicity as major environmental pollutants because of their likely presence in food products when applied for the protection of crops and/or for their preservation after harvest. It is true that many of these chemicals are poisonous to animals, birds, fishes and can adversely affect soil organisms. However, no reliable estimate is currently available on the extent of harm that these chemicals have caused to man and animals in different parts of the world.

While discussing the future role of the plant protection chemicals from the industrial point of view, Stetter (1993) presented an interesting table showing the probability of death of human beings from various causes such as cigarette smoking (1 in 200), alcohol consumption (1 in 250), medicines (1 in 80,000) etc. and different types of accidents. In this table chemical residues and food additives have been stated to account for only one death in 500,000. The author envisages that the use of plant protection chemicals will continue for a long time to come from risk-benefit considerations, but future chemicals will be less toxic and more specific in action. Only such chemicals will be blended into the integrated pest management (IPM) programme.

Economic injury level (EIL) is that when the pest population is large enough to cause crop losses costing more than the control measures. Economic threshold (ET) is pest population level at which control measures should commence. EIL and ET for different pests and for the same pest at different times are the primary requirement for proper use of pesticides in the IPM programme. Simple and rapid methods have to be worked out for determining these levels for different pests under diverse situations since incidence and damage caused by pests are influenced to a large extent by environmental factors e.g. temperature, rainfall, sunshine, humidity and their interactions. In IPM, pesticides should be used only when pest damage exceeds the ET level. However, due to the presence of multiple pests and large seasonal variation of pest population, determination of EIL and ET is not at all easy.

Synthetic organic pesticides used in tea in different countries belong mainly to the following categories :

Organochlorine compounds	:	DDT, BHC, Endosulfan etc.
Organophosphates	:	Ethion, Malathion, Monocrotophos etc.
Synthetic pyrethroids	:	Fenvalerate, Permithrin, Delta-methrin etc.
Carbamates	:	Carbofuran, Aldicard, Carberyl etc.

Many of the pesticides belonging to these classes have been tried against different tea pests with varying degrees of success. Only a few of these have been found suitable for use in commercial tea plantations.

A new nitromethylene group of pesticide has been developed in recent years of which Imidachloprid is the first product successfully tested against a number of pests.

The Codex Committee on Pesticide Residue (CCPR) under the Joint FAO/WHO Codex Alimentarius Commission established the maximum permissible amounts of pesticide residues in food and animal feedstuffs moving in international trade. It monitors the methods for sampling and analysis of pesticides and proposes definition of relevant terms such as Maximum Residue Limit (MRL), which is expressed as milligram per kilogram (mg/kg) of commodity. Other agencies like the EPA (Environmental Protection Agency) of the USA, EC (European Tea Committee) and a few other European countries determine MRLs of pesticides used in tea. Some difference is generally observed between the MRL values of different agencies. Secondly, MRL values are revised from time to time on the basis of fresh evidence regarding the toxicity of the pesticides and the quantum of tea consumption.

The European Tea Committee (1992-98) had published a long list of pesticides used in tea with MRLs determined by various agencies. However, the MRLs of many of the pesticides mentioned in the list is only 0.1 milligram per kilogram of tea(mg/kg). Such low MRL precludes the use of these pesticides in tea.

It may be noted in connection with the MRL values that only a fraction of the pesticide residues present in dry tea passes into the hot water brew prepared for drinking. In the case of **ethion** only 2.36 per cent of the residue present in dry tea passed into the hot water brew which, in the case of **dicofol**, was only 1.64 per cent. (Barooah *et al*, 1994). Choudhuri (1999) also has discussed these and other problems relating to pesticide residue in tea.

Future chemical pesticides for tea

Low MRL (0.1 mg/kg) has already drastically limited the number of pesticides used in tea until the recent past. Among the few still in use MRLs of some are so low that their use may have to be discontinued soon. One of the reasons for the rejection of a number of relatively safer pesticides is their long persistence in nature. This causes their build up in soil and hence in the crops grown. Hence unless a new generation of environmentally and biologically safer pesticide is developed soon, use of synthetic chemical pesticides in tea may have to be further reduced if not completely abandoned.

At present efforts are in progress in different parts of the world for the production of plant protection chemicals from fungal metabolites. Metabolites of fungal origin are generally known as antibiotics of which penicillin was the first to be discovered more than 50 years ago. The antibiotics were developed and used for medicinal purposes but their use is now spreading to plants for the control of pests and diseases. Reference to the use of streptomycin in the USA for the control of blights has already been made.

Insect pathogens have been increasingly used for crop protection. *Bacillus thuringiensis* (Bt) which produces insecticidal crystel protein has been extensively investigated and used for the control of pests, but development of resistance by certain pest species to Bt has now become a cause of worry. Viruses, bacteria and nematodes have also been exploited for the control of pests in different crops. However, great caution is necessary in the use of these agents for pest control as pointed out by Misato and Yamaguchi (1984). Despite problems, effort towards production of mycochemical, bacterial and viral pest control agents is bound to continue and intensify in the coming years.

Integrated pest management lays emphasis on husbanding existing populations of predators and parasitoids within cropping systems. This is closely linked with the use of pesticides as mentioned earlier. Build up of reservoirs of predators and parasitoids to recoup and enhance their number under field conditions is an important aspect of IPM.

It has been known from the remote past that certain higher plants repel insects which avoid feeding on those plants. Plants in possession of these properties have been utilized for centuries as best as possible for the protection of various crops before or after harvest. The Neem tree (*Azadirachta indica)* is a very prominent example of such plants. Recently Simmonds *et al.* (1992) have reported the results of survey of 59 higher plant families in which 188 genera with potent anti-insect activity were identified. However, the active constituents have been identified only in plants of a few genera like *Chrysanthemum* and *Azadirachta*. The compounds derived from higher plants are referred to as 'botanicals'. It is expected that more attention will be paid in the coming years to the production of botanicals which, being natural compounds, will readily decompose in soil unlike the synthetic chemical pesticides. This is a very great advantage, which will make them environmentally safer and easy to accommodate in the IPM programme.

DESCRIPTION OF TEA PESTS

The pioneering investigations of Watt and Mann (1903) in India drew attention to the need of systematic studies on the problems created in tea by pests and diseases. From early 1900 till date a large number of workers, particularly of the Asian countries where the pest problem is more acute, have carried out investigations on tea pests and published their findings in books, scientific papers, conference proceedings and various reports. The extensive literature on the topic have been summarized in a number of useful reviews and monographs including those of Watt and Mann (1903); Beeson (1941); Hainsworth (1952); Cranham (1966); Das (1965); Oudijans (1991); Abdul Aziz *et al*. (1992); Muraleedharan (1991) and (1992); Davies (1992); Rattan (1992) and Sivapalan (1999).

The most damaging pests of tea belong to the orders Acarina, Hemiptera, Isoptera, Lepidoptera, Coleoptera, Thysanoptera and Nematoda. The total number of pest species feeding on tea vary between geographical regions although a few of them are common to most regions.

Muraleedharan (1992) has listed all pest species infesting tea but, as mentioned earlier, only a few of them cause serious damage and loss of crop. The place of occurrence, severity and duration of infestation, climate, cultural operations and control measure determine the extent of crop loss from pest attack. Besides, a harmful pest like the mosquito bug is not usually equally severe in different locations within a country. Hence crop loss caused by pest is a highly variable factor which is reflected by the wide variation in the estimates of loss (10 to 50%) mentioned by different workers.

Pests infesting tea can be categorized on the basis of the organs of the plant, namely *foliage, stem, root* and *fruit* which they attack.

Foliage feeders

Mites : Among the foliage feeders, the mites belonging to the order ACARINA occupy a very prominent place. Tea bushes throughout the world are attacked by one or more species of this pest. Mite infestation causes discolouration and, in severe attack, drop of leaf which reduces photosynthetic surface followed by loss of crop. Bushes may be attacked simultaneously by more than one mite species.

Mites are recognized generally from the colours of their bodies. Some of the mites are very small in size which can be seen only with the aid of a hand lens. Majority of the mite species occupy the under surface of tea leaves but a few prefer the upper surface. Pruned bushes have been observed to suffer less from the attack of mites than unpruned and skiffed bushes. The mites are perennial pests, a few of which persist on the bushes even when weather conditions become cold and otherwise unfavourable for their growth during the winter season at higher latitudes. They may also subsist on the alternate host plants which are many for every species of mite.

The mites exhibit preference for different kinds of tea and the biotypes within each kind. They are also sensitive to dry and wet weather conditions.

Red spider mite (*Oligonychus coffeae* Nietner) (Fig. 1) is the most widely occurring species in Asia, USSR and in a number of African countries. In size it is the biggest mite which feeds on the cell sap by puncturing upper surface of mature tea leaves. The attack starts along the midrib and veins and spreads to the whole leaf. In severe infestation even the young leaves are not spared. The punctured spots initially turn reddish brown and finally bronze. Tea fields severely attacked by red spider appear bronze from a distance. If uncontrolled this species can cause very heavy loss of crop.

Red spider mite prefers Chinary kind of tea. In India this mite multiplies very rapidly in the early part of the growing season (February - May) when weather conditions remain relatively dry. Heavy monsoon rain washes away some of the mites. Shade reduces incidence of red spider mite.

Fig. 1. Different stages of Red spider mite

Another species of spider mite *Tetranychus kanzawai* Kishida is a serious pest of Japan and Taiwan.

Pink mite also known as orange mite (*Acaphylla theae* (Watt) Keifer is another destructive pest which occurs in all countries of Asia and in the USSR. This very minute, orange coloured mite is generally found on the under surface of young leaves and tender shoots and occasionally on the upper surface. The infested leaves turn brown. In South India it has caused more damage than red spider. This mite prefers the Assam type of tea. Heavy rain washes off some of the mites.

Scarlet mite is another harmful pest which has occasionally caused heavy loss of crop in different countries. *Brevipalpus phoenicis* Geijskes is the most widely occurring species in N.E. India, Bangladesh, China, Indonesia and a number of African countries (Fig 2) while *B. australis* Tucker is predominant in South India and Sri Lanka. Another species of this mite, *B. obovatus* Donnadieu also occurs sporadically in Kenya and a few other countries of Africa. Scarlet mite attacks the under surface of leaves, chiefly along the midrib and petiole. The damaged parts become brown and in case of severe attack, split and dry up. Axillary buds are also attacked, which cease to grow. The attack debilitates the bushes. These mites can cause death of young plants by premature defoliation.

Fig. 2. Leaves infested by Scarlet mite

Purple mite (*Calacarus carinatus* Green) is another harmful mite common to Asia, USSR and a few African countries. It usually infests the upper surface of mature leaves, but in severe attack, young leaves are equally affected. Leaves, particularly their margins, become copperish bronze following the attack by this mite.

Some other mite species of lesser economic importance also attack tea.

As pointed out in Table 1, the synthetic chemical pesticides available now for the control of mites (also other pests) are very limited. Ethion and Dicofol which provide excellent control of mites can still be used judiciously. Neem and sulphur formulations can also be included along with these in an Integrated Pest Management (IPM) programme.

A number of natural highly efficient predators of red spider and other mites such as *Sterthorus gilvifrons*, *Agistemus* sp., and *Phytoseilus persimilis* have been identified (Hazarika *et al*., 1994; Barbora, 1995), but their activity in commercial tea fields, where chemical pesticides are used, appears to be low. The possibility of utilizing some of the natural predators is worth exploring.

Thrips (Order THYSANOPTERA) can inflict serious damage by feeding on the unopened and partially opened buds on young shoots. During feeding they make slits on the upper surface of leaves. The slits made in continuous lines later become corky. There may be two or four such lines on either side of the midrib. The initial symptoms of attack appear as brownish discolouration of tip and basal part of leaf. The badly affected leaf may get deformed and curl up. The shoots remain stunted. Thrip attack occurs prominently in fields recovering from pruning and before the start of plucking. Tipping and plucking get delayed involving loss of crop.

Scirtothrips dorsalis Hood is the commonest species of thrips in India, Bangladesh, China and Japan. *Taeniothrips setiventris* Bagnall is a species of thrip which causes serious problem particularly in the hill district of Darjeeling (N.E. India) in the early part of the growing season. *Scirtothrips bispinosus* Bagnall is an important pest of South India. *S. kenyesis* Mound and *S. aurantii* Faure occur in Africa.

For control, spraying of such pesticides as Endosulfan, Malathion etc. should start as soon as the attack is noticed on new growth. Neem formulations can also be used.

Hard plucking in badly infested areas, weed control, soil stirring to kill pupae and caustic washing of bush frame are recommended cultural measures (Das, 1994).

Leaf and stem sucking bugs (Order HEMIPTERA)

Among this group of pests *Helopeltis*, commonly known as tea mosquito bug, caused heavy loss of crop in N.E. and South India, particularly before the advent of the chemical pesticides starting with DDT. Incidentally, 'mosquito bug' is a misnomer since *Helopeltis* comes under the order HEMIPTERA while common mosquitoes belong to the order DIPTERA. The species responsible is *Helopeltis theivora* Waterhouse, which caused similar harm in Bangladesh, Sri Lanka and Indonesia (Fig 3). Another species *H. schoutedeni* Reuter is a major pest of tea in many African countries.

Adults and nymphs of *Helopeltis* suck the sap of young leaves, buds and tender stems by puncturing the tissues. While feeding, the pest injects a toxin that causes necrosis of the area around the feeding spot. The area turns blackish and dries up. In a severe attack bushes look scorched, cease to produce shoots and yield is drastically reduced. The damage is generally caused at night and in the morning and evening hours. *Helopeltis* is a perennial pest which prefers damp and shady conditions.

Fig. 3. Tea mosquito bug

Hard plucking during the flushing season and pruning of infested fields are effective cultural operations. Low MRLs do not permit the use of many pesticides tried in the past except Endosulfan, Deltamethrin and perhaps one or two more. Neem formulations have proved useful when tried in combination with the chemicals. For the control of *Helopeltis* 8, 10 rows of tea bushes at the periphery of the infested field should be sprayed first. The operators should then move towards the centre of the field. This type of barrier spraying helps in checking migration of the insects to the neighbouring fields. For better control spraying should be done in the morning and afternoon hours when the bugs are active.

Some species of *Lygus* also occasionally cause damage to tea.

The Jassid, *Empoasca* (*Amrasca*) *flavescens* Fab., commonly known as 'Green fly', attacks many cultivated crops besides tea. In India, China and Bangladesh this widely distributed insect sucks the sap of tender growing shoots of tea, usually from the under surface of leaves. The affected leaves curl downwards and the leaf margins become recurved, turn brown and dry up, producing characteristic symptoms known as "rim blight." Lush shoots produced by bushes in the early part of the year normally get heavily infested by this pest causing loss of crop. *E. onuki* Matsuda and *E. formosana* Paoli are the injurious species in Japan and Taiwan. The insect occurs on tea bushes throughout the year but remains quiescent during winter until bushes start flushing when the weather warms up (Fig 4).

The aphid *Toxoptera aurantii* Boyer de Fons is one of the most common pests of tea in all tea growing countries. Adults and nymphs of aphids suck the sap from tender stems, buds, petioles and lower surface of tender leaves. As a result leaves crinkle and curl downwards followed by marginal necrosis. The fields recovering from pruning and young sections suffer badly from the attack of this pest. The aphids are regulated to a large extent by a number of their natural enemies.

Jassid and aphids can be controlled to a large extent by careful plucking and hand removal. Amongst chemical pesticides, MRL levels of Endouslfan and Malathion are still sufficiently high and can be used for their control.

Fig. 4. Tea jassid (Greenfly)

Scale insects and mealy bugs constitute a large group of sucking insects which attack foliage and stems of tea plants. A few of these species have been observed to infest root also (Das, 1994). However, a very limited number of these species such as *Saissetia coffeae* Walker, *S. formicarii* Green, *Eriochiton theae* Green, *Pinnaspis theae* Maskell, *Florinia theae* Green, *Phenacaspis manni* Green have, on occasions, been observed to cause debility and defoliation of plants. These harmful species are generally found throughout the year. They secrete honey and ants inhabiting plucked tea bushes and seed trees feed upon the honey. In return the ants afford protection to the insects from their natural enemies which are many. Infestation by these insects can be controlled to a large extent by eliminating the ants thereby ensuring the activity of their natural enemies. All sucking insects reduce quality and flavour of tea.

Several species of shooty moulds have been reported to grow on the honey excretion falling on tea leaves and other vegetation amongst tea bushes, but none of them is parasitic.

Leaf feeding caterpillars (Order LEPIDOPTERA)

These insects form a large group which can be divided into two categories depending on whether they attack (a) young or (b) mature leaves of tea.

Among many species attacking young leaves only a small number have been reported to cause substantial harm to tea bushes. To illustrate the nature of attack by these insects the flushworm, *Cydea leucostoma* Meyrick can be cited as an example. This is a seasonal pest of India and Indonesia which had, on occasions, caused heavy loss of crop. The larvae of this insect soon after hatching tie up the margins of two or three tender leaves of a growing shoot forming a case enclosing the apical bud. The larva lives within the case and feeds on tissues on the upper surface of leaves and the apical bud. The affected shoot cannot develop properly, internodes become short and the tender stem of the shoot bends over due to binding of the leaves (Fig 5). The same larva when mature may attack another shoot. Shoots affected by flushworm produce tea of poor quality.

Most of the harmful insects of this category fold and web leaves in distinctive patterns. The leaf roller *Caloptilia theivora* Walsingham which occurs almost everywhere in Asia, starts as a

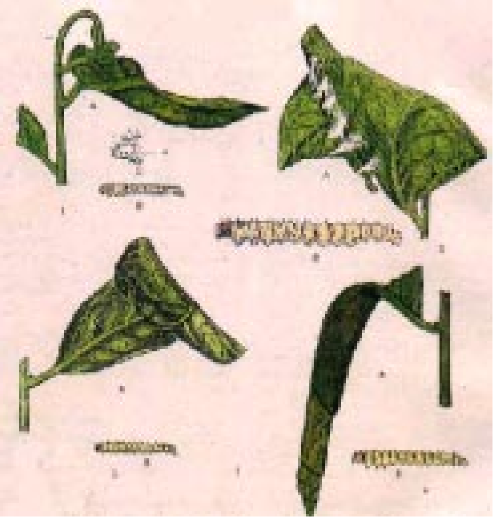

Fig. 5. Leaf rollers and leaf tiers

leaf miner but subsequently the larva, while feeding, rolls up the leaf from tip downwards. *Homona coffearia* Nietner of wide distribution in India, Bangladesh, China and Sri Lanka also bends young leaves and the larva feeds from inside. *H. magnanima* Diakonoff and a few *Adoxophyes* species are injurious leaf binding insects of Japan and Taiwan. These and a few other less harmful species of this group attack actively flushing tea fields, depressing crop to a greater or lesser extent depending on the species involved, location and intensity of attack.

It is difficult to control these pests by spraying insecticides since the spray fluid hardly reaches the caterpillars remaining inside their leafy cases. Manual removal of the affected shoots and their destruction is the effective method of control of these pests. It has been reported that formulations of the bacterium *Bacillus thuringiensis* have been successfully used in Japan for the control of these tortricides.

Caterpillars feeding on mature leaves of tea also form a large group of which only a few can be ranked as major pests. The bunch caterpillar *Andraca bipunctata* Wlk. which can be easily recognized from the bright clusters formed on branches occurs in

India, Bangladesh, Indonesia, China and Taiwan. This is one of the oldest pests recorded in tea which can cause serious trouble unless controlled in time. The caterpillars remain clustered during day and feed on the mature leaves at night denuding the bushes of leaves in a short time by moving from branch to branch. Four generations of this caterpillar have been recorded in N.E. India between March and November (Das, 1994) (Fig 6). The red slug caterpillar *Eterusia magnifica* Butl. occurs in many Asian countries, but is not as harmful as the former. However, if mature leaves are not available for feeding, this pest does not spare even young leaves and barks of young stems. These are sporadic pests.

The looper caterpillar, *Buzura suppressaria* Guen., though sporadic in nature, can cause very severe damage to productivity of tea when it occurs. It spreads so rapidly by defoliating the bushes that control becomes difficult unless measures are initiated at the start of attack. *Ectropes bhurmitra* Walker is less injurious than looper. Both these species are found in India, Bangladesh, Indonesia, Sri Lanka and China. Other caterpillars of this group are economically less important.

Fig. 6. Bunch caterpillar

The caterpillars in general have many alternate hosts, including some of the shade trees of N.E. India. Mention has already been made of the shade tree *Dalbergia assamica* as a favourite host of the looper caterpillar.

Natural enemies are involved in the regulation of caterpillar pests. A bacterial disease was observed to take a heavy toll of the late instar looper caterpillars under warm and humid conditions. An endoparasite *Apanteles taprobanae* Cameron was found to parasitize on looper caterpillar. This caterpillar is also attacked by a Reduveid bug predator.

Cultural measures recommended in N.E. India for the control of looper caterpillars consist of :

1. Hand collection as soon as the pest is detected.
2. Light trapping of moths
3. Collection of chrysalides during the dormant season by light forking of the soil around the collar of tea bushes in affected areas.
4. Avoidance of the use of such shade trees as *Dalbergia assamica*. These recommendations are applicable to other caterpillars also.

Use of only such chemical pesticides should be considered which do not exceed the MRL values.

Non-conventional methods of control should be explored. A strain of *Bacillus thuringiensis* when sprayed even at very low concentration gave complete control of bunch caterpillar. At a higher 1 in 100 concentration, 95 per cent control of looper was achieved (Barbora, 1995).

Among the mature leaf-eating caterpillars Nettle grubs and Gelatine grubs belonging to the family Limacodidae are minor pests. However, nettle grubs *Parasa lepida* Cramer, *Thosea cervina* Moore and a number of allied species create nuisance by stinging workers with their sharp hairs which are poisonous and cause pain lasting for several days. Workers avoid such sections of tea. Gelatin grubs do not sting.

Faggot worm, Bag worm, Basket worm etc. of the family Psychidae are another group of caterpillars attacking tea. These names are derived from the cases of diverse shape and size which the insects build and live in. They carry the cases when they move about. A few well known species are *Clania cramerii* Weston. *Eumeta variegata* Shell, *Mahasena theivora* Dudge etc. These two groups of minor tea pests are found in India and a few occur also in Sri Lanka, China and Taiwan.

A number of predators prey upon these caterpillars. Timely collection and destruction of the nettle grubs and the phychid caterpillars and caustic washing of bush frame are effective cultural measures.

In addition there are a few leaf eating weevils of limited significance.

PEST ATTACKING STEM

Two groups of pests feed on the bark of tea bushes, the bark eating borers and the bark eating caterpillars. The common bark eating borer *Indarbelda theivora* Hampson attacks numerous species of trees besides tea. The larva bores a small hole in the young stem especially in pruning cuts and spins a spiral run round the stem with fragments of bark and excreta and feed on bark inside this spiral, retreating into the hole when disturbed. This hole provides a suitable place for the entry of fungal parasites like *Poria* species and termites. Another similar bark eating borer *I. quadrinotata* Walker attacks many shade species like *Albizzia odoratissima, A. lebbek* etc. growing in tea areas of N.E. India. *Haplothrix griseatus* Gah. also had caused serious harm to tea bushes in N.E. India . Attack by these borers and the bark eating caterpillars is an indication of debility of the tea bushes, the causes of which should be removed. In China, USSR and Turkey *Parametriotes theae* Kusnetsov is an important stem-boring caterpillar. Maintenance of bush hygiene is essential for the control of these pests.

The red borer *Zeuzera coffeae* Nietner is a widely distributed pest of tea and other plantation crops, shade trees and numerous forest species. It has been reported to cause considerable damage to young and nursery plants and occasionally some damage even to mature tea bushes in India, Sri Lanka, Indonesia, Malaysia and Taiwan. The larva usually bores into one and two year old branches and nursery plants. Sometimes old stems of plucked bushes and seed trees are also attacked. While tunneling downwards, the larva feed on the woody tissues. The tunnel may extend upto thicker stems and, in case of young plants, even upto the roots. In the course of tunneling circular holes are bored at intervals through which pallatised excreta is ejected. Heavily infested young plants cannot be saved. In older plants, the infected branches should be cut down to healthy wood.

The beetles and weevils of the order *COLEOPTERA* infest foliage and stems of tea bushes. Among the Coleopteran pests the shot-hole borer *Euwallacea* (*Xyleborus*) *fornicatus* Eichoff is a highly destructive pest in South India and Sri Lanka. It occurs in Indonesia also. In Sri Lanka the pest is commonly found below 1500 m elevation. Females of this beetle construct galleries usually in primaries from the second year of pruning. This pest has been observed to bore holes in mature wood down to the collar region. The galleries constructed by the beetles can be spiral or vertical accompanied at intervals by pin head like holes on the surface of the stem for their exit. The newly hatched grubs feed on the *Ambrosia* fungus implanted by the adult females on the sides of the galleries. The infected branches break up, causing debility, crop loss and even death from repeated attack.

Control of this borer has proved very difficult as pesticides donot reach the beetles remaining inside the galleries. Selective pruning of branches down to healthy wood and drenching of the bushes with such chemicals as Endosulfan during dry periods are the measures currently followed in South India and Sri Lanka.

In N.E. India and Bangladesh several species of Cockchafer grubs particularly *Holotrichia impressa* Burm (Order COLEOPTERA) occasionally cause serious harm to young plants, particularly to clonal plants raised by vegetative propagation. This happens in the nursery as well as in the field upto 3 years after transplanting. The larva eats away the bark in the collar region either in patches or in rings (Fig. 7) just below the soil surface, resulting in death of the plant. June-August is the main period of attack in N.E. India. Cultural measures like avoidance of organic manure at planting, proper cleaning of the soil around planting pits, elimination of depression of the collar region of the plant below ground level etc. and use of pesticides like Endosulfan around planting pits are recommended for control.

Termites (Order ISOPTERA) are destructive pests eating away timber, wood as well as dead, dying and living wood of plants

Fig. 7. Damage caused by Cockchafer

like tea. Two types of termites attack tea bushes of N.E. India and a few other countries like Bangladesh, Sri Lanka and China. These are scavenging termites of *Odontotermes* species and a few live wood eating *Microtermes* species.

The scavenger termites cle
tissues of the stem and bark preve
repairing damage. These termites
sometimes may be as tall as 1.5 m
which build underground nests.
initially gets entry into the plant vi
they excavate channels along the he
enlarged. Eventually the stems bec
wood and bark. The attack spre
destruction of the whole bush. Th
20 cm below ground level. Hoein
cultural practice in N.E. India.
proportion of the termite nests, keeping the pest under reasonable control. Replacement of hoeing by surface cheeling for the control of weeds has been suggested to be an important cause for resurgence of activity of the live-wood eating termites (Das, 1994).

For the control of scavenger termites, bush sanitation coupled with breaking and removing the mounds from the plantation area, treatment of the mound sites with pesticides, correction of soil acidity and growing of a rehabilitation crop at least for a year are recommended.

The recommendations for the control of the live-wood eating termites are : removal of dead and dying branches, caustic wash of the bushes and periodical stirring of the soil by forking. A new chemical pesticide Imidachloprid has shown promise for effective control of these termites.

PESTS OF FLOWER AND SEED

In the past tea seeds derived from heterogenous populations were used for commercial planting. Following the introduction of vegetatively propagated clonal plants from the early fifties, the use of the old seed jats virtually ceased in all tea-growing countries. However, with the production of biclonal seed stocks of equal merit by TES in N.E. India from the sixties, use of seed revived concurrently with the clonal plants. This situation has necessitated more care and attention to the clonal tea seed baries (orchards), which have been planted in large numbers

It has been a known fact that pests attacking tea seed baries are remarkably less than those infesting tea bushes under plucking. Nevertheless for ensuring viability and productivity, the location of the seed baries should be carefully selected so that these are not exposed to drought and drying wind during the flowering season. If this happens, the opened flowers and unopened buds dryup causing loss of seed production which can be total.

Poecilocoris latus Dall, the tea seed bug (Fig. 8), is the most destructive pest of tea seed. The insect punctures the pericarp of the seed when it is still soft and sucks the juice from the cotyledons on the surface of which a star-shaped mark usually develops at the point of sucking. A large percentage of the bugs carry various types of fungal spores on their proboscis. The attack causes premature fall of fruits and/or production of non-viable seeds. The bug also attacks the flower buds which drop off. In China a weevil causes injury to tea seeds by growing inside the fruit and feeding on its contents.

Fig. 8. Tea seed bug

Hand collection of the lethargic bugs, which congregate on undersurface of leaf, is the best method of control. Pesticides cannot be sprayed as it interferes with pollination by other insects.

PESTS OF THE ROOT SYSTEM

Nematodes (Order NEMATODE) commonly known as eelworms are the major pests of tea roots. However, out of around 50 species of nematodes reported from different tea growing areas, only about half a dozen species have been observed to be injurious to tea roots. The pathogenic nematodes are of two types : the 'root knot' nematodes and the 'root lesion' nematodes. The root-knot nematodes usually attack young seedlings and clonal plants in nursery and sometimes in the field during the first year after planting. The infected roots exhibit numerous galls or knots, swelling, curved and twisted formations (Fig. 9).

These changes interfere with the uptake of water and nutrients, as a result of which the plants get debilitated and susceptible to drought. If transplanted the severely infested plants remain staunted and do not produce healthy stands of tea. *Meloidogyne incognita* Chitwood and *M. javanica* (Treub) Chitwood are the two most injurious species of root-knot nematodes for young plants in N.E. India and Bangladesh. Another species of root-knot nematode, *M. brevicauda* Loss is reported to attack roots of mature plants in Sri Lanka and South India. The root-knot nematodes create problems also in China, Indonesia and some African countries. Infested nursery plants contribute towards spread of the nematodes. Certain ectoparasitic nematodes occur also in Japan and Taiwan.

Fig. 9. Root knot nematode

The migratory root lesion nematodes are endoparasitic. They feed and lay eggs within the cortex of young roots and move from root to root in search of food. These movements and feeding activity disintegrate cortical tissues and retard growth of the plant. Such debilitatid plants may not recover after pruning. *Pratylenchus loosi* Loaf is the most serious lesion nematode pest in Sri Lanka. It occurs also in China and Japan. *Hemicriconemoides kanayensis* is another nematode of this type widely distributed in Japan and Taiwan. All the nematodes have innumerable host plants in and around tea areas.

For the control of eelworms, every care should be taken in the selection of nursery sites since nurseries play an important role in the spread of nematodes. If virgin land is not available, soil remaining under wild vegetation for a number of years should be selected for nursery. After thorough ploughing and harrowing, undecomposed organic matter should be removed from the site. After that soil samples should be examined for eelworm population. In N.E. India the soil is considered unsuitable for nursery if the eelworms exceed five per 10 g of soil. Soil considered unsuitable for nursery on account of high eelworm count can be rehabilitated by putting under the green crop *Crotalaria anagyroides* at least for two years, more if the eelworm count still remains high. Other vegetation growing in the area along with *Crotalaria* should be periodically removed. *Crotalaria* is not infested by eelworm.

The soil meant for filling up polythene sleeves should also be tested for eelworm. Heating of the soil to about 65°C kills the nematodes.

The mealy bugs *Cataenococcus theaecola* Green is observed to attack roots of mature tea plants. Two other species, viz. *Crisicoccus* sp. and *Rhizoecus* sp., infest roots of young plants, but these root borers are occasional pests of limited import.

There are instances of rats burrowing tea fields and feeding on tea roots. Fortunately such instances are very few. Rats can be controlled by using appropriate baits.

PROBLEMS IN PEST MANAGEMENT IN TEA

Fixation of very low MRLs for a large number of proven pesticides used during the last 2-3 decades for the control of pests in tea has created a grave situation for the tea growers throughout the world. Some comments and suggestions made earlier on this situation are elaborated in this resume. Under this changed situation, the tea growers will have to rely more on cultural, biological and genetical methods for the control of pests than on synthetic pesticides. In other words, the tea growers are under pressure to adopt integrated pest management policy.

Amongst cultural methods, pruning plays an important role as it removes a very large fraction of the pest population from the bushes. Proper timing of the pruning operation can also reduce crop loss in that year caused by such pests as mosquito bug which attack young shoots. Hard plucking of bushes attacked by pests of young foliage also helps in reducing damage. Heavy doses of unbalanced nitrogenous fertilizer should be avoided. Shade trees acting as hosts to any serious pest of tea should not be used. Weed control is another cultural operation which helps in pest management by removing host species. Periodic forking of soil reduces the attack of live-wood eating termites.

Preservation of predators and parasitoids in tea fields is an important aspect of IPM. However, it is a very difficult proposition if pesticides are to be used in the same fields for the control of pests. In view of this, attempts are in progress towards production of bacterial and viral pest control agents. Some success has already been reported, but, as mentioned earlier, possible adverse effects of such agents on the environment require critical assessment. Fungal metabolites like streptomycin as pest control agents appear to be another promising line to persue.

Production of resistant cultivars is obviously the ideal solution of the pest problem but its achievement appears to be very remote, particularly in a perennial crop like tea which is attacked simultaneously by more than one serious pest. For this reason breeding for complete pest resistance will be a formidable task. Nevertheless the plant breeders should not give up efforts towards the production of pest free or pest repellent plants. At present every tea growing country is in possession of some clones which are partially resistant to one or more important pests.

High density planting with vigorous cultivars has raised yields of tea, but along with it the congestion in the tea areas has vastly increased. This has made pest control more difficult even with synthetic pesticides. The sprayed pesticides cannot penetrate into the lower parts of the congested bush canopies which provide shelter to the pests. To make pesticide spray more effective the volume of spray fluid has to be increased. More fluid means more pesticide, more work and increased cost. This situation demands more efficient spraying equipment at reasonable cost which can convert the spray fluid into a sort of fog inside and around the canopies of tea bushes. This aspect requires attention.

It is hoped that less toxic synthetic pesticides will be available for use in tea in the near future.

Neem based pesticides have shown promise in India against a number of pests. As mentioned earlier, there is scope for exploiting other plant species for the production of 'botanical' pesticides. It also appears that pheromones have not been fully exploited for the control of pests in tea.

The MRLs for different pesticides are fixed on the basis of analyses of dry tea samples. It is observed that only a very small fraction of the pesticide residue remaining in dry tea passes into the hot water infusion prepared for drinking. Attention had already been drawn to the analyses of Dicofol and Ethion residues in dry tea samples and their hot water brews. The hot water extracts had less than 2 percent of the amount in dry tea. Under these circumstances it is felt that the tea growers of different countries should jointly take up the issue of MRL fixation for tea with the relevant authorities (Choudhuri, 1999).

DISEASES

OCCURRENCE AND DISTRIBUTION

The tea plant suffers from a number of diseases, mostly of fungal origin. Watt and Mann (1903) reported 12, Butler (1918) 17 and Petch (1923) described more than 60 fungal species infesting tea. Subsequently, Agnihothrudu (1964) found 385 and Chen and Chen (1989) 507 species of fungi on tea. Fortunately, only a very small fraction of these fungus species has proved pathogenic to tea. For detailed description of the diseases of tea and their remedies the reader is referred to the papers and monographs of Gadd (1944), Hainsworth (1952) and Sarmah (1960), and the recent reviews of Arulpragasam (1992), Jayraj (1996), Chandra Mouli (1999) and Agnihothrudu (1999).

Fungi, algae, bacteria and virus are the organisms responsible for diseases of higher plants. Fungi alone cause all the important diseases of tea with the exception of red rust (*Cephaleuros parasiticus* Karst.), which is caused by an alga. No important disease of bacterial or viral origin has so far been reported in tea.

Fungi are either parasitic deriving their nourishment from living plants or saprophytic growing on dead organic matter. Some fungal species can thrive on both living and dead matters. All these three types of fungi are found on tea bushes.

Diseases of tea are of two types : (a) primary diseases capable of causing death not only of healthy tissues but of whole plants even under favourable growing conditions and (b) secondary diseases which become harmful from other causes.

Fungi usually reproduce by tiny, microscopic spores which are dispersed by wind, water, agents like bird, animal, field worker etc. The spores do not last long but they are so numerous that at least a few usually find some suitable site soon after liberation and germinate to produce the fungus if the climate is congenial. Some fungus like thread blight does not produce spore. Such fungi are dispersed by bodily displacement of the infected material by various agencies. A third group of fungi, which, in addition to spores, produces resting bodies known as *sclerotia*. These are lumps of ramified mycelial structures varying in size from a pin head to a golf ball, which remain viable for a long time. *Rhizoctonia bataticola* infesting tea is an example of such fungi.

It appears that the diseases of tea are endemic to certain regions. For instance *Armillaria* root disease is common in India and Africa but not found in Sri Lanka. Most of the important root diseases recorded in India, Sri Lanka and Indonesia are absent from China, Japan and Taiwan.

Under conditions of closely planted monoculture as in tea, it is much easier for a disease to spread and assume epidemic proportion if the climate remains favourable. At present there is no clone or seed cultivar in tea, which is fully tolerant/resistant to any important disease anywhere in the world. Partial tolerance has been observed in some clones in different countries. It is necessary that efforts to produce resistant/tolerant clones continue with vigour.

Some important diseases of tea

LEAF DISEASES

Blister blight is presently the most injurious leaf disease in all the tea-growing countries of Asia. The disease is caused by the fungus *Exobasidium vexans* Massee. The first report of this disease came from Assam in 1868. The blight spread to Darjeeling in the early years of the 19th century. Afterwards the disease was reported simultaneously from South India and Sri Lanka in 1946 and from Indonesia in 1950. The disease causes heavy loss of crop in all these and other countries of Asia.

Another fungus, the net blister blight, *Exobasidium reticulatum* common in the tea plantations of the mountainous regions of Japan and Taiwan, is equally harmful.

Tender leaves and stems of young tea shoots are infested by air borne spores of the fungus. Initially after germination the fungus produces translucent spots on the undersurface of leaves, which develop into circular blisters after a few days. The blisters become white on spore production. After sporulation the blisters turn brown and dry up. Multiple blisters cause curling and twisting of the young leaves. Young stems attacked by the disease ultimately break off. The disease builds up rapidly in cold, misty and wet weather (Fig. 10). Fortunately the fungus does not attack mature leaf and hard stem.

Fig. 10. Leaf diseas

Adjustment of the time of
the epidemic period, hard plucking
infected shoots, thinning of overhe
are the normal cultural measures a
copper fungicide adjusting freque
good protection from the disease. Some synthetic fungicides like Tridemorph, Pyracarbolid, Bitertanol etc. have been found effective. These can be used provided it does not infringe on interna

tional regulations about the use of agricultural chemicals.

Black rot : This common disease is caused by two species of fungi, namely *Corticium theae* Bernard and *C. invisum* Petch. The fungi grow from air borne spores, sclerotia as well as by contact with infected material. The fungi mainly attack maintenance foliage. The infested leaves get detached but remain suspended to branches on mycelial strands. The white mycelial cords of *C. theae* can be seen lengthwise on the stem, which later turn brownish (Fig. 11), while the brown mycelial cords of *C. invisum* are loosely arranged.

Fig. 11. Leaf disease : Black rot

Long spells of humid climate, heavy overhead shade, poor drainage of the soil and closeness to jungle are predisposing causes of the diseases. Removal of dense shade, improvement of drainage, pruning of infected sections followed by caustic wash of the bush frame and improvement of aeration by judicious removal of side branches are the recommended cultural measures for control of the disease. Spraying of copper oxychloride on the affected leaves had been the standard practice. Synthetic fungicides like Hexaconazole and Carboxin have proved effective in controlling the diseases, but their use is subject to the same considerations as mentioned under blister blight.

Grey blight (*Pestalotia theae* Sawada) and brown blight (*Colletotrichum camelliae* Massee) are wound parasites commonly found on damaged old tea leaves. These fungi are common in Africa also, where they are not of economic importance, as in India and Sri Lanka. However, in mechanically harvested tea areas of Japan, grey blight caused a serious problem. The attack of grey blight was controlled by the application of Thiophanate methyl within 3-5 days after harvesting.

STEM DISEASES

Heavy, medium and light pruning of very old, old and relatively younger stems at long and short periodic intervals is an essential feature of tea culture. However, the pruning cuts act as the primary centres for entry of the fungal parasites into the bush frame. Hail, sun scorch and other mechanical injuries of the branch system also invite fungal attack but some of the injuries can be controlled or avoided while periodic pruning is not avoidable. The pruning cuts, particularly the thicker ones, take a long time to heal allowing fungal infection to take a strong hold and advance its destructive process. Secondly, a small piece of stem remains below the pruning cut and the point of origin of the topmost lateral shoot below the cut, thus leaving a small stub. This stub dies where saprophytic fungi start their rotting process. The saprophytes may travel down the dead wood even up to the living portion of the stem. The stem diseases of tea will have to be viewed against this background.

The stem diseases known as branch canker in N.E. India is caused by the fungus *Poria hypobrunnea* Petch. The fungus is dispersed by air-borne spores which germinate on wounds on the body of the plant, particularly on thick pruning cuts. In weaker bushes even wounds on small branches may be infested by the disease. The disease extends down the branches, killing them one by one, until it reaches the main stem and finally the root when the whole bush dies. This disease can kill young plants within 2-3 years while infected old bushes may take much longer to die (Fig. 12). This is a serious stem-cum-root disease of almost all Asian countries.

Fig. 12. *Poria* branch canker

The fungus *Aglaospora aculeata* Petch = (*Tunstallia aculeata*) is the cause of the disease known as thorny stem blight. It is very common in the hill district of Darjeeling of N.E. India and is of limited occurrence in the plains. The disease occurs also in Sri Lanka. Mode of attack of the disease resembles that of *Poria hypobrunnea*. It is a disease of weak bushes.

Macrophoma theicola Petch is another fungus which causes stem canker. It has been recorded at lower evaluations in Sri Lanka, N.E. India and Taiwan. The disease is prevalent mostly in sandy/stony areas prone to drought. Only in severe attack the fungus may kill bushes.

Pellicularia (=Corticium) salmonicolor (B. & Br) Rogers causes what is known as the pink disease. The fungus is closely allied to the black rot fungus of tea. The fungus has occasionally been found to attack tea in Assam and Bangladesh.

Crotalaria anagyroides and *Tephrosia candida,* two widely cultivated green crops in N.E. India, are very susceptible to attack by this fungus, where it produces thin, rosy-pink fructifications. The fungus also occurs in wetter parts of Kenya, Madagascar, Burundi and a few other countries of Africa where affected branches crack and usually die.

Nectria are wound parasites, several species of which occur on tea and shade trees of N.E.India. Only two of the species have so far been found to be harmful to tea, *Nectria* attack mature tea bushes; those below 5 years are very rarely affected. Affected branches die back from the seat of infection. The weak bushes suffer the most. The fungi spread by air-borne spores.

The fungus *Phomopsis theae* Petch was found to be the cause of death of plants in new clearings at higher elevations in Sri Lanka. Death was caused by collar and branch canker. In Africa the disease is rarely found in tea above 8 years. Worst attack usually follows prolonged drought. Since incidence of the disease is related to water stress, cultural practices should be organised to limit water scarcity. Stem cankers are harmful but the danger is aggravated when scavenging termites attack the damaged tissue.

The fungus known as collar rot in N.E. India causes death of plants in the nursery by attacking the collar region of the young plants. Application of copper fungicide on nursery bed is recommended for its control.

There are many common features in the methods used for the control of stem cankers. These are :

Improvement of health and vigour of the bushes since these diseases attack and cause more harm to weak than to healthy bushes.

At the time of pruning, thorough cleaning out of bushes by removing all dead and dying snags and application of caustic wash to bush frame.

Pruning of infected branches down to healthy wood and protection of the cut surfaces by fungicidal paint.

Moisture conservation during periods of water stress.

Prevention of waterlogging of tea areas and provision of shade where necessary.

Avoidance of the use of susceptible clones/cultivars.

Discovery of *Trichoderma* as a very effective mycoparasitic fungus capable of destroying many fungal plant pathogens is significant event in plant pathology (Weindling, 1932). The fungi occur in most soils throughout the world. The antagonism of *Trichoderma* species towards fungal plant pathogens is attributed to production of antibiotics and chitinolytic enzymes supplemented by very fast growth rate of the fungi (Dennis and Webster, 1970(a), (b); Elad *et al*., 1982). In tea, application of spore and mycellial preparations of *T. viride* and *T. harzianum* to pruning cuts protected fungal infection as effectively as copper fungicide (Barbora, 1995, Barthakur *et al*., 2004).

Mixing of *Trichoderma* preparations with organic manures for use in planting pits is now gaining popularity in N.E. India (Fig. 13).

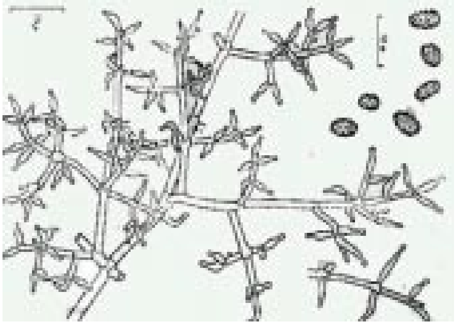

Fig. 13. Vegetative growth of *Trichoderma*

Red rust disease of tea is caused not by any fungus but by an alga *Cephaleuros parasiticus* Karst. The disease usually attacks tea bushes weakened by adverse soil and climatic conditions. In warm climate lack of shade or poor shade is also a predisposing factor. The disease is dispersed by air or water-borne spores, which germinate on one to three years old stems and grow into the bark tissues where they multiply and penetrate deeper. The plant attempts to throw off the infection by developing new bark underneath the affected parts. Due to pressure of the developing disease the bark of the affected patches split, producing minute cracks. Hair like orange coloured fruiting bodies emerge through the cracks, bearing sporangia at their tips where spores are produced in large numbers. The affected patches of stem appear orange-red when the alga produces its main crop of fructification. The leaves produced above the affected parts of the stem become variegated with yellow patches, which can be seen from a distance (Fig. 14).

Fig. 14. Red rust disease

Badly affected branches often die back. The new shoots developing below the affected portion of the stem may also get infected. If the disease is not checked and infection continues, the bush gets weaker and weaker, resulting in reduction of crop and even death of young plants in newly planted fields. The disease occurs in most of the Asian countries as well as in Central Africa.

The alga attacks old leaves also, but the damage caused to the bush by leaf infection is never serious.

Besides tea the alga attacks a large number of plants. One of which, *Tephrosia candida*, was a widely used green manure crop in N.E. India. Use of this plant in tea areas is no longer advocated.

Application of a few rounds of copper fungicide before and during fructification helps in controlling the disease. However, the tea areas affected by this disease should receive fungicidal treatments at least for two, may be three, consecutive years. Meanwhile every effort should be made to improve the health of the affected bushes.

ROOT DISEASES

A large number of parasitic fungi attacking roots of tea plants have been identified in different parts of the tea-growing world, out of which only about a dozen species have proved harmful to tea economy.

Normally spores are the carriers of fungal diseases. However, in the case of tea there is another major source of infection of tea roots by disease causing fungi. Tree stumps left behind in the soil at the time of clearing virgin forest land for planting of tea are attacked by many harmful parasitic fungi. The fungi infect tea plants when their roots come into contact with the disease infested tree stumps. The diseases spread from one tea bush to another when roots of adjacent healthy plants come into contact with the diseased roots of its neighbour. Similarly shade tree stumps left behind in soil at the time of uprooting old tea areas for replanting, become the sources of infection of harmful root diseases. It may be noted in this connection that fungi causing root diseases of tea attack and thrive on a large number of other plant species. The roots of hard-wood trees rot slowly and continue as sources of infection for many years.

Root diseases do not give any indication until the infection has sufficiently advanced. When this happens, leaves on one or more branches of a tea bush and sometimes of the entire bush suddenly turn yellow, dry up but remain hanging on to the branches for a few days before dropping. This is an indication that a root disease has damaged the conducting tissues of the root system impairing movement of water and nutrients to the above ground parts. These symptoms are common to all root diseases of tea. When this stage is reached, nothing can be done to save the bush. It will have to be uprooted and destroyed.

Charcoal stump rot caused by the fungi *Ustulina zonata* (Lev.) Sacc = *U. deusta* (Fr) Petrak is perhaps the most common and harmful root disease of tea in N.E. India and Bangladesh. The disease occurs also in South India, Sri Lanka and Indonesia and sporadically in Africa. It attacks all kinds of tea bushes usually above three years. Diseased bushes, particularly the young ones, die suddenly after exhibiting the characteristic symptoms described earlier. Decaying tree stumps are usually the sources of infection.

Roots attacked by *Ustulina* do not have any visible symptom on the surface. Fan-like belts of white, silky mycelium grow on the surface of diseased wood below the bark. Colour of the wood is almost normal. It is permeated by black sheets which appear as black lines when these are cut. Such lines are found on all woods killed by other fungi, but in the case of these fungi the lines are duplicated as parallel lines. Fructifications are abundant on tree stumps, but less on the collar of tea bushes. The fructification is characteristic of the fungus, which is initially white changing with age to charcoal-black

Fig. 15. Charcoal stump rot

brittle encrustation, wavy on the surface (Fig. 15).

Red root rot is caused by the fungus *Poria hypolateritia* (Berk) Cooke. It is a disease of economic importance in South India, Sri Lanka and Indonesia but its importance in N.E. India is much less. In the early stages of the disease, white threads or cords of mycelium can be seen on the surface of the diseased root. Later these cords change colour, fuse with one another or spread out to form chocolate-red to black sheaths. The cords and sheaths are white underneath. Roots are usually encrusted with soil, sand and stone particles held by the coloured cords or sheaths. Fructification of the fungus is very rare. Infection spreads mostly by contact with diseased material. Infected root tissues get completely disintegrated.

Brown root rot is caused by the fungus *Fomes noxius* Corner. This is the first root disease discovered in tea (Petch, 1923), which occurs in India, Bangladesh, Sri Lanka, China and Indonesia. The disease is usually found in more than 3-year old plants, but younger plants may also be attacked. Roots of affected plants are encrusted with soil, sand and stone particles held firmly by brown mycelium. There is usually a white to brown layer of mycelium on the surface of the wood below the bark of the root. In advanced stage of the disease the wood is permeated by yellow-brown sheets of mycelium which appear as a network of lines inside the wood. Fructification of the fungus is very rare.

Black root rot : The fungus *Rosellinia arcuata* Petch is the cause of this disease. This disease is common in N.E. India particularly in the hills. It occurs also in Indonesia, Japan, South India and Central Africa. The fungus can grow rapidly in soil surface containing a lot of dead vegetable matter. The fungus forms black, irregular, adherent cords of mycelium and small, isolated black dots and dashes on the root surface. Wooly, grey and black mycelium may be produced on the stem to a few centimeters above the soil surface. Small, white to black star like markings develop on the wood below the bark.

Two types of fructifications are produced on the stem a little above the collar. Infection spreads either through air-borne spores or by direct contact with diseased material. Another species *R. necatrik* (Hartig) Barlese has been observed under certain specified situations in Japan. Broth culture of the fungus *Bacillus subtilis* has been successfully tried in N.E. India for the control of black rot (Barbora, 1995).

Tarry root rot caused by the fungus *Hypoxylon asarcodes* (Theiss) Mill is not a common disease. It has been observed in the plains tea district of West Bengal. The fungus does not produce any external symptom on the affected roots. A few centimeter of the stem from collar upwards shows a black, smooth, hard, effused and adherent encrustation. Thin, dark, black lines, similar to those of *Ustulina zonata* are formed on the wood of the root. Air-borne spores and contact with diseased material spread infection.

Violet root rot is produced by the fungus *Sphaerostilbe repens* B. & Br. The fungus attacks all young and old tea plants, which suffer from bad soil aeration. The leaves of diseased plants turn yellowish, droop, become flaccid and often drop off. Roots of affected plants are inky black or light violet in colour. Wood of the root below the bark is covered with thick, irregular, purplish black flattened stands. Freshly dug root often small sour and vinegary. This fungus is very common in Assam but rare in other countries.

Elimination of waterlogged condition and improvement of soil aeration are essential for controlling this disease.

Almost all these root diseases are found in the Asian countries. The black root rot occurs in Central Africa also.

Armillaria mellea (Fr.) Vahl. is a major root rot fungus of Africa where it causes significant losses (Rattan, 1992). The fungus occurs also in Indonesia and rarely in India. Stumps of felled trees harbouring the fungus act as sources of infection of tea bushes. Infected bushes exhibit the usual overground symptoms of root disease. The fungus forms a thick layer of mycelia between bark and wood of the root, destroying cambium of the root and also of the stem at the collar region. Roots of the diseased bushes often show longitudinal cracks in the back and the wood from which the term bark-splitting disease originated. Sheets of creamy white mycelia are seen on the wood in the collar region underneath the bark. Healthy bushes get infected when their roots come into contact with diseased material from infected bushes.

Control of root diseases

A diseased bush must be uprooted with all the roots as promptly as possible. The uprooted plant should be removed from site for identification of the causative fungus and then destroyed. In fact removal of the diseased bush alone is not enough since the disease may have infected the neighbouring bushes already, although these bushes have not yet shown any aboveground symptoms. Uprooting and removal of two rows of apparently healthy bushes surrounding the diseased bush is currently the standard procedure. However, the roots of the second row of bushes should also be examined after uprooting to make sure that the disease has not advanced beyond this line. After removing all roots, the uprooted patch should be put under a grass like Guatemala for a minimum period of two years. The area can be planted with tea after the period of rehabilitation. Watering of the plants with systemic fungicides at three to four months interval for a period of one year has proved highly satisfactory in Sri Lanka. The method is cheaper than fumigation with methyl bromide (Arulpragasam, 1992).

As a measure of safety, dead tea bushes or shade trees should not be left for long in tea fields, even if the cause of death is other than primary root disease.

Since shade tree stumps have been observed to increase the incidence of root diseases of tea, ring barking of shade trees a year or two ahead of felling should be scrupulously followed (The bigger trees may require ring barking in successive years for exhaustion of the root reserve). Ring barking depletes the carbohydrate reserves of the roots, depriving the parasitic fungi of their sustenance. The reserve-depleted roots will be available for attack by saprophytic fungi.

Even after ring barking, tree stumps should be removed from tea areas. Where removal is not possible, the trees should be cut a little below the ground level to enable burial of the stumps to prevent infection by air-borne spores.

Weak bushes are more susceptible to attack by all kinds of disease organisms. Hence, improvement of health of tea bushes should receive top priority in the control of diseases. For instance, improvement of drainage of a waterlogged tea area will improve health and productivity of tea preventing infection by violet root rot at the same time.

In fighting diseases, delay is dangerous. Whatever steps are necessary for the control of a disease should be taken promptly.

Mention has already been made that the fungus species attacking tea roots have many other host plants including some species of shade trees and cover crops grown in tea areas. As a precautionary measure, the plant species highly susceptible to the root rot fungi should not be planted amongst tea.

Other diseases

The fungus *Botryodiplodia theobromae* Pat, which is the cause of Diplodia disease, is found almost on all debilitated and dead plants. General debility is the predisposing cause of this disease.

Rhizoctonia bataticola (Taub) Butler is a disease similar to Diplodia. It is more common in sandy soil. A few *Ganoderma* species of fungi attack roots of tea bushes severely damaged or killed by other agencies. Brown blight and grey blight of tea are caused by *Colletotrichum camelliae* Mass and *Pestalotia theae* Sawada, respectively. These fungi attack leaves, particularly old leaves, when the bush is weakened by adverse environmental conditions and inept cultural practices. These diseases are of little economic importance.

DAMAGE BY NON PARASITIC DISEASES AND OTHER CAUSES

Rim blight (Marginal necrosis) is a common disease in N.E. India, which occasionally causes substantial loss of crop. It is not a disease but an expression that the tea bush is experiencing some difficulties. The symptoms of such condition appear on young leaves. The serrations and margins of young leaves turn chocolate brown, which gradually extends towards the mid-rib. As the green, unaffected parts of the leaf continue to grow and expand, the leaf bends either downward or sideward. The affected leaves are often infected by diseases like grey blight and brown blight. Light leaf tea bushes are more prone to Rim blight than dark leaf bushes.

A number of factors initiate Rim blight. Damage by sucking insects, attack of stem by wood rot fungi, hot and dry weather after bud break following pruning, chlorosis of leaf due to attack by red rust, overdose of soluble chemical fertiliser, application of fertiliser before adequate leaf growth in pruned sections, bud break in a dry spell are some of them.

For controlling Rim blight, the predisposing causes must be identified and remedial measures taken promptly.

Lightening

In lightening damage the leaves of tea bushes appear scorched, as if by fire. The bushes die. The dead bushes should be dug up and removed immediately. Then the soil should be rehabilitated properly in the usual way. The process of rehabilitation may have to be continued for two years to increase the organic matter content of the soil, which was burnt by lightening to a great extent.

Hail

Hail storm belts are present in a few tea-growing countries where pockets of tea occasionally get extensively damaged. Presence of good stands of shade trees minimises hail damage. Hail damaged tea fields should be sprayed with copper fungicide within 48 hours of hail, repeating spraying if necessary.

Heat

In the plains of N.E. India, the daily mean maximum temperature usually remains above 30°C during the main tea growing season from May to October. High respiratory rate under such temperature conditions reduces net photosynthesis. Furthermore, tea bushes planted in stony ridges, south and western aspects of hills and sandy patches suffer from heat injury, if not protected by shading. Tissues of the main stems of bigger bushes near the soil surface are scorched usually on southern and western aspects by high soil temperature and those of small plants almost completely in a girdle. As a result the small plants usually die and the bigger plants get debilitated. To avoid heat injury tea area should be put under a good stand of shade trees. Some green crop should be grown to provide early protection from hot sun until the shade takes over. Dead and damaged bushes should be uprooted and replaced.

Sun scorch

Young tea plants in nursery get sun-scorched when the cover on top of the nursery bed suddenly collapses exposing the plants to the direct rays of the sun. This may happen also to the young transplants if planting is done in hot weather without adequate provision of shade.

When strong rays of the sun hit the frame of tea bushes continuously for a few days, the bark of some of the branches, particularly of horizontal ones, split and peel off exposing the wood below (Fig. 16). Such wounds on small branches of vigorous bushes may heal up by callusing, but on weak bushes the wounds, specially on thick stems, remain open for a long time inviting infection by parasitic fungi like *Poria hypobrunnea*, *Aglaospora* sp. etc. leading to damage of the branches.

Fig. 16. Sun scorch

Sudden exposure of the lower portion of the bush to direct rays of the sun following pruning has, on occasions, been observed to cause sun scorch.

These problems caused by sun scorch are common in regions experiencing high ambient temperature for a part of the year as in N.E. India. Protection of bushes from direct rays of the sun by providing shade eliminates or minimizes damage from sun scorch. Since shade cover of tea bushes is essential in such hot regions for healthy growth and productivity of tea, elimination of sun scorch should not be a difficult problem.

Drought

This appears to be the most harmful non-pathogenic problem faced by the tea industry in many parts of the world. Heavy loss of crop results from drought if adequate precautions are not taken in time. Debility and death of bushes are likely to occur especially when high ambient temperature accompanies scarcity of water in the soil. Drought is mentioned here to draw attention to the fact that no less importance is to be paid to this harmful environmental factor than pests and diseases.

Waterlogging

Waterlogging is caused by submersion of root systems of tea bushes by flood water and/or by the presence of a high water table in the soil resulting from stagnation of water due to faulty drainage. Waterlogged condition of the soil is extremely harmful for healthy growth of tea. It prevents penetration of air into the root zone of tea bushes disturbing the normal metabolic activities of the root system in the absence of oxygen. Under such conditions, photosynthetic production of dry matter by the leaves stops completely (Barua, 1989) although the leaves do not exhibit any symptom of stress for a long time.

Bushes suffering from drought can be revived easily by supplying water if the damage has not been severe, but there is no such quick remedy for waterlogged bushes. Hence every effort should be made to prevent waterlogging.

APPENDIX A

The maximum residue limits (MRL) in mg/kg of some of the plant protection chemicals for tea as on 31.12.2007

Pesticides	India MRL	Japan MRL	EU MRL
Dicofol	5	3	20
Ethion	5	0.3	(0.01)LA
Endosulfan	-	30	LA
Deltamethrin	-	10	5
Cypermethrin	-	20	0.5
Glyphosate	1	1	0.1
Chlorpyriphos	-	10	0.1
Dimethoate	-	1	0.2
Profenophos	-	1	0.1
Propargite	10	5	5
2,4-D	-	UL	-
Fenazaquin	3	-	-
Simazine	-	UL	-
Copper	-	Exempted	-
Paraquat	-	0.3	0.1
Quinalphos	0.01	0.1	LA
Diflubenzuron	-	20	-
Thiamethoxam	-	20	-
Fluvalinate	-	10	0.05
Hexaconazole	-	0.05	0.05
Propiconazole	-	0.1	0.1

Note :

UL = Uniform Level of 0.01 mg/kg

LA = Lost Authorisation for use in Europe

APPENDIX B

Scientific and common names of some pests and diseases attacking tea

Scientific names	Common names
PESTS	
Euwallacea (Xyleborus) formicatus Eichoff	Shot hole borer
Exobasidium vexans Massee	Blister blight
Foirinia theae Green	Scale insect
Helopeltis antonii Kirby	Mirid bug (cashewnut)
H. theivora Waterhouse	Tea mosquito bug
H. magnanima Diakonoff	
H. schoutedeni Reuter	
Haplothrix griseatus Gah.	Cerambycid stem borer
Hemicriconemoides kanayensis	
Holotrichia impressa Burm	Cockchafer bettle
Homona coffearia Nietner	Tea tortrix
I. quadrinotata Walker	Large bark eating borers
Indarbelda theivora Hampson	Common bark eating borers
Lygus sp.	Turnished plant bug
Meloidogyne incognita Chitwood	Root knot nematode
M. brevicauda Loss	Root knot nematode
M. javanica (Treub) Chitwood	Root knot nematode
Mahasena theivora Dudge	Basket worm
Microtermes	Live wood eating termites
Odontotermes	Scavanging termite
Oligonychus coffeae Nietner	Red spider mite
Parametriotes theae Kusnetsov	
Parasa lepida Cramer	Slug caterpillar
Phenacaspis manni Green	Armoured scale insect
Phytoseilus persimilis	Predatory mite
Pinnaspis theae Maskell	Armoured scale
Poecilocoris latus Dall	Tea seed bug
Poria hypobrunnea	Branch canker
Pratylenchus loosi Loaf	Root lesion nematode

Rhizoecus sp.	Root mealy bug
Saissetia coffeae Walker	Naked scale insect
S. aurantii Faure	
S. formicarii Green	Naked scale insect
S. kenyesis Mound	
Scirtothrips dorsalis Hood	Tea thrips (Assam tea thrips)
Stethorus gilviforns	Coccinellid predator of red spider mite
Taeniothrips setiventris Bagnall	Common thrips
Tetranychus kanzawai Kishida	Tetranychid mite
Thosea cervina Moore	Saddle backed Nettle grub
Toxoptera aurantii Boyer	Tea aphids
Xyleborus fornicatus Eichh	Shot hole borer
Zeuzera coffeae Nietner	Red borer

DISEASES

Armillaria mellea	Armillaria root rot
Rosellinia arcuata Petch	Black root rot
Corticium theae Bernard,	
Corticium invisum Petch	Black rot
Exobasidium vexans Massee	Blister blight
Poria hypobrunnea Petch	Branch canker
Colletotrichum cammelliae Mass	Brown blight
Fomes lamaoensis (Murr) Sacc & Trott	Brown root rot
Ustulina zonata (Lev.) Sacc.	Charcoal stump rot
Botryodiplodia theobromae Pat.	Diplodia disease
Pestalozzia theae Sawada	Grey blight
Physalospora neglecta Petch.	Macrophoma die back
N. cinnabarina (Tode Ex. Fr.)	Nectria die back
Pellicularia salmonicolour (B & Br)	Pink disease
Poria hypolateritia (Berk) Cooke	Red root rot
Cephaleuros parasiticus Karst	Red rust
Rhizoctonia bataticola	Rhizoctonia root rot
No. pathogen involved	Rim blight
Hyposylon asarcodes (Theiss.) Mill	Tarry root rot
Tunstallia aculeata	Thorny stem blight
Sphaerostilbe repens B & Br.	Violet root rot
Phomopsia sp.	Collar rot

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Deltamethrin	-	10	5
Cypermethrin	-	20	0.5
Glyphosate	1	1	0.1
Chlorpyriphos	-	10	0.1
Dimethoate	-	1	0.2
Profenophos	-	1	0.1
Propargite	10	5	5
2,4-D	-	UL	-
Fenazaquin	3	-	-
Simazine	-	UL	-
Copper	-	Exempted	-
Paraquat	-	0.3	0.1
Quinalphos	0.01	0.1	LA
Diflubenzuron	-	20	-
Thiamethoxam	-	20	-
Fluvalinate	-	10	0.05
Hexaconazole	-	0.05	0.05
Propiconazole	-	0.1	0.1

Note :

UL = Uniform Level of 0.01 mg/kg

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APPENDIX B

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H. schoutedeni Reuter	
Haplothrix griseatus Gah.	Cerambycid stem borer
Hemicriconemoides kanayensis	
Holotrichia impressa Burm	Cockchafer bettle
Homona coffearia Nietner	Tea tortrix
I. quadrinotata Walker	Large bark eating borers
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Lygus sp.	Turnished plant bug
Meloidogyne incognita Chitwood	Root knot nematode
M. brevicauda Loss	Root knot nematode
M. javanica (Treub) Chitwood	Root knot nematode
Mahasena theivora Dudge	Basket worm
Microtermes	Live wood eating termites
Odontotermes	Scavanging termite
Oligonychus coffeae Nietner	Red spider mite
Parametriotes theae Kusnetsov	
Parasa lepida Cramer	Slug caterpillar
Phenacaspis manni Green	Armoured scale insect
Phytoseilus persimilis	Predatory mite
Pinnaspis theae Maskell	Armoured scale
Poecilocoris latus Dall	Tea seed bug
Poria hypobrunnea	Branch canker
Pratylenchus loosi Loaf	Root lesion nematode

Rhizoecus sp.	Root mealy bug
Saissetia coffeae Walker	Naked scale insect
S. aurantii Faure	
S. formicarii Green	Naked scale insect
S. kenyesis Mound	
Scirtothrips dorsalis Hood	Tea thrips (Assam tea thrips)
Stethorus gilviforns	Coccinellid predator of red spider mite
Taeniothrips setiventris Bagnall	Common thrips
Tetranychus kanzawai Kishida	Tetranychid mite
Thosea cervina Moore	Saddle backed Nettle grub
Toxoptera aurantii Boyer	Tea aphids
Xyleborus fornicatus Eichh	Shot hole borer
Zeuzera coffeae Nietner	Red borer
DISEASES	
Armillaria mellea	Armillaria root rot
Rosellinia arcuata Petch	Black root rot
Corticium theae Bernard,	
Corticium invisum Petch	Black rot
Exobasidium vexans Massee	Blister blight
Poria hypobrunnea Petch	Branch canker
Colletotrichum cammelliae Mass	Brown blight
Fomes lamaoensis (Murr) Sacc & Trott	Brown root rot
Ustulina zonata (Lev.) Sacc.	Charcoal stump rot
Botryodiplodia theobromae Pat.	Diplodia disease
Pestalozzia theae Sawada	Grey blight
Physalospora neglecta Petch.	Macrophoma die back
N. cinnabarina (Tode Ex. Fr.)	Nectria die back
Pellicularia salmonicolour (B & Br)	Pink disease
Poria hypolateritia (Berk) Cooke	Red root rot
Cephaleuros parasiticus Karst	Red rust
Rhizoctonia bataticola	Rhizoctonia root rot
No. pathogen involved	Rim blight
Hyposylon asarcodes (Theiss.) Mill	Tarry root rot
Tunstallia aculeata	Thorny stem blight
Sphaerostilbe repens B & Br.	Violet root rot
Phomopsia sp.	Collar rot

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