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MANUAL
OF
GENERAL SILVICULTURE FOR INDIA

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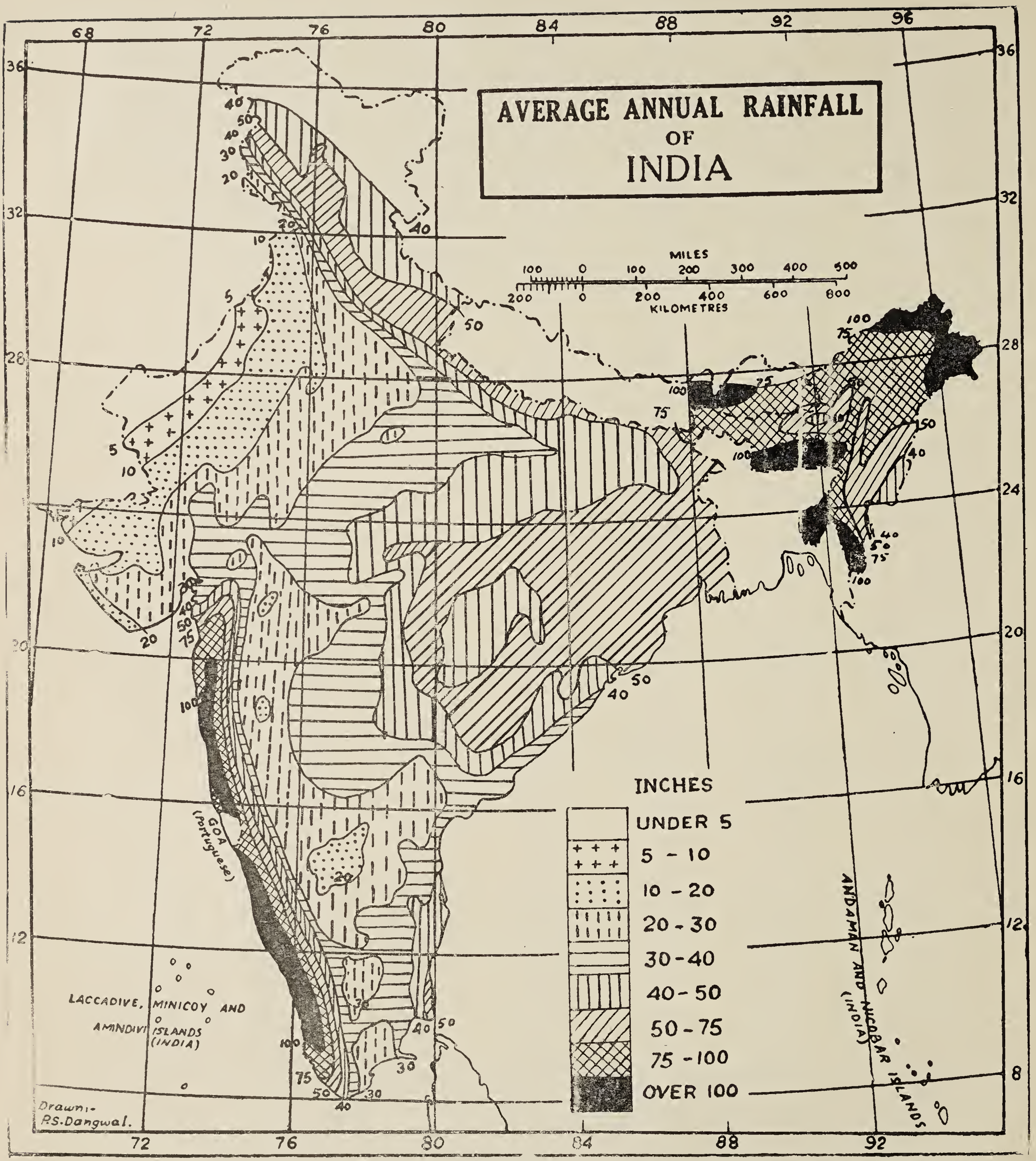

Sikkim and Bhutan States are attached to India by special treaties.

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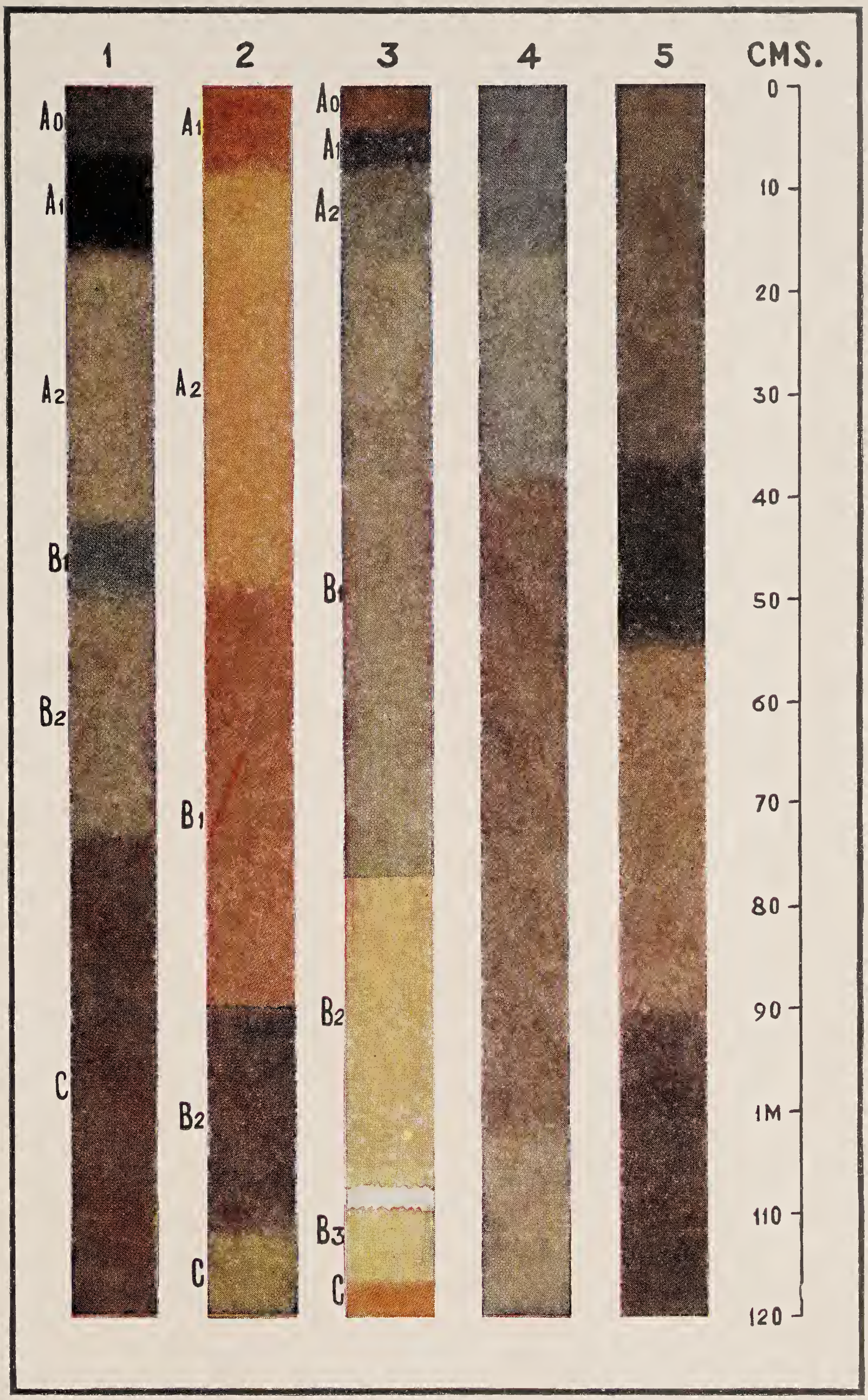

Diagram I. Typical Soil Profiles

1. Podsol over mica schist, carrying natural deodar with good regeneration.
2. Brown earth over mica schist, carrying deodar poles in overgrazed forest.
3. Immature podsol over quartzite, carrying chir pine crop with regeneration.
4. Tropical red soil over gneiss, carrying tropical evergreen forest, Mudumalai, Madras.
5. Laterite soil over crystalline rock, carrying tropical deciduous forest, Central Provinces.

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MANUAL
OF
GENERAL SILVICULTURE FOR INDIA

BY

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ERRATA

Page 12, line 6, *for* 'Annal' *read* 'Annual'.
Page 47, line 3, from bottom, *for* 'descicating' *read* 'desiccating'.
Page 69, line 3, from bottom, *for* 'covern' *read* 'covered'.
Page 73, last line of table under diameter class '29' *add* "½".
Page 78, line 9, from bottom, *for* 'relay' *read* 'rely'.
Page 81, column 3 of table, *for* 'plnt' *read* 'plant'.
Page 103, line 2, from bottom, (Table) *for* 'Darjeeling Dn, S. P.' *read* 'Darjeeling Dn. S. P. 5'.
Page 110, line 8, *for* 'of ten' *read* 'often'.
Page 126, para 3, line 3, *for* 'on' *read* 'in'.
Page 144, para 2, line 8, *for* 'orginated' *read* 'originated'.
Page 146, para 2, line 5, *for* 'reacts' *read* 'react'.
Plate 11, opposite page 153, *for* '*Boswellia ersata*' *read* '*Boswellia serrata*'.
Plate 13, opposite page 161 *for* 'LATE 13. Teak P plantation' *read* 'PLATE 13, Teak plantation.'
Page 166, line 9, *for* 'liekly' *read* 'likely'.
Page 207, line 2, from bottom, *for* 'In' *read* 'It'.
Page 223, para 2, line 10, *for* 'ndrsery' *read* 'nursery'.
Page 230, para 2, line 6, *for* 'beeds' *read* 'beds'.
Page 273, line 9, *for* '*Dodonca*' *read* '*Dodonea*'.
Page 281, para 2, lines 9 and 13, *for* '*Legerstroemia*' *read* '*Lagerstroemia*'.
Page 287, line 8, for '*Ischnocarpus*' *read* '*Ichnocarpus*'.
Page 293, para 2, line 2, *for* 'espcially' *read* 'especially'.
Page 297, para 2, line 6, *for* '1(b)' read 'I(b)' and *for* '1(a)' *read* 'I(a)'.
Page 297, para 3, line 3, *for* '1(b)' *read* 'I (b)'.
Page 309, para 3, line 6, *for* 'corps' *read* 'crops'.

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Note. The photographs not expressly acknowledged are from negatives in the Forest Research Institute collection, and were mostly taken by H. G. Champion, M. V. Laurie or A. L. Griffith.

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INTRODUCTION

Whilst agriculture is understood to cover the whole theory and practice of raising and harvesting field crops, and horticulture similarly deals with everything concerning gardens, the terms 'silviculture' in English commonly refers only to certain aspects of the theory and practice of raising forest crops. 'Forestry' is the true equivalent of 'agriculture', and 'silviculture' is used to imply only the methods of raising tree crops and their growth and care up to the time of the final harvesting. The organization of forests to meet as fully as possible the objects of management, the determination of the best time for harvesting, and a number of other aspects of forestry are dealt with separately as 'forest management'; and the assessment of their contents, the determination of their rate of growth, etc., come under 'mensuration'.

The forester in India is called on to apply his silvicultural knowledge and experience to all the land included within certain legally determined boundaries, irrespective of the nature of the growth they may carry. The legal meaning of 'forest' may be very different from the ordinary or botanical meaning, and the forester will usually have in his charge not only tree growth of very varying density and quality, but scrub and grass lands, perhaps even waste areas more or less bare of vegetation and hill tops above the altitudes at which tree growth is possible.

The forests of India, whether considered in the wide sense of the foregoing paragraph or in the usual narrower sense, probably include a greater range of composition and appearance than can be found over a similar area in any other part of the globe. Their silviculture is accordingly more complex by far than that of the relatively small range of types and conditions met with in Europe and temperate North America. The number of tree species of importance runs at least into several hundreds, and not only has their individual silviculture to be studied, but their relationships and reactions on one another. The science of forestry has been developed in the temperate forests of the Northern Hemisphere, and whilst many general principles remain valid under the most varied conditions, the application of knowledge and experience obtained in these temperate forests to the tropical forests of India requires the greatest caution. Tropical forestry has, in fact, to build up its own silvicultural science, for experience has already taught that the differences from temperate forestry are often not merely differences in degree, but are liable to be differences in kind. The development of recent years in the knowledge of tropical soils brings out this point and goes some way towards providing a partial explanation.

Some of the forests of the country, notably the tropical evergreen forests of the wetter portions, are undoubtedly still in their original state, just as they have developed in accordance with natural conditions of climate, topography and soil. By far the greater part of them, however, have been much influenced directly or indirectly by human activities. Recognition of this fact and an understanding of the ways in which these activities have affected and are still affecting the forest is most important to silvicultural practice, and so with a survey of the undisturbed development of forests, this subject forms one of the chapters of this Manual (Chapter IV).

Although sometimes owing to the different hardiness of different tree species under ill-treatment, the impact of a human population may favour a more valuable tree species against less valuable ones, the results of human activities are almost invariably destructive to the forest. In the earlier stages of the occupation of the land, the forest has everywhere been looked upon as the enemy of mankind, and its destruction as indicating progress. This hostile attitude still persists where local conditions promote luxuriant growth and the pressure of population is not too great, but where the larger part of the forest has already been destroyed and the last remnants are seen to be doomed to early disappearance unless something is done to protect them, the realization of the great benefits conferred by the forest is gradually dawning on those who are at the same time both the destroyers and among the victims. The climatic conditions of India, and in many parts soil conditions also, are such as to cause the evil consequences of forest destruction to follow at a greater rate than in most other countries, particularly greater than in Europe, the heavy monsoon rainfall being largely responsible for this difference.

How far forest destruction has gone is illustrated by figures given on a later page, but some idea must be gathered by any passenger travelling westwards by rail up the Gangetic plain and on into the Punjab and the North-West Frontier. On his whole journey he will not see a vestige of forest worthy of the name. Similarly the traveller in parts of the Himalayas may see everywhere extensive views with range after range of hills completely denuded of tree growth, or with mere remnants of the original forest on the hill tops or in the steeper ravines. Nor is Peninsular India much better off, and everywhere are to be seen hills not only denuded of the vegetation which once covered them, but scoured of soil down to bed-rock and absolutely unproductive ; on the more level ground also the destruction of the forest has often only resulted in a short period of cultivation before the soil has lost its original fertility, as is indicated by the abandoned fields which would in time be re-occupied by tree growth restoring them to productivity were it not for excessive grazing by inferior cattle.

The silviculturist encounters these aspects of forestry in almost all branches of his work. He is called on to reclothe the denuded hill-sides with forest, and so to stop the erosion of the soil and the burying of the agricultural lands down the valleys with sterile sand, gravel and boulders. He is required so to tend and harvest the timber from his forests that the protective functions of the tree cover are disturbed as little as possible. He must also tend, harvest and regenerate them satisfactorily while at the same time he supplies from them the many needs of a local population which is generally entitled by rights to much forest produce ; and often, most difficult of all, he must also provide grazing for a large number of cattle.

Of recent years, foresters have been learning to turn to good account the various destructive influences threatening the forest. Thus shifting cultivation has been controlled and converted into a valuable agency for increasing the value of the tree crops where formerly it was purely destructive. Grazing and burning also are now being brought into extensive use in regeneration work, the essential being that the silviculturist shall have them under his control instead of having to fight them as declared enemies. It may be predicted that in India one of the directions in which forestry will develop will be in the increased control of these influences with their marked potentialities for both harm and good.

In this Manual, a rapid survey will be made of the climatic and soil conditions under which our forests grow (Ch. I) followed by an equally condensed account of the primarily botanical subjects of the form and growth (Ch. II), and physiological processes (Ch. III) of trees and crops. The natural development of forests and their reactions to the various agencies affecting them (Ch. IV) are generally treated as forest ecology, consideration of which completes the preliminaries to the essential part of silviculture, viz. the regeneration of forests either naturally (Ch. V) or artificially (Ch. VI), the establishment of forest on non-forest land, or afforestation (Ch. VII), and the tending of forest crops (Ch. VIII). The combination and application of the available information on all these subjects to a given forest area to cover its whole life cycle with different methods of tending, harvesting and replacement, each method giving a forest of characteristic form, is dealt with in a separate publication on Silvicultural Systems.

H. G. CHAMPION

GLOSSARY OF VERNACULAR NAMES AND TERMS

Babul	*Acacia arabica.*
Blue pine	*Pinus excelsa.*
Chir pine	*Pinus longifolia.*
Deodar	*Cedrus deodara.*
Garjan	*Dipterocarpus* spp.
Khair	*Acacia catechu.*
Mulberry	*Morus indica.*
Oak	*Quercus* sp.
Sal	*Shorea robusta.*
Silver fir	*Abies pindrow* (unless otherwise indicated by the context).
Simal	*Bombax malabaricum.*
Sissu	*Dalbergia sissoo.*
Spruce	*Picea morinda* (unless otherwise indicated by the context).
Teak	*Tectona grandis*

Taungya plantation . . . A clearing, made by cutting and burning forest, in which forest trees are raised in combination with field crops.

PREFACE

In his *Silviculture of Indian Trees,* Troup collected in a form most convenient for reference all the knowledge that was available up to about 1919 on the silviculture of each of our forest trees. This invaluable reference work was compiled from the published and unpublished data on the specific files of the Silviculturist's office, and a wide personal experience of the forests of India. In the quarter of a century which has elapsed since this book appeared, the volume of material collected on these files has increased over fivefold, and the preparation of a general revision has become so great a task as to be out of the question with present staff and facilities. More necessary however than such a revision of the existing published information, is the compilation of a silvicultural reference work by subjects, based not on foreign but on Indian experience, and this task has been undertaken in preparing this Manual. During the past ten years, a series of general silvicultural files has been maintained by subjects, on which have been recorded all information received. The chief sources have been the current published literature both Indian and foreign, the Silviculturist's tour notes, working plans, inspection reports, research reports, experimental results from all provinces and the Research Institute, and extracts from correspondence. Although it has been impossible to go through all the older literature for earlier records, these subject files come nearer to containing a full account of what is known in this field than anything that has hitherto been available, and the preparation of this Manual has to a considerable extent consisted in summarizing their contents to supplement personal experience in all provinces except Sind—though that experience is not very recent in the case of Upper Assam and Burma.

Throughout, the object has been to use information from Indian sources as exclusively as possible. In several fields, notably soil science and tree physiology, data from the forests of India are sadly lacking, and foreign experience has had to be accepted for the present. In accordance with the same general principle, references to the voluminous foreign literature which has been consulted but is not generally accessible to forest officers have similarly been avoided except where specially important. It has also been considered advisable to omit references by name to the hundred or more foresters

who have contributed to this compilation through their publications, correspondence or conversation. The author also gratefully acknowledges the special assistance given by the Silviculturists and other forest officers of all provinces in supplying notes on special subjects for which the data appeared inadequate or out of date ; the help given by several of his colleagues at the Forest Research Institute in kindly checking sections overlapping their own fields of work ; and finally the valuable suggestions made by Mr. W. T. Hall, Director of the Forest College, who has read the whole of the typescript and rendered possible various amendments which should make this Manual better suited to the educational uses for which it has primarily been written.

H. G. CHAMPION
Silviculturist
Forest Research Institute

1 September 1936

PREFACE TO REVISED EDITION (1948)

In the eleven years that have elapsed since this Manual was written many changes and great progress have been made in Indian Forestry, particularly in the artificial regeneration of various forest types. The technique of raising teak plantations has been revolutionized, resulting in the production of better plantations at considerably reduced costs. This in itself shows that forestry in India is alive when it is remembered that we have been raising teak plantations for the last 105 years. After many years of patient district work and research it is now possible to regenerate artificially with certainty of success the dry fuel forests which are so essential to the villager. Great progress has been made in the work of afforestation in really arid areas and it is now possible to raise a vegetative cover, if not a tree crop, in areas with a rainfall as low as five inches. Soil conservation and anti-erosion work have gone ahead in a number of provinces. With the co-operation of the Survey of India, through a piece of survey research we have been able to estimate the rate at which the Great Indian Desert has been spreading in the past fifty years.

The period since the Manual was written included the war period with its great demands on the forest department, not only for essential war timber but for temporary building timber and, above all, for very large quantities of fuel for the local populations as well as for the troops and industrial workers. All this was complicated by inadequate and over-worked transport facilities and by a steadily rising population both transient and permanent.

These factors have caused a great change-over in forest needs and forest policy. We are steadily veering from the big timber forests to the scrub forests of the drier areas and to the farm lands. The scope of our activities has now to include the afforestation and proper management of the dry and desert areas, the raising of local fuel plantations, farm forestry, and the protection of the soil from the evils of erosion. The change-over in forest outlook is very evident from a comparison of the proceedings of the fifth all India silvicultural conference (1939) with those of the sixth conference (1945) and the seventh conference (1946).

In consequence, a revision of this Manual has become necessary, not in any way to change its basic nature, but to bring it up to date with modern developments. In the past eleven years the Silviculturist's ledger files have greatly increased and this information has been largely used in this revision. In addition, current published literature, the Silviculturist's tour notes, working plans, inspection reports, research reports, experimental results from the provinces, and from the Research Institute and extracts from correspondence have all been consulted. Also, the reviser has spent a great deal of the last decade touring in the drier areas particularly of Sind, the N. W. F. P., Baluchistan, the Punjab, the Great Indian Desert, Bombay, and many of the States. The reviser gratefully acknowledges the assistance given by the provincial and state silviculturists and the many other forest and agricultural officers who have helped in this revision and in particular those who contributed such excellent papers and discussions to the sixth and seventh silvicultural conferences.

A. L. GRIFFITH
Silviculturist
Forest Research Institute

Independence Day
15 August 1947

Photo : H. G. Champion. 1934.

PLATE I. Teak plantation of 1846 at Nilambur, Madras.

Facing p. 5.

I

THE LOCALITY FACTORS OF THE FOREST

The locality factors :

Since the potential benefit and profit which may be derived from a forest are primarily determined by the conditions prevailing in the site it occupies, an understanding of the reactions between forest and locality forms the essential foundation of sound silviculture, and hence of sound forest management. The type of forest occurring naturally on any site is very largely dependent on such factors as general climate, geology, and topography, which can hardly be altered by the forester, but it is also related to soil and biological factors which can be significantly influenced by the treatment he applies. It will also be found that there is a general aspect to most of these factors applying to large tracts of country, and a special or local aspect varying from point to point in the forest, and resulting sometimes in very marked differences in development or response to a given treatment.

The factors of a locality which call for study can mostly be grouped under the three main heads, climate, soil, and topography, but a fourth head is required for the biological factors which must be reviewed here but are dealt with in detail under the subject of Forest Protection.

CLIMATE

The chief elements of climate are temperature, barometric pressure, and rainfall and their seasonal variations.[6]

Temperature

Zones :

Figures for representative stations are given on pp. 16-17. The familiar rough differentiation of climates on a basis of latitude with average temperatures falling as one goes north or south from the equator, leads to the recognition of tropical, subtropical, temperate and arctic zones, but owing mainly to the very uneven distribution of land and water, great variations are encountered within the zones as defined by latitude.

The Tropic of Cancer, following 23°27′ N. Latitude and limiting the regions north of which the sun is never vertically overhead, runs roughly through Cutch, Bhopal, Katni, Ranchi, Burdwan and Comilla, and should mark the change from tropical to subtropical temperatures. The mean temperature for the year which is accepted as characterizing tropical climates is 75°F. Now not only the whole area of India within the geographical tropics—excluding of course the higher hills—but also all Northern India up to the great range of the Himalayas, experiences a mean annual temperature of 75°F. or more, and so on this basis should be considered as within the climatic tropics. The only clear indication of the normal fall of mean annual temperature with rising latitude is a fall of roughly 1°F. for each 1° of N. latitude in the Indo-Gangetic plain, the effects of other factors resulting in an abnormal course in the lines of equal temperature (isotherms) over the rest of the country. The chief of these factors are the very influential monsoon winds, and the distribution of the mountains which affects both the course of the winds and the rainfall they yield.

Winter temperatures :

In the winter months, however, conditions approach much more to the theoretical normal, and the isotherms run very fairly east and west except for a minor downward dip over the east coast. The January mean drops roughly 1°F. for each degree of latitude northwards, though the drop gradually increases in the north to about $1\frac{1}{2}$°F. This January mean near the Tropic of Cancer is 65°F. indicating that the northern parts of the country experience a quite well-marked cool season, thereby differing from the southern parts with the tropical characteristic of little or no winter. This difference does not however exert as great an influence on the vegetation as might perhaps be anticipated, for several types of forest extend with but little change from the foot of the Himalayas to the south of the peninsula.

Altitude and temperature :

Altitude has of course a very pronounced effect on temperature as is well illustrated on the plateaux of Peninsular India, *e.g.*, in such places as Bangalore which lies at 3,000 ft. In a general way, a rise of 450 ft. corresponds to a fall of 1°F. in mean temperature up to 3,000 ft., above which the fall is more rapid, but the rate of fall may vary considerably at different times of the year, being greater in summer than in winter. Aspect is also influential; further details are given for both altitude and aspect on p. 17.

Annual range of temperature :

The variation of temperature in the course of the year differs greatly in different parts of the country. It tends to be greater with increasing latitude, which implies a greater difference between the longest and shortest day. It is also greater in the drier parts of the country, but less in the hills, and markedly low near the sea coast. The following figures for stations otherwise fairly similar will serve to illustrate these points, the range given being the difference between the mean highest and mean lowest temperatures of the year.

Effect of latitude : Peshawar 86°F. ; Nagpur 69° ; Coimbatore 46°.

Effect of rainfall : Coimbatore (21″) 46° ; Cochin (115″) 28°.

Effect of altitude : Chakrata (7,000 ft.) 61° ; Dehra (2,200 ft.) 69°.

Proximity to sea : Calcutta 54° ; Jubbulpore 75°.

The smallest range is experienced on the west coast of Southern India where it is about 30°F.

Diurnal range of temperature :

The diurnal range shows generally similar variations. The maximum diurnal range is met with in the dry tract of the Indus valley, where it may reach 40°F. in Oct.-Nov. ; N. Bombay stations record a range of over 35° in Feb.-Mar., at which time the range in Upper India is about 30°. In the south, the range is again less, being 20° at Madras.

Frost :

The occurrence of frost is of considerable importance to the vegetation. It occurs regularly every winter on the plains in the upper part of the Indus valley and on the hills above about 3,000 ft. in the C. Himalayas, above 4,000 ft. in C. India, and above 6,000 ft. in the more equable south. Local topography however exerts a marked influence on the occurrence of frost, especially ground frosts which may result in the killing back of low vegetation even when no frost is recorded on the standard screened thermometer at $4\frac{1}{2}$ ft. above ground level. The frost may either be caused locally by radiation, in which case usually only a thin layer of air near the ground is chilled below freezing-point and established forest is but little affected; or heavy cold air from outside may flow down into natural depressions, filling them to a much greater depth and so exerting a far greater effect than the former type of frost. The local type explains most small frost holes, such as those met with in Dehra Dun, whilst the *chandars* of Pilibhit division on the United Provinces appear to provide a good example of the second kind.[7]

Snow :

At sufficiently high altitudes, the drop in temperature results in the precipitation taking the form of snow, which accumulates to a depth and lies on the ground for a period depending on the temperatures prevailing and the amount of winter precipitation. A cover of snow has an important protective effect on the soil and the ground vegetation in checking further drop in temperature, and its gradual melting in spring is also important especially with regard to moisture supplies, which will be discussed later. Snow occasionally falls down to 4,000 ft. in the C. Himalayas, but does not lie for any length of time below about 7,000 ft. The limits are lower to the NW., and they are higher to the east and south, so that Shillong and Ootacamund at 4,800 ft. and 7,250 ft. respectively never experience snow. At the higher elevations, the total snowfall, the depth to which it accumulates, and the length of time it lies in the spring, increase with latitude and the strength of the western disturbances which bring it, and aspect naturally makes a great difference.[7a]

Wind

Barometric pressure and wind :

Winds are generated by differences of barometric pressure, air flowing away from places where the pressure is high to those where it is comparatively low. The wind rarely blows directly outwards from the high pressure centre but tends to leave it with a clockwise deflection (anticyclone), and similarly reaches the low centre with an anticlockwise movement (cyclone).

Wind velocity :

The general lightness of the winds in India is one of its more marked climatic characteristics, and gives rise to one of the differences between Indian forest practice and that of Europe, where the prevalence of strong winds has to be taken more into consideration. However, parts of the country, notably the region round the head of the Bay of Bengal, experience very violent cyclonic storms. The coastal areas of Orissa, further south, are also subject to cyclones and such violent storms occur occasionally on the Malabar coast.

Monsoon winds :

The great annual variations in wind direction known as the monsoons are a most influential factor in the climate of the country. From June to August, a low pressure centre persists in the NW., and steady SW. winds blow up from the sea forming the summer or SW. monsoon. The direction of the wind is, however, often considerably deflected from the general SW. direction by the ranges of mountains and hills. Thus the Bay of Bengal current, striking the Himalayas, partly swings round along them in an ENE. direction, and the Arabian Sea current sweeping up the Indus valley is also deflected in the same direction. In the winter months, the position is reversed, with high pressure in the NW. and a low pressure centre over the sea to the south which generate winds known in the SE. of the country as the NE. monsoon where they bring important rainfall and the north-westerly disturbances which blow along the Himalayas where they bring winter rain and snow with important effects on the vegetation.[8,9].

Diurnal variations of wind :

Changes in direction and velocity of the wind during the day are also usual. Hot winds generated by the heated ground and blowing during the heat of the day are general in the plains during the summer months. Cold winds blow, often with great violence, down the larger valleys of the Himalayas in the night and early morning, a corresponding up-valley wind being experienced in the passes but being relatively slight at the lower elevations. These down-valley winds may be responsible for frost damage (cf. p. 8).

Rainfall and Humidity

Rainfall distribution :

The generalized world distribution of rainfall is characterized by two dry zones roughly along the 30° parallel of latitude both north and south, and an increase of rainfall outwards from these zones towards the poles and the equator. The dry parts of the Punjab fall on the northern dry zone, but rainfall distribution in India, as illustrated by the map at the front of the book and by the representative figures given in the table on p. 15, is fundamentally influenced by complicating factors. Few countries show a greater range of rainfall, for the annual precipitation may be anywhere between *nil* and 500″ and a very big change may occur in a few miles.

Monsoon rainfall :

With the exception of the extreme west and north-west, the rainfall is almost entirely brought by the monsoon winds, by the advancing SW. monsoon over practically the whole country, and to a less extent, notably in the south-east, by the retreating or NE. monsoon. The SW. monsoon prevails from June to September or October, *i.e.*, during what would without it be the hottest months of the year, and is accordingly of the greatest importance in moderating the heat and desiccation which would be experienced in its absence, and actually are experienced in the western parts of Sind and Baluchistan. The NE. monsoon succeeds the SW. in October-November and prolongs the rainy season in the south-east, and locally provides the chief rainfall of the year. In the north-west of the country, the monsoon is less effective, having travelled 1000 miles or more across the continent, and winter rain from the NW. becomes a decisive factor creating a quite different climate much more like that of Europe.[9a] This difference is illustrated by the rainfall figures given on p. 15 for Srinagar, Almora and Darjeeling, successively further east.

Regions of heavy rainfall :

With tropical temperatures and the summer monsoon prevailing throughout the country, the amount of the rainfall becomes the primary factor determining the luxuriance and type of the vegetation which can exist. The heaviest rainfall occurs where the moisture-laden SW. monsoon winds first strike high land, *viz.*, the west coast of the Peninsula, and the north-eastern part of the country in Bengal and Assam. Here the average annual rainfall commonly exceeds 100″ and ranges up to even 500″ at Cherrapunji in Assam. There are five tracts in which the average rainfall exceeds 100″. The west coast tract is a relatively narrow strip hardly anywhere 100 miles wide and is practically continuous from Bombay to Travancore, though the Palghat gap is noteworthy. The north-eastern tract is broken up by strips of rather lower rainfall (but still over 75″) into four blocks, *viz.*, (1) North Bengal, a rather small tract centring on Cooch Behar, (2) Upper Assam, above Dibrugarh, (3) the Khasi Hill tract in Assam, and (4) the Chittagong area in South Bengal. The Chittagong block is continuous with the Arakan coastal strip which is comparable with the Peninsular west coast, whilst the Upper Assam block is the northern end of the great unbroken rainy belt extending southwards to Malay.

These wet tracts carry the most luxuriant types of tropical forest, as will be described in Chapter IV, and as one moves outwards from them and traverses regions of less and less rainfall, with an increasingly long dry season, there is a steady falling off in the density and height of the forest till it finally merges into mere desert scrub no longer worthy of the name of forest.

Topography and rainfall :

Rainfall is often much higher in places where the local topography is favourable to its concentration, as where the big rivers of the Himalayas, including the Brahmaputra in Upper Assam, debouch on to the plains.

Hilly tracts in general experience a higher rainfall than the surrounding lowland country owing to the upward deflection and consequent expansion and cooling of the moisture-bearing winds; and a comparison of the rainfall and orographical maps of India shows this very clearly, the highest rainfall occurring where high land masses stand most exposed to the prevalent SW. wind. In the hills, aspect exerts a considerable influence on the climate and the rainfall experienced ; this subject is dealt with separately on p. 47. Greater atmospheric humidity and a reduced temperature-range likewise prevail in hilly country, giving it a climate differing in several respects from that of lowland tracts with the same mean temperature, so much so that many authors distinguish *montane climates* as a class by themselves. Somewhat similar differences due to the proximity of the sea are encountered generally over a strip of varying width along the coast, leading to the recognition of *coastal climates* which differ from *continental climates* in their more equable temperature and greater humidity, a good example being the east coast, *e.g.*, near Puri.

Evaporation :

The relation between rainfall and evaporation is of great importance through its influence on soil conditions. If rainfall exceeds evaporation, there will be a balance of downward movement of moisture in the soil, and conversely when evaporation exceeds rainfall, the balance of movement will be upwards. The consequences of this difference will be discussed in connexion with the soil later on (pp. 21-4.) Of course there may be seasonal fluctuations. As evaporation is related to temperature, the latter can be used as an indication of the former, temperature data being more generally available. Factors such as Lang's *Rain factor=Anual rainfall/ Mean annual temperature* have accordingly been proposed as expressions of humidity conditions. Such factors, however, are of limited value except over restricted tracts with fairly similar conditions.[6]

Seasonal distribution of rainfall :

The seasonal distribution of rainfall is a matter of the greatest importance to vegetation, not only as regards the time of the year in which most of the rain occurs, but the length of the period over which it is distributed. As already mentioned, except in the north-west, Indian climates are characterized by summer rainfall, but the period over which this is distributed varies very greatly, increasing from north-west to east and south-east.

Upper Assam on the average only experiences three months (November to January) with less than 2″ rainfall per month, whilst in the north-west the dry period lasts nine months or even longer. Of course, a heavier rainfall is often associated with a longer rainy season, but this is by no means invariably so.

The duration of the dry period exerts a very great influence on the nature of the vegetation which can exist, especially as in India the dry months may include a varying period when high summer temperatures and hot, desiccating winds prevail, and this influence is greater, the less the total rainfall. The type of forest developed depends in the first place on the joint effect of these two factors and secondarily on soil, topography and history, as will be seen later.

Winter rainfall :

When the rainy season falls mainly in the colder months, the summer being dry, as is the case in the north-west, growth conditions are changed enough to cause the development of a recognizably different vegetation type rather similar to that of the Mediterranean region in Europe. So also in the south-east, where the summer monsoon brings little or no rain and the vegetation is dependent on the retreating monsoon at the end of the year, a type of forest is encountered different from that found with the same mean temperature and total rainfall but with summer rain.

Rainfall intensity :

In addition to the quantity of rain and its seasonal distribution, rainfall intensity (*i.e.*, the rate at which the rain falls) is of vital importance to the forester particularly in his artificial regeneration and his anti-erosion works. In these works it is the maximum flow of water that has to be allowed for and not the total quantity of rain. It is not generally realized that a low rainfall of high intensity does far more damage than a high rainfall of low intensity. Rainfall intensity data are very sparse in India as yet but recent measurements in Dehra Dun have shown that even in this 'gentle' climate, rainfall intensities of 5 inches per hour and more are not uncommon.

Annual variation of rainfall :

It must also be borne in mind that the weather variations from year to year may be of decisive importance to the vegetation. In many dry localities, natural regeneration can only take place when a chance coincidence of weather conditions occurs such as to result first in the production of an adequate seed crop and then in favourable conditions for germination and establishment. Timely rain often of course determines success or failure in plantation work, whilst the occurrence of unusual droughts or frosts may have far-reaching effects on the nature of the vegetation. Not only do these climatic factors determine the natural distribution of forest types, but they also have an important bearing in limiting the season during which various important silvicultural operations can be carried out, particularly in the field of artificial regeneration; illustration will be given in a later section.

Dew :

The formation of dew requires mention as probably of considerable importance locally in maintaining humidity for the seedling stages of trees. The very heavy dew formation during the cold weather months in Upper India is a noticeable feature, very little rain falling at that time of the year, and it may possibly exert a greater influence than is realized ; detailed investigations are wanting. Mention must also be made of certain other secondary sources of moisture which are locally of more importance than has been realized till lately, *viz.*, condensation by the tree canopy from the air which can amount to at least 15″ in the year under favourable conditions[10,11] though these are perhaps not met with in India, and condensation in the soil where the gain may be 2-3 per cent.[12] In the dry parts of Madras it has been recorded that the dust-dry soil in mounds made for sowings became moist inside without rain.[13]

Seasons :

The changes in temperature, wind, and rainfall during the year lead to the differentiation of more or less well-marked seasons. A *rainy season* due to the SW. monsoon is experienced over almost the whole country in July and August, beginning a month or more earlier in many parts, and also lasting a month or more longer locally. In the south-east this is followed, with or without a short pause,by the NE. monsoon, some localities along the Carnatic coast getting little or no rain till it arrives. October and November are elsewhere very generally dry with falling temperatures, leading on to the *cold weather*, much more marked in the north than in the south. During the cold weather, winter rain and snow-fall in the north-west brought by the prevalent NW. wind, and light showers fall in many other parts of the country. The cold weather is at its height in January, and gradually passes on to the *hot weather* of April to May or June, which is very dry over the greater part of the country with only occasional thunderstorms, and is ended by the arrival of the SW. monsoon rain.

Microclimate :

More attention has been paid of recent years to what is termed microclimate, *i.e.*, the climatic conditions prevailing in any quite localized site, in contrast to the general climatic conditions existing over a tract of country, and in silvicultural practice this is liable to be an important matter, particularly in hilly country. In such work as natural regeneration, local failure is often due primarily to purely local unfavourable climatic conditions involving exposure to excessive insolation, hot dry wind, frost, or other limiting factor. Again *soil climate* may vary greatly within the limits of a single air climate, with the extreme example of the tropical rain forest soil and the soil of the same area after clearfelling.

Climatological data for selected stations :

In the following tables, temperature and rainfall data are given for a few stations to illustrate the chief climatic types met with in India[1,3]. The features of the selected stations are as follows:—

(1) *Lahore*, 31° N. The dry north-west with a long hot dry season : thorn forest.

(2) *Dibrugarh*, 27° N. Wet Upper Brahmaputra valley with high and well-distributed rainfall : tropical wet evergreen forest.

(3) *Raipur*, 21° N. Northern Peninsular India with medium rainfall but long dry season : sal forest.

RAINFALL IN INCHES

Station and Forest type	January	February	March	April	May	June	July	August	September	October	November	December	Year	Number of rainy days	Months with less than 2"	Mean annual humidity
Lahore (N. thorn forest)	0·9	1·0	0·8	0·5	0·7	1·5	5·1	4·7	2·3	0·3	0·1	0·4	18·3	33	9	50
Dibrugarh (Wet tropical evergreen)	1·5	2·6	5·0	9·9	13·1	18·9	21·2	18·7	18·8	5·5	0·9	0·6	116·7	138	3	?
Raipur (Moist sal forest)	0·4	0·7	0·7	0·7	1·0	9·5	14·3	13·3	7·4	2·0	8·4	0·2	50·7	64	7	?
Nilambur (Moist teak forest)	0·2	0·2	0·5	2·6	5·6	28·1	33·8	15·6	7·9	10·0	4·7	0·9	110·1	121	4	?
Mangalore (Wet tropical evergreen)	0·1	0·1	0·1	1·4	6·4	37·7	38·0	23·2	11·1	7·8	2·8	0·5	129·2	134	5	77
Madras (Dry tropical evergreen)	1·0	0·3	0·4	0·6	2·2	2·1	3·8	4·4	4·7	10·8	13·7	5·1	49·1	96	4	71
Bangalore (S. thorn forest)	0·2	0·1	0·6	1·3	5·0	3·2	4·0	5·9	6·3	6·4	1·9	0·7	35·6	96	6	66
Ootacamund (S. wet temperate evergreen)	0·9	0·6	1·1	3·2	6·2	6·8	7·7	5·2	7·6	8·1	5·0	1·8	54·2	96	4	71
Darjeeling (N. wet temperate evergreen)	0·6	1·1	1·8	3·9	8·7	24·9	32·3	26·1	18·4	4·5	0·8	0·2	123·2	150	5	82
Almora (Chir pine)	2·0	1·8	2·0	1·1	2·3	5·9	10·4	9·7	5·2	1·3	0·2	0·6	42·5	57	5	?
Srinagar (Deodar)	2·8	2·7	3·6	3·8	2·3	1·5	2·3	2·3	1·6	1·1	0·4	1·4	25·8	48	5	?

TEMPERATURES (Fahrenheit)

Station and Forest type		January	February	March	April	May	June	July	August	September	October	November	December	Year	Mean annual extremes
Lahore (N. thorn forest)	Mean	54	59	69	81	88	93	89	88	85	77	64	55	75	..
	Mean max.	68	71	83	95	102	107	99	98	97	93	81	71	..	117
	Mean min.	43	46	57	66	73	81	81	80	75	62	49	43	..	34
Dibrugarh (Wet tropical evergreen)	Mean	60	63	69	72	77	80	81	82	81	77	70	61	73	..
	Mean max.	71	72	78	80	84	87	87	87	87	85	79	73	..	..
	Mean min.	49	54	60	65	71	74	75	76	75	70	60	50	..	..
Raipur (Moist sal forest)	Mean	68	73	82	90	94	88	81	80	81	79	71	66	79	..
	Mean max.	82	87	96	103	107	98	87	86	88	88	83	79	..	..
	Mean min.	55	60	68	77	82	79	75	75	75	70	60	54	..	..
*Cochin (Moist teak forest)	Mean	79	80	83	84	82	78	77	79	78	79	79	79	80	..
	Mean max.	89	90	91	91	89	85	83	83	84	86	87	88	..	95
	Mean min.	71	73	76	78	77	74	74	74	74	74	74	72	..	67
Mangalore (Wet tropical evergreen)	Mean	76	78	81	83	83	78	77	77	77	78	78	77	79	..
	Mean max.	88	87	89	91	90	85	83	83	83	85	87	88	..	94
	Mean min.	69	71	76	79	79	75	74	74	74	74	73	71	..	63

Madras	Mean	76	77	81	85	87	88	86	85	84	81	78	76	82	..
(Dry tropical evergreen)	Mean max.	85	87	90	93	98	99	97	95	94	89	85	83	..	108
	Mean min.	68	68	72	77	81	81	79	77	77	75	72	70	..	60
Bangalore 3,000 ft.	Mean	67	72	77	80	79	74	72	72	72	72	70	67	73	..
(S. thorn forest)	Mean max.	79	85	90	93	92	85	83	83	82	82	79	78	..	98
	Mean min.	56	59	64	69	69	67	66	66	65	65	62	59	..	51
Ootacamund 7,250 ft.	Mean	54	55	58	61	61	58	57	57	57	57	55	54	55	..
(S. wet temperate evergreen)	Mean max.	65	67	69	71	70	64	62	63	64	64	63	64	..	77
	Mean min.	43	44	48	52	53	52	52	52	51	51	48	44	..	25
Darjeeling 7,400 ft.	Mean	40	39	47	53	54	56	61	61	59	54	48	43	51	..
(N. wet temperate evergreen)	Mean max.	45	45	56	62	62	65	67	66	65	61	56	50	..	72
	Mean min.	36	33	43	47	49	55	57	56	55	49	43	38	..	25
†*Ranikhet* 6,070 ft.	Mean	46	48	57	65	68	71	68	67	66	61	55	49	60	..
(Chirpine)	Mean max.	55	55	65	73	76	78	74	73	73	69	62	57	..	86
	Mean min.	42	40	49	56	59	64	63	62	61	54	47	43	..	30
Srinagar 5,000 ft.	Mean	34	36	46	56	64	70	74	74	66	55	46	38	55	..
(Deodar)	Mean max.	41	44	56	67	76	82	85	85	79	70	61	48	..	..
	Mean min.	27	28	37	45	52	58	64	63	54	41	32	28	..	..

* Temperature data are not available for Nilambur. Cochin is hardly affected by the NE. monsoon and is on the coast.

† Ranikhet observatory is at the upper cool limit of chir pine forest.

(4) *Nilambur*, 11° N. Southern Peninsular India with medium rainfall and marked dry season: mixed deciduous forest with teak.

(5) *Mangalore*, 13° N. West coast with heavy rainfall fairly well distributed : tropical wet evergreen forest.

(6) *Madras*, 13° N. East coast with medium rainfall partly from the NE. monsoon : dry evergreen and thorn.

(7) *Bangalore*, 13° N. South Indian plateau at 3,000 ft. with low rainfall and long dry season : thorn forest.

(8) *Ootacamund*, 11° N. South India highlands (7,250 ft.) with good rainfall from both monsoons : temperate evergreen forest.

(9) *Darjeeling*, 27° N. East Himalayas at 7,400 ft. with heavy well-distributed rainfall : temperate evergreen forest.

(10) *Almora*, 30° N. Central Himalayas at 5,500 ft. with medium rainfall : pine forest.

(11) *Srinagar*, 34° N. Western Himalayas at 5,000 ft. with winter rain and snow but little SW. monsoon rain : coniferous forest with deodar at its optimum.

Influence of climate on vegetation

Illustrations have already been given of the close relation between the climate and the vegetation it supports, the distribution of the luxuriant tropical evergreen forest providing a good example in its association with abundant and well distributed rainfall and temperatures always well above freezing. At the opposite extreme, open thorn scrub is found wherever the rainfall is very low and temperatures are high. In the hills, the distribution of the conifers, notably deodar in the north-west, in relation to the amount of winter snowfall and the strength of the SW. monsoon, provides an equally instructive illustration. [8,9]

THE SOIL

The soil in relation to forestry

It has been well said that the first duty of the forester is to maintain and improve the productive capacity of the soil. To execute this duty, he needs as complete a knowledge of soil properties and behaviour as he can get.[1-5] Unfortunately, knowledge is still very inadequate in this field, particularly for tropical soils, and above all for tropical forest soils.[6,7]

The soil has been defined as ' the uppermost weathered layer of the solid crust of the earth ; it consists of rocks that have been reduced to small fragments and have been more or less changed chemically, together with the remains of plants and animals that live on it and in it. '[4]

Parent Rocks

Types of rock

Although the soil derived from a given type of rock varies considerably with climatic conditions, the nature of the parent rock exerts a considerable influence on the properties of the soil, and the forester needs to be acquainted with the more important types of rock and their characteristics. It will ordinarily suffice to recognize the following petrological types :—

(1) *Granites and gneisses,* complex crystalline rocks of very varying composition and appearance, typically containing felspar, mica and quartz. The gneisses have a more or less banded appearance lacking in the granites. These rocks include the oldest on the earth and also more recent intrusions.

(2) *Schists,* foliated crystalline rocks differing from the gneisses in the lack of felspar. Mica is often conspicuous, but composition and appearance vary widely.

(3) *Trap rocks.*—Crystalline, usually fine textured and dark coloured, rocks originating from volcanic action. They are often rich in bases in contrast with the granites typically rich in acid silica.

(4) *Quartzites.*—Hard bedded rocks usually breaking into angular fragments, originating from sandstones by heat and pressure and so consisting almost entirely of silica.

(5) *Sandstones.*—Compacted sand with granular structure still evident.

(6) *Shales.*—Fine textured fissile rocks derived from clay and mud sediments by heat and pressure.

(7) *Limestones.*—Rocks consisting very largely of calcium carbonate compacted to a varying degree by pressure and heat, from soft crumbling forms, to hard more or less banded formations and, finally, marble.

(8) *Recent alluvial deposits.*—Sands and clays with varying amounts of stony material.

Distribution of rock types

Crystalline rocks strongly predominate throughout the lower half of the Peninsula extending north-eastwards into Orissa, and they also form the central mass of the Himalayan range. The Deccan trap covers the whole north-eastern part of the Peninsula. Quartzites and sandstones are characteristic of the northern limits of the Peninsula (*e.g.* the Vindhya hills) and the outer ranges of the Himalayas, limestones occurring locally in the same tracts. Alluvial deposits form the vast Indo-Gangetic plain across the north of the country including the Brahmaputra valley, and an appreciable strip along the east coast. The depth of this Gangetic alluvium is very great and provides an interesting geological problem. Wind-drifted sand and fine sandy loam (loess) generally occur locally but a large area of drift sand is to be found in the Thar desert of Sind and Rajputana.

Weathering Processes

The soil itself is derived from these rocks as a result of the processes known as weathering, accompanied or followed by a sorting process by which some of the products of weathering are removed by chemical, physical or mechanical agencies, sometimes only to be redeposited in a different layer. Superimposed on these processes is the action of organic life, which will be considered separately. Ultimately, all soil is derived from the crystalline rocks, the other classes of rock themselves originating from them by these same processes of weathering, sorting, transportation, and more or less subsequent alteration by geological forces (primarily compression) rendering them more compact.

Physical weathering

The breaking up of crystalline rocks by weathering is due to a number of agencies acting simultaneously but in very varying degree dependent on local conditions. Physical weathering results in the shattering of the rock into fragments presenting an increased surface for the other forces to attack. Frost is a most effective agency, though except at high elevations it is of limited occurrence in this country ; its action depends on the expansion of water on conversion to ice in the crevices of the rock. Heat is an important agent of physical weathering in the tropics. Temperature changes resulting in unequal expansion and contraction are a very effective factor in weathering in dry climates, especially with the big daily range of temperature typical of most parts of India. The excavation of valleys by water or ice action, and the sculpturing of rocks by wind action are further examples of physical weathering.

Chemical weathering

Chemical weathering goes much further than physical weathering in that it involves fundamental irreversible changes in the rock constituents. It is also even more important to vegetation, as in the course of these changes certain inorganic substances are freed which are soluble in the soil water, and so may become available as plant food. The general trend of chemical weathering is the breaking down of complex compounds, mainly through the agency of water containing dissolved carbonic acid and other acidic substances derived from organic matter in the soil. The weakly acid solution contains hydrogen ions which displace the alkali (*e.g.* sodium and potassium) and alkaline earth (calcium) in the silicate minerals. The chief end-products are silica, clay, and inorganic salts and hydrated oxides. Oxidation may also take place, notably of ferrous iron compounds. A typical example of the process of chemical weathering is provided by the felspars, which form over half the earth's crust and are broken down in this way into aluminium silicate (kaolin clay), silica, and potassium, sodium or calcium salts. The latter are ordinarily removed in moist climates by being washed out of the soil or absorbed by plants, whilst the silica and clay may remain *in situ* or be themselves removed mechanically by water action. Most crystalline rocks include a good deal of quartz which is practically unaffected by chemical weathering. It is also possible for new substances such as hydrated iron oxides to be precipitated in the soil either at the seat of weathering or elsewhere after transport by percolating water.

Translocation of products of weathering

The insoluble products of physical and chemical weathering may accumulate where they are formed especially under a full cover of vegetation, but more usually they are subject to the mechanical action of moving water which transports and to a considerable extent sorts them out. The carrying power of water is proportional to the fourth power of its velocity, and as the speed of a stream slackens, it drops first the gravel, then the sand, and finally the clay as these classes of material are composed of successively smaller particles. Clay particles, being very small, remain a long time in suspension, and even in nearly stagnant water may not settle unless they are caused to join up to larger units, as happens when they reach salt water in an estuary.

Soil Profiles

Origin of profiles

If a section of soil is examined from the surface to the underlying rock, it will very generally be found to have a more or less stratified structure, which is traceable to rough equilibria in the processes of translocation of the constituent materials which are continuously going on in it, both mechanically and in solution.[8,9] Diagram I shows some typical forest soil profiles.

Lateritic profile

Under moist tropical conditions, chemical decomposition is rapid, and water movements being predominantly downwards, the bases (potash, soda and lime) are split off from the minerals and are dissolved out, leaving an acid residue which tends to break down further into silica and the oxides of iron and aluminium ; most of the silica is removed in solution in the presence of the alkaline bases, particularly in the absence of acid humus, and the residuum, consisting mainly of oxides of iron and aluminium, is the *laterite* so familiar in the southern parts of the country.[10, 11, 75] In extreme cases of this process of laterization, the percentage of silica may drop from 50 in the original rock to 4 in the laterite. In laterites, the molecular silica/alumina ratio of the clay fraction is generally under 1·33, but as long as it is under 2 the soil may be termed lateritic.[11]

A typical lateritic profile shows the following layers :

(1) Thin dark organic layer (often indistinguishable).

(2) Horizon with iron concretions (*murram*).

(3) Laterite proper, mottled red, yellow and purple and often vescicular.

(4) A pale coloured soapy clay.

(5) Partly decomposed zone, often mottled in colour.

(6) Parent rock.

Although the laterite can be cut with a spade when freshly exposed, it may harden on exposure to a material hard enough for use for building. The characteristic vegetation on such lateritic soils, except where they have been hardened by exposure, is tropical evergreen forest.

Red soils

With rather less rainfall, the typical soil is what is known from its colour as a *red soil*.[12, 13, 14] The process of laterization has taken place to some extent, but not so far as with laterite soils, and the results of another very important process known as *podsolization* become to a certain extent more evident. This consists in the leaching out from the surface layers of the soluble salts, including the less soluble lime and magnesium carbonates, by an acid soil solution. The surface layers remain acid because insufficient bases are returned through leaf fall, etc., to keep the humus neutral.

The proportion of silica remains high in this acid type of weathering. The iron dissolved, and a large proportion of the organic and inorganic colloids, are redeposited in the lower layers. In the tropical evergreen forest, when the rate of humus decomposition is not too fast, a thin podsolized layer is found, but usually the amount of bases returned in the leaf fall, etc., is enough to prevent or effectively mask this process of podsolization. Tropical red soils mostly carry deciduous or semi-deciduous forest and are often incorrectly described as lateritic, *e.g.* those usually found on basaltic rocks in which the bases are largely retained in a soluble form available to vegetation and in which the silica content is high.[19]

Temperate soil profiles

In cooler climates, where there is plenty of acid humus which dissolves out oxides of iron and aluminium, the process of podsolization predominates, and better developed soil profiles are formed [13] in which the layers from which material is being leached—these are known as the *A horizons*—are often well differentiated in colour, texture and acidity from the underlying *B horizons* in which the materials are being redeposited. The *A horizons* have typically lost the finest soil particles and so tend to be of light sandy texture, whilst the *B horizons* in which this fine material is redeposited are heavier ; this difference cannot develop on heavy soils. These *A* and *B horizons* form the true soil in the narrower sense, and overlie in turn the *C horizons* or *subsoil* of weathered, usually stony parent material, and *D*, the bed-rock. Each of these horizons may show texture differentiation in layers of different colour and composition, which are numbered A_1 A_2 A_3 etc., from the top downwards, the partially decomposed organic debris on top being known as the A_0 *horizon.*

A temperate soil of this kind from a Punjab deodar forest[9] may thus show the following structure :—

A_0 0-6 cm.—a dark humus layer of leaf mould (peat).

A_1 6-16 cm.—a black compact layer rich in organic matter.

A_2 16-42 cm.—a light sandy coloured layer with much less organic matter.

B_1 42-50 cm.—a brown layer again rich in humus in which the materials, including iron hydroxide, leached from *A* are redeposited.

B_2 50-73 cm.—a lighter compact layer with less organic matter and much more clay.

C .. stony subsoil.

D .. underlying parent rock.

What are termed *brown forest soils* are found in the same areas under conifers and broad-leaved forest[9] ; these are characterized by a rather brown A_2 horizon in place of the pale or gray colour of this horizon in the podsol, and correspond to a less acid type of weathering leaving the iron and alumina more or less evenly distributed in the A and B horizons ; the A_0 horizon is very thin, or absent, owing to its more rapid decomposition.

Soils of hot, dry climates

Under dry hot conditions such as prevail in the north-west and west of India, and locally elsewhere, where the rainfall is insufficient to wash the bases down into the deeper layers, there is a tendency for them to accumulate, in fact the excess of evaporation over precipitation may even result in an upward movement, and *alkali soils* with alkali carbonates, or *saline soils* with neutral salts, become characteristic. (These soils are technically known as *solonetz* and *solonchak* soils respectively.)

Immature profiles, etc.

A long period of time is required for the full development of this profile structure, the soil being termed immature meanwhile, and where erosion processes are effective as on steep hill slopes, it may not take place. Another type of soil in which no profile is discernible is black cotton soil, which will be described later. It must also be noted that the upper layers may be removed after formation by erosion, as has very often happened under cultivation, whilst erosion and redeposition is a common phenomenon further complicating the issue—thus lateritic soil is often redeposited, with admixture of other materials altering its characteristics to a varying degree.

Transitions from one type of soil to another are also very commonly encountered, and it is not to be expected that any given sample will agree exactly with the central form of one of the standard types.

Pan formation and concretions

In some soils, hard layers or local round or irregularly shaped concretions are encountered, which are evidently not directly derived from the underlying parent rock but have been formed in the soil itself. These are known as *pans* and are due to the local concentration of certain soil constituents which are deposited from true or colloidal solution, usually in the B horizons as seen above. In temperate climates, the pan is usually of hydrated ferric oxide, an iron pan ; topographical conditions in Indian temperate climates

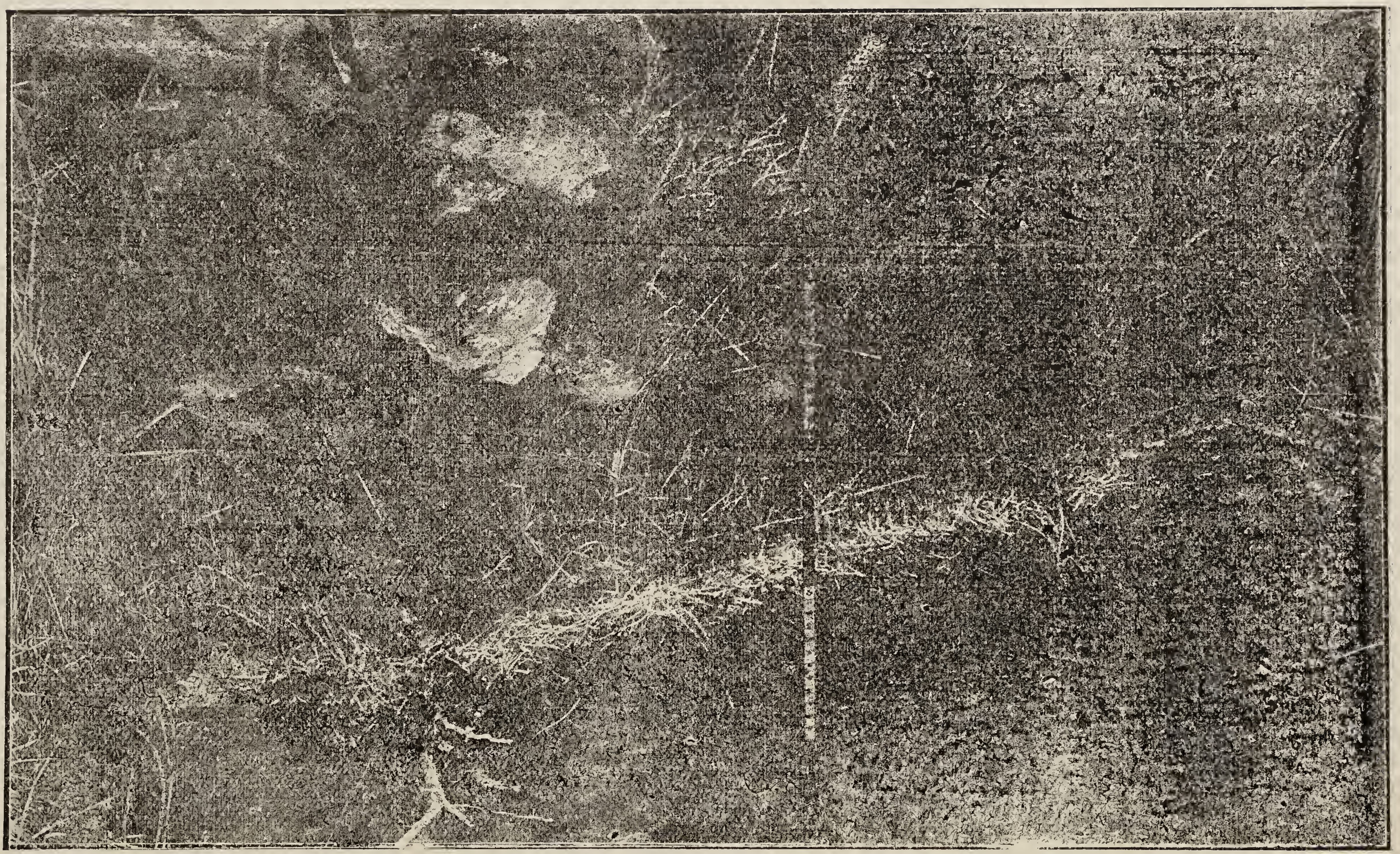

PLATE 2. Root systems in a young teak plantation invaded by *imperata* showing the dense mat formed just below the surface by the rhizomes and roots of the grass. New Forest, Dehra Dun.

Facing p. 25.

do not usually favour the formation of iron pans, but a similar pan may be formed in the moist tropics in sandy soils and it has been recorded that patches of *Imperata* grass promote its formation.[6] They are occasionally found under coniferous plantations in the south Indian hills.

Limestone or kankar pans are characteristic of dry climates where the soil is subject to alternate wetting and drying. They are frequently met with in the drier parts of the Indo-Gangetic plain, the alluvium there containing a good deal of lime, which in the older deposits has become concentrated in bands by processes of solution and reprecipitation. They are commonly found under south Indian black cotton soils.

In seasonally moist tropical climates, laterite may form a rather different type of pan. The exact processes involved in its formation are still rather uncertain.

Physical Structure of Soil

The physical structure of the soil is of importance in many ways, though it can only be very briefly described here. The particles of which the soil consists range in size from stones and gravel down to submicroscopic clay particles, and the relative proportions of these several constituents have a great influence on the suitability of the soil for tree growth. Most of these particles consist of rock fragments or their decomposition products, but coarser material may be of secondary origin as in hard laterites and *murram*.

Size of soil particles

The internationally standardized nomenclature[2] for soil particles by size is as follows:—

Coarse sand from	2·0-0·2 mm. diameter.
Fine sand .	0·2-0·02 mm. ,,
Silt . .	0·02-0·002 mm. ,,
Clay . .	Less than 0·002 mm. diameter.

The percentage figures for these constituents should refer to the residuum dried at 100-105°C. after removal of calcium carbonate and organic matter. This mechanical analysis is not a difficult matter, the coarse fractions being usually separated by sieving and the finer by use of the centrifuge or by differential settling from suspension in water[15]—thus the whole of the silt fraction will settle out of the top 10 cm. in 8 hours at 20°C., and a sample of the suspension at this depth has been shown to be acceptable as an average for the clay content of the whole column.

The clay fraction

The clay fraction differs from the coarser material in being mostly derived not directly from the parent rock, but by secondary processes involving chemical weathering and it is also different in being colloidal in character. It is not necessary here to discuss in any detail the physics of colloids though they contribute some of the most striking and important properties of soil. The chief is their property of retaining water, not merely as surface films as with the non-colloidal sand and silt, but by imbibition. Loss of water content from colloidal clay is accompanied by a marked shrinkage in volume accounting for the cracking of heavy soils, and it is also the colloidal clay which holds together the clods of worked soil, and absorbs inorganic substances from solution. The fertility, of a soil depends a good deal on the maintenance of a '*crumb*' structure even when moist ; this property also depends on the colloidal structure and varies with the bases present, calcium being most desirable in this respect.[12]

Descriptive terms for soils

Rough but useful descriptive terms are in common use to distinguish different types of soils. These are based on the proportions of sand, silt and clay present, and all types are approximately recognizable by appearance and feel. An international standard has not yet been agreed upon but the following is a useful classification which has been proposed [16] :—

Soil Class	Percentage limits of mechanical composition		
	Sand	Silt	Clay
1. Sands	80—100	0—20	0—20
2. Sandy loams	50—80	0—50	0—20
3. Silt loams	0—50	50—100	0—20
4. Loams	30—50	30—50	20—30
5. Silty clay loam	0—30	50—80	20—30
6. Sandy clay loams	50—80	0—30	20—30
7. Clay loams	20—50	20—50	20—30
8. Silty clays	0—20	50—70	30—50
9. Sandy clays	50—70	0—20	30—50
10. Clays	0—50	0—50	30—100

Clay soils thus do not contain less than about 30 per cent clay and a sandy soil less than 50 per cent sand, loams falling between. It must however be realized that these terms are more useful for description than actual classification.

Surface area of soil particles

The more finely a soil is divided, the greater the aggregate surface of its ultimate particles, and various properties are related to this surface. In work which has been done on forest soils in Burma,[13, 17] a numerical expression of relative surface is used termed *soil texture index*. Dominant teak in Burma requires a texture index of not less than 3 (say 60 per cent gravel and sand and 2½ per cent of clay) and does not occur if the figure exceeds 20 in the upper soil unless there is at least 1 per cent of lime present, lime pushing the upper limit much higher. The influence of texture is also strikingly seen in Pilibhit division, United Provinces, where the *chandars*, in which copious sal regeneration is unable to grow up, are found to have only a thin loam layer overlying a considerable depth of coarse dry sand which effectively isolates the root system from the deeper water supplies. Conversely in Prussia, on dry sandy soil it was found that regeneration, artificial or natural, of pine could only be obtained where a loam soil occurs only a few feet below the surface.[18]

Soil Types

So many factors contribute to the properties of the soil that a logical classification is doubtfully possible. Climate is clearly as important a factor in soil formation as parent rock, and though the fundamental processes are the same, their relative rates vary with conditions, and there is a recognizable tendency for the mature soil under a given climate to be similar for a wide variety of rocks. Perhaps the most satisfactory classification available at present[19] is :—

(A) *Immature soils*, in which the parent rock is the dominant influence. Calcium carbonate is invariably present.

- (1) *Alluvial soils* of the Indo-Gangetic plain.
- (2) *Skeletal soils*—the result of physical weathering.

(*B*) *Mature soils*, in which the parent material is exerting a minimum influence.

- (3) *Laterites and tropical red and yellow earths* of the Peninsula and north-east.

(4) *Black earths*, especially associated with trap rock.

(5) *Grey forest soils* (podsols) in the hills.

(6) *Peat soils*—relatively uncommon in India.

(7) *Saline and alkaline soils*, found in patches in the Indo-Gangetic plain.

A few notes and references may be useful for these seven main types :—

(1) *Indo-Gangetic alluvial soils.*—Limestone concretions (*kankar*) are characteristic of the older and higher alluvium which is often redder in colour than the more recent, usually greyer and *kankar*-free lower alluvium. A varying depth of humus-containing loam has been built up by the action of the vegetative cover, the nature of which latter is often indicative of the stage reached.

(2) *Skeletal soils* are met with in the drier tracts such as the low hills of North India (Aravallis) and the inner dry ranges of the Himalayas (Upper Bashahr, Punjab). They are relatively unimportant.

(3*a*) *Laterites* are stiff red soils with a low silica/alumina ratio, and are associated with crystalline rocks in the moister and hotter parts of the country.

(3*b*) *Tropical red and yellow earths* predominate over a large part of the country.[10, 12, 13]

(4) *Black earths*, exemplified by *regur* or black cotton soil, predominate on the Deccan trap. The mode of their formation is still not fully understood and the black colour is mainly due to the presence of several per cent of titaniferous magnetite, not to humus substances which are only present in small amount.[20]

(5) *Grey forest soils* are met with throughout the temperate hill tracts and are very similar to those found in Europe.[9]

(6) *Peat soils* have hardly been studied in India and are relatively rare though conspicuous where occurring, as in the Nilgiris.

(7) *Saline and alkaline soils* have been a good deal studied in connection with canal irrigation schemes in the Indus and Ganges valleys.[21, 76]

Soil maps

Most countries are at present engaged on a soil mapping programme in the realization that, valuable as are geological maps, they cannot serve as substitutes for a true soil map. In a recent attempt to prepare such a soil map [22] for India, it was found that the available data were too scanty for the purpose.

Much work remains to be done before soil maps will be available which could be utilized in such silvicultural problems as site selection for various species in plantation work, a matter to which far more attention is now realized to be necessary than has been given to it in the past.

Soil description

In describing a forest soil,[13, 23, 23a] its place in the above classification and an account of the typical profile will give a fair picture and indicate most of the chief characteristics. Notes on texture and moisture conditions are also required, and the *p*H values (cf. p. 33), which can be determined in the field, should be added for special studies ; all further detail should be left to the trained pedologist.

The description of a forest soil and its site in a standard form is a matter of great importance and as a result of recent experimental work and experience a technique suitable for Indian conditions has been evolved.[77]

Soil indicators

Unquestionably one of the best keys to the nature and fertility of the soil is the vegetation it carries ; and even where the plant cover has been considerably altered by human activities directly or indirectly, it should still be of service in that direction.[24] The attempt has accordingly often been made to deduce the suitability of a soil to the growth or regeneration of different tree species from the predominant ground cover, whether under existing forest growth or on denuded land. Within the range of single dominating tree species, similarly, it has been attempted to correlate the varying growth with differences in the associated subsidiary vegetation. In North Europe this idea has been developed into a general theory for forest practice, the (Cajander's) *theory of forest types*,[25] which claims to go some way towards solving the difficulty of assessing site quality irrespective of tree species, but attempts made to extend it to cover other countries[26] and a wider range of conditions have not been very successful, nor have the attempts to apply it in India to deodar and sal forests succeeded.

Existing vegetation does however sometimes provide useful indications as to what tree crops an area is capable of carrying, as was shown long ago for sal by Hole.[27] Thus in the western sub-Himalayan tract the dominant grass on land suitable for sal is usually *Saccharum narenga*, soils too stiff and badly drained carrying predominantly *Imperata arundinacea*, whilst wet low soils definitely unsuitable are characterized by *Saccharum procerum*. Wild violet indicates a soil suitable for the regeneration of deodar and *Pinus excelsa*, while a soil covering of balsam and *Strobilanthes* shows that the humus layer is excessive and natural regeneration is almost impossible. When steps have been taken to reduce this humus, the latter plants will disappear and the violet will come in. Similarly a growth of the grass *Sporobolus arabicus* after heavy rain is very typical of patches of highly saline soil in the Indus basin and serves to indicate their position and extent. For some of the important forest types of Burma useful information on these lines is available.[28]

Water Relations in Soil

The moisture content of the soil

The amount of moisture in the soil varies so greatly with day and season that except in the vicinity of permanent water, it is not possible to give an average figure of any value. In the moister parts of the country, soil moisture is adequate for growth throughout the year, but during the inter-monsoon dry period, the soil over the greater part dries out to an extent which largely determines the nature of the vegetation. The moisture in the soil is partly closely associated with the colloidal complex as *water of imbibition* and partly as rings of water round the points of contact of the soil particles, or as a continuous system interpenetrated by a network of air spaces and passages if the moisture content is higher. The forces of surface tension only come into play with this latter *capillary water*. A soil with a high proportion of colloids, such as a stiff laterite, retains more moisture than a light sandy soil of low colloidal content, but this extra amount is not available to plants. A convenient measure of water capacity is obtained by determining the moisture content of a soil-water paste which can be just worked in the hand without being adhesive ; this is called the *sticky point*. It has been shown that a soil containing no colloidal matter would have a sticky point of about 16 per cent. Any higher water content of an actual soil sample may be looked on as the amount held by the soil colloids, and in combination with other factors is a useful measure of soil fertility.

Water movements in soil

It has already been seen that the upward and downward movements of water in the soil are largely responsible for the development of the soil profile and the concentration of certain materials in certain horizons. Moisture in excess of water of imbibition and capillary water sinks down as *gravitation water*.

Water table

At a certain depth, generally following the contour of the land in the absence of impervious layers, the soil is completely saturated with water. This depth is known as the *water table.* It varies with the year and the season and its fluctuations have long been studied in many parts of the country. Of recent years additional data have been collected in connexion with the spread of irrigation by canals and tube wells as in the Gangetic plain. It is of interest to know to what extent moisture can rise in the soil under purely mechanical forces to make up for evaporation losses. It was formerly thought that a considerable rise was possible by capillary action, but even in heavy loams, the lift does not exceed two or three feet,[2] so that in almost all places, the moisture found in the soil must be ascribed to the percolating rainfall or other superficial water supplies such as that gradually working down a hillside. Lateral movement is also much slower than it was thought to be till quite recently ; this matter is attracting increased attention with the rising importance of tube well irrigation.

In swampy areas the water table is at or near the surface, but under certain conditions it can be at very great depths as for example in parts of the Thar desert of Sind and Rajputana where it is sometimes as deep as 800 to 1000 feet below the surface of the land.[78]

Evaporation

Much attention has been paid to the losses of moisture by evaporation,[5] particularly the relative losses with different types of soil cover. The following figures from one European authority are given as an example indicating the importance of this source of loss, though there is a good deal of discrepancy between the data of different workers, and Indian figures are likely to be very different except perhaps in the hills.

Percentage of the total rainfalls

	Beech forest	Crops	Bare land
Intercepted	15	..	..
Evaporated	7	17	30
Transpired	25	37	..
Run-off and seepage	53	46	70

In general, evaporation in the temperate forest appears to be only one-third to one-half that in the open, whilst transpiration may be either more (beech) or less (pine) than for average agricultural crops.

It may be noted also that the tree canopy intercepts a good deal of the rainfall before it reaches the soil (though some of this runs down the trunks). Thus in contrast with the 15 per cent the above table, in a 100-year-old beech forest, 25 per cent of the fall was found to be intercepted, and in a dense fir crop, even 80 per cent. Indian data are again lacking.

Conservation of moisture in dry climates

In dry climates, the loss of moisture can be considerably reduced by suitable cultural methods. A deep cultivation will allow such rain as falls to penetrate readily, and it has long been known that frequent surface [5] cultivation will appreciably reduce moisture losses by breaking the continuity of the evaporating surface with the deeper moisture-containing layers. Recently, experimental evidence has been produced against the general validity of this view, through the importance of removal of competing weeds, etc., is further demonstrated.[30] The curve in Diagram II shows the variation in soil moisture at different depths in the Forest Research Institute plantations.

A mat of grass roots occupying the surface layers of the soil is liable to prevent moisture from penetrating to the deeper layers, *Imperata* providing a striking example. (Plate 2.)

In dry climates or during dry seasons, competition for the limited available moisture supplies between the individual plants rooted in the soil may become severe and may determine the death or survival of the weaker individuals. The root competition of the older growth already on or immediately adjoining the area may also greatly influence the establishment of natural regeneration and the development of plantations.[31, 32, 33] Cf. pp. 100, 287.

Effect of forest cover on soil moisture

In N. Temperate forests an amount of water corresponding to a rainfall of 2″ to 11″ is consumed by the trees (cf. transpiration, p. 111), which is probably rather more than the amount transpired by average agricultural crops. This is drawn from the deeper layers of the soil which accordingly may become drier in a rainless period than a treeless area despite the greater surface evaporation from the latter. Clear-felling may result in an increase in soil moisture till coppice and weed growth renew the drain. This does not of course diminish the great value of the forest cover in conserving and regulating run-off.

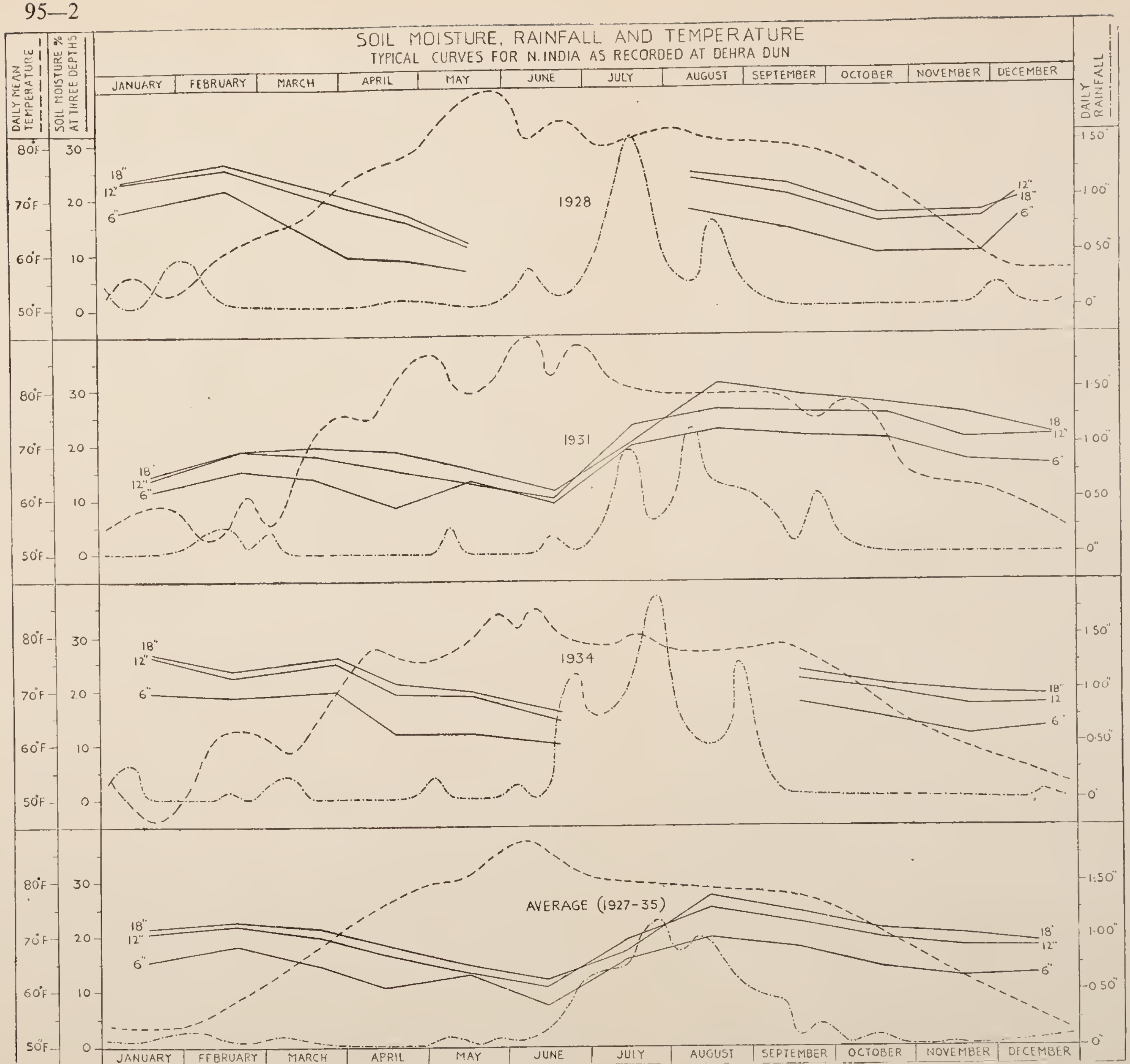

Diagram II. Soil Moisture, Rainfall and Temperature Curves (Dehra Dun)

Facing p. 32.

Investigations made in the Changa Manga irrigated *sissu* plantations for 2 years showed that the average moisture of a column of soil to a depth of 2½ ft. was practically the same under the *sissu* as for bare land, a soil cover of *kana* grass under the trees keeping the soil somewhat moister, and a cover of grass without trees maintaining the highest moisture content. Only in July was the bare land rather drier than the soil under tree growth only. This implies that the trees transpire more moisture than they preserve by reducing the amount of evaporation from the soil surface, and that the grass actually conserves soil moisture. These deductions may however be questioned owing to difficulties of the experimental work.

Soil cover crops such as *Tephrosia* do not make any significant difference to the moisture content of the soil according to Dehra Dun [34] and Malayan data, but much may depend on the amount and distribution of the rainfall in the area in question.

Excessive moisture acts as if it were a poison to crops when it excludes air from the roots,[35] and this is borne out by many forest instances where a raising of the water level has resulted in the death of the trees, root rot being the apparent immediate cause.[36] Apparently leguminous crops are particularly sensitive to inadequate aeration. The marked difference between moving and stagnant water in their effects on tree growth must likewise be related to the difference in aeration, stagnant water being often very deficient in dissolved oxygen whilst flowing water may be well aerated.

The soil solution

Great as is the direct importance of the water content of the soil to the vegetation it supports, its function as a solvent of essential inorganic food substances is hardly less. The solutions are of course extremely dilute with only 0·05 to 0·2 per cent dissolved salts,[1] so much so that the latter are almost completely dissociated into their component ions, and adsorption by the soil colloids comes freely into play, conditions being quite different from those prevailing in the solution extracted from the soil.

Soil acidity (*p*H) *and lime requirement*

The most easily determined and perhaps the most important feature of the soil solution is its acidity. The usual measure of soil acidity is the negative logarithm of its hydrogen ion concentration, this value being known as *p*H. In pure water, the *p*H should be 7 and it may fall to 5 or less for acid soils, and rise to 8·5 or more for alkaline soils. The simplest methods of measuring are the electrolytic methods determining the conductivity of an aqueous extract of the soil using standard quantities of dry soil and water, and the colorimetric methods depending on the comparison of the colour assumed by such a solution with the addition of standard indicators, in comparison with the colour obtained by solutions of known *p*H. Another commonly used method of estimating soil acidity is by determining the *lime requirement*, which is done by titrating a solution of calcium bicarbonate against a standard acid before and after shaking it up with the soil sample, the difference giving the amount of lime as calcium carbonate absorbed.

Typical *p*H values for forest soils are :—

Red laterite [37]	4·5
Black alluvium [37]	4·7
Spruce soil without regeneration [9]	4·7
Red clay [37]	5·0
Deodar soil, B_1 horizon [9]	5·8
Chir pine soil, B_1 horizon [9]	6·3
Deodar soil, A_1 horizon [9]	6·9 (Neutral)
Black cotton soil [38]	8·7-9·0
Alkali soil	9·6-10·4

The podsols referred to above are dependent for their origin on a humid climate, an acid soil, and a vegetation-forming acid humus. As a rule, *p*H value is lower (more acid) under a coniferous crop than under a broadleaved crop growing on similar sites, but higher under mixed conifers and broadleaved trees than under either type of pure crop. In one European instance the introduction of oak in a pine crop was found to raise the *p*H from 3·6 to 4·7 and oak is not so effective as many other broadleaved species.[36] Certain trees such as *Tamarix dioica* demand alkaline conditions for their germination and growth.

A practical illustration of the value of a knowledge of *p*H values is provided by the discovery that in the irrigated areas of the Punjab, soils with *p*H exceeding 8·5 cannot satisfactorily be planted up with *Dalbergia sissoo*. Up to 9·0, several of the indigenous trees can grow, but above 9·5 the soil is barren.

Mineral salts and base exchange

The colloidal parts of both the clay and the organic matter behave somewhat like acid radicals, and there is an intercharge on their surface of positive ions such as those of hydrogen and of the inorganic bases potassium, sodium and calcium, the equilibrium position depending on the relative concentrations. The most prevalent base is calcium, which except in alkaline soils is normally present to the extent of 2 or 3 times as much as the potassium, sodium and magnesium together; calcium carbonate (lime) is freely soluble in the soil solution which contains carbon dioxide. If the lime is leached out most of the other exchangeable bases are also lost and the soil becomes acid, particularly if rain water which contains a great deal of dissolved carbon dioxide is the leaching agent. Conversely, in the presence of an excess of ordinary salt, sodium clay is formed. This makes the soil alkaline, and, incidentally, very impermeable owing to its 'deflocculation' and breaking up of the crumb structure, thus making it sticky.

Inorganic food substances

A number of elements have been shown to be necessary to normal plant growth if only in minute amounts, the chief besides carbon, oxygen and hydrogen, being nitrogen (see p. 41), potassium, phosphorus, iron and sulphur. The percentage composition of the dry weight of green leaves and timber gives some indications of requirements, and some European data [40] follow :—

	% ash	Percentage in the ash									
		K_2O Potash	Na_2O Soda	CaO Lime	MgO Magnesia	Fe_2O_3 Iron	Mn_3O_4 Manganese	P_2O_5 Phosphorus	SO_3 Sulphur	SiO_2 Silica	Cl Chlorine
Oak timber .	0·48	38·4	2·4	22·4	16·5	0·6	2·7	17·0	2·8	0·7	0·3
Pine timber .	0·30	14·3	1·0	53·6	10·7	0·1	3·3	6·1	3·5	2·6	..
Beech leaves (green).	3·6	20·5	0·9	35·3	8·7	1·1	..	8·0	3·0	21·7	..

The amount of inorganic materials taken up annually by a tree crop is exemplified by the following figures calculated for an acre of teak forest,[41] the phosphorus figure being usually high: nitrogen 4 lb., phosphorus $1\frac{1}{2}$ lb., calcium and magnesium 14 lb., potassium 6 lb. Very little is known about the phosphorus economy of soils and trees but this element also is closely associated with the humus. In a general way, the mineral requirements of tree crops are much lower than those of agricultural crops, thus cereal crops are stated to require annually per acre about 17 lb. potassium, and 32 lb. nitrogen. Provided the litter is not removed a good deal of the necessary mineral requirement remains in circulation through the leaf fall, only that in the timber being temporarily withheld or ultimately removed. It is apparently unusual for these requirements not to be met by forest soils.[5]

Soil porosity

If the soil particles were uniform spheres with closest possible packing, the pore space would be about one quarter the total volume, but ordinarily it is much greater, from one-third to one-half the total volume the rest of the space being occupied by gases and water. The pore space is increased by the presence of organic matter, but the high figure is largely due to the aggregation of finer particles into larger units, giving the crumb structure already referred to. To maintain the soil in a healthy condition, it is important to prevent it from getting compacted as this results in reduced porosity and impeded circulation of air and water. A surface covering of leaf litter, etc., prevents the compacting of the surface soil under heavy rain and so maintains the natural porosity,[42] though indirectly it may raise the CO_2 content higher than is desirable, as shown by Hole's experiments on sal seedlings.[43]

Both an over dense canopy or excessively heavy thinning affect the porosity of the soil in such a way that the water-absorptive power is reduced.[44] The afforestation of grassy blanks (old fields) very greatly improves the porosity of the soil (and simultaneously, its water-retaining power), though the effect is very slow in extending downwards, particularly with a pure coniferous crop which is far less effective than broad-leaved trees.[45] The lighter forest soil conditions may be restored in about 25 years after reforestation, but the soil in heavily grazed woods loses its porosity and closely resembles that in open fields.[46]

This loss of porosity due to heavy grazing may become locally important. It is quite common in the forests of South India to find the trees on the sites of old elephant camps stag headed and dying (particularly in teak plantations) due to the continued heavy trampling. Without intensive soil working such sites are often very difficult to regenerate.

Soil Gases and Soil Aeration

Soil gases

The gases in the pores of the soil differ from the air chiefly in the much higher proportion of carbonic acid, especially in soils rich in organic matter ; the oxygen/nitrogen ratio may or may not be altered. Circulation is primarily a matter of diffusion and is active enough to ensure the complete renewal once an hour of all the air in the uppermost 10″ of soil.[42] The soil gases, except in dry soils, are more or less saturated with water, being in contact with the water films round the soil particles. A series of analyses of soil gases from depths of 13″-18″ in areas under *taungya* plantations at the Forest Research Institute showed :—

Date	Depth	Percentage of gas by volume of soil *in situ*	% CO_2 in soil gas	% O_2 in soil gas
January 18	3″—9″	35·9	0	20·4
	9″—18″	32·3	0	20·2
March 1	3″—9″	28·3	0	19·8
	9″—18″	30·8	0·3	19·7
May 23	3″—9″	35·1	0·3	20·4
	9″—18″	32·2	0·8	19·8
August 17	3″—9″	26·7	3·6	14·9
	9″—18″	34·4	4·6	13·9
November 22	3″—9″	31·5	0·1	20·7
	9″—18″	32·3	0·8	20·0

The carbonic acid is largely the product of the respiration of soil organisms and roots : it is soluble in water, and its toxic effects on sal seedlings was demonstrated many years ago by Hole.[47]

Soil aeration

Soil working not only facilitates root penetration and favourable moisture movements, but, by increasing the decomposition of organic matter, tends to increase the rate of carbon dioxide production. The maintenance of a suitable tilth round the young plants is often the chief condition for success in plantation work particularly in dry soils, both aeration and moisture factors being involved. Soil aeration is particularly liable to become unsatisfactory during a period of heavy rainfall, and a soil working is then very beneficial to both natural regeneration (sal) and plantations (teak). The check in height growth of most trees at this period is well known,[48] as is also the regeneration of roots near the surface in many trees when the aeration of the deeper layers becomes defective owing to the displacement of the soil gases by water during the wet monsoon period.[49] For the sal, this soil loosening is an essential to success in some localities whilst the average height attained by young teak plants six months later may even be doubled by the operation. Soil working also contributes largely to the success of second rotation teak plantations.[50]

With very young plants particularly in the dry districts, great care must be taken in soil working that the roots of the plants are not injured, otherwise more harm than good may result. A practical rule has been evolved that soil working should not be done nearer than 3 inches to the plants. [79]

Effect of burning on soil aeration

The soil gases in burnt sal forests in Dehra Dun were found to contain much more CO_2 than those in the unburnt parts, suggesting greater biological activity in the former. The unburnt soils showed no measurable CO_2 at 3″-9″ as compared with 1 per cent in the burnt. [51]

Cover crops and aeration

Some cover crops such as *Cajanus* and *Tephrosia* improve soil aeration by developing an extensive but relatively short-lived root system which, on the death of the plant, is opened out by decay and termites. On the other hand, a mat of grass roots such as that formed by *Imperata* (Plate 2) is liable to check aeration. [52]

Organic Matter

Humus

All soils contain more or less organic matter, mostly in the form of colloidal substances the presence of which, as has already been seen, is of the greatest significance to fertility. The amount tends to be low in tropical soils, and may increase up to 100 per cent in peats. The loss of weight of dry soil on ignition is a very rough method of determining the amount, but more refined methods are necessary for detailed study. The term *humus* is commonly used for referring to all soil organic matter, though it is better restricted to that portion which has lost its structure. Classifications of humus forms have been put forward, using the terms *raw humus, mor* or *duff* for the layer not mixed with the mineral soil, in which the nature of vegetative material is still evident, and *mull* for the more finely comminuted material mixed with the mineral soil.[53] In tropical rain forest, it has been estimated [6] that the yearly production of fresh organic matter is of the order of 100 tons per acre, but its decomposition proceeds so rapidly that there is next to no forest litter and usually less than 1″ depth of visibly darker humic surface soil. In the typical tropical deciduous forest with an annual organic production of perhaps 20 tons per acre, *e.g.*, sal forest it is likewise often difficult to demonstrate the presence of a humus layer. One reason for this is that tropical organic soil matter is mostly only faintly coloured, and actually the usual red soils may be richer in organic matter—and that to a greater depth—than corresponding darker temperate soils. The latter are estimated to receive annually about 2½ tons dry weight of dead leaves per acre.

In dry thorn forests the humus content of the soil is extremely low, particularly as most of the vegetable debris is swept away by wind. Black cotton soil, however, forms a marked exception to this generalization, though its dark colour is not due to its humus content. Such black soils are heavy and crack deeply during the dry season surface dust and organic matter filter in and are incorporated when the soil is again moistened and swells up.

Decomposition of litter

The plant residues reaching the soil consist largely of lignified tissues devoid of starches, sugars and fats ; they are mainly cellulose and lignin, and contain about 48 per cent of carbon, and 10-30 per cent ash, as well as a small amount of nitrogen which will be considered separately. A great variety of soil organisms mostly small or microscopic are chiefly responsible for the decomposition of these residues ; among them the bacteria are probably the most universally important. The protozoa also fill a significant role, both directly in the decomposition of cellulose (in the intestines of various wood-eating insects, notably termites) and indirectly by influencing the number of bacteria on which many species feed. Reduction of the protozoan population of the soil by heat (forest fires) or disinfectants may result at least temporarily in increased plant growth and provides one reason for the better growth of seedlings reported to take place on burnt seedbeds.[80] Fungi appear to be at least equally important with bacteria in tropical soils.

Soil fauna

Worms and termites exert a considerable influence especially in distributing organic matter through the soil ; termites play a large part in tropical forests,[7] and the activities of worms may be very apparent locally, as in the *khorkani* soils of Assam where the whole surface is closely set with large heaps of castings.

Soil bacteria

Aerobic bacteria work in the presence of oxygen whilst *anaerobic* bacteria are found with deficient oxygen. The aerobic organisms oxidize the organic matter to carbon dioxide and water, the process being facilitated by the presence of adequate lime. With lime deficiency and acid soils, the decomposition may be either by aerobic or by anaerobic organisms. The presence of alkali in the soil is associated with a very small bacterial flora, [21] high acidity having a similar result. [54]

The rate of this transformation of forest litter into humus depends on conditions and the kind of material, and comparative studies show rates for thin broadleaved litter nearly twice those for pine needles. The rate at which the litter is lost with a mean annual temperature of 77°F. (=25°C.) equals the rate at which the vegetative cover can form it, and so no accumulation is possible.[7] The activity of the process can be measured by the rate of CO_2 evolution, which varies from 2 to 50 grams per sq. metre per diem under temperate conditions; in the tropics it rises till it is up to ten times as great as the summer maximum in temperate climates.

Humus decomposition in temperate climates

The relatively slow rate of humus decomposition in temperate climates results in the soils being mostly of a dark-brown colour for a considerable depth, gradual accumulation taking place: with unfavourable drainage conditions and poor aeration, considerable depths of nearly pure humus (peat) may develop. Mixture of species favours the breaking down of the more resistant leaves and needles.

Humus decomposition in tropical climates

There is again far greater biological activity and turnover of organic material in tropical soils. The decomposition products here are strongly acidic (*p*H under 5·5) and so tend to oppose lateritic weathering unless the parent rock is rich in bases which can neutralize them. In the tropics, the living vegetation is the more directly active soil-forming agent, in contrast with conditions in temperate climates where it is the dead detritus from the vegetation and its humification which affect soil development.[19] Peat can only accumulate in swampy ground.

Burning and humus

The effect of forest fires is one requiring closer study, but it is self-evident that the destruction of the organic matter which should maintain or increase the humus content of the soil must cause deterioration. Not only are the organic carbon compounds of the dry leaves and wood lost, but the nitrogen in them is almost entirely lost as free nitrogen, and the only apparent gain is a supply of immediately available potash. Under certain conditions, however, it has been shown that the above ground portions of the soil cover are in any case lost to the soil, so that any gain in organic matter must depend on the decay of roots.[55]

Fires of course have other effects of significance such as direct physical effects from the heat generated, and an often pronounced influence on the relative proportions of the different types of soil organisms and hence on the results of their activities ; moreover the removal of the undecomposed litter may facilitate regeneration by permitting to seedlings access to the mineral soil necessary to their development. At the same time it is known that heat produces in all soils a soluble organic substance inhibitory to germination, which should react on weed growth.[56]

The general effects of burning on a forest soil have recently been considered in some detail.[80] Precise data are however in general lacking.

Maintenance of humus

The influence of the humus content of the soil acting on it physical, chemical and biological composition is so far-reaching that its maintenance must be a guiding principle in silvicultural practice, and for many soil types the percentage of organic matter provides a fair indication of fertility.

Soil Nitrogen

Plant residues contain about ½ to 3½ per cent nitrogen with 45 to 50 per cent carbon, the relation between the amounts of these two elements being referred to as the C/N ratio ; rotting timber with only 0·2 per cent nitrogen in its dry weight has an exceptionally high C/N ratio, even up to 200 or more. The proteins in the soil are insoluble and seem to be combined with lignin, forming insoluble complexes resistant to decomposition by micro-organisms. The carbon goes more quickly than the nitrogen, and the C/N ratio gradually falls to about 10 for the organic matter in average temperate soils—it is about 20 for artificial manure, and only 3 in proteins corresponding to their 16 per cent nitrogen content. When the proportion of nitrogen has reached this normal figure, water-soluble nitrates or ammonia appear in the soil, rarely exceeding 1 per cent of the total soil nitrogen, and these substances can be absorbed by the roots. Whatever treatment in the way of cropping or manuring be applied, the C/N ratio in the soil always tends towards this equilibrium position which falls somewhat with rising temperature. If the forest cover is cleared in the tropics, there is a marked rise in soil temperature causing a rapid fall in the organic content, relatively greater in the nitrogen than the carbon.[7]

Nitrifying bacteria

The production of ammonium salts from the decaying organic matter is due to a number of organisms, but their oxidation first to nitrites and then to nitrates is due to specific aerobic bacteria. *Nitrosomonas* and *Nitrobacter* respectively, and as the latter processes take place more rapidly than the former, usually only traces of ammonium salts occur in the soil. Where the forest cover has been removed, these processes also occur photochemically under the influence of ultra-violet rays, energy being provided by the oxidation of organic matter; sterilized soil mixed with sugar solutions and exposed to sunlight shows after a time an increased nitrogen content.[57] Some accumulation of ammonia occurs in the more acid soils,[58] and nitrification proceeds most rapidly in a neutral or slightly acid medium; it is very slow indeed in pronouncedly alkaline soils, largely accounting for their infertility.[21]

Denitrifying bacteria

Denitrifying bacteria are also found in the soil, which under certain conditions break up nitrates with the liberation of free nitrogen. Humic matter is rapidly decomposed by photochemical action with the same end result when tropical forest soils are exposed by clear-felling.

Nitric acid in rain

An appreciable amount of combined nitrogen is contributed to the soil as nitric acid in rain (formed from the air by electrical discharges) ranging from about 5 to 50 lb. per acre annually depending on local climate, but this is sufficient under the favouarble conditions of tropical rain forest to account for existing supplies and for forest requirements, which are of the order of 50 lb. per acre.[7, 40, 60]

Bacterial nitrogen fixation

Besides this direct addition of nitric acid, there are both aerobic and anaerobic bacteria in the soil which can fix atmospheric nitrogen, viz., *Azotobacter* and *Clostridium* respectively. *Azotobacter* is intolerant of acid conditions (below pH 6·0) but *Clostridium* is hardier; both are more resistant to ultra-violet light than most bacteria and so may be important in exposed soils. Their activity is greater when suitable organic compounds are freely available, and so is stimulated by the addition of such substances as molasses to the soil.[57]

Variations of nitrate content with season

Seasonal changes in nitrogen content have been studied in the Gangetic alluvium,[59] and show that there is rapid nitrate accumulation immediately after the first monsoon rain, followed by a marked fall (as the soil gets overwet) to approximately the original figure, and a second accumulation at the end of the rains in October, apparently continuing to a maximum in March-April when the soil gets too dry and hot.

Silviculture and nitrogen cycle

It is self-evident that good silviculture calls for a knowledge of the reactions on the nitrogen cycle in the soil of any manipulation of the soil cover and surface soil. European examples of this are available ; for example, success in natural regeneration in pine and spruce is closely bound up with the nitrification of the humus, slowness in this process being the main obstacle to regeneration ; increased light accelerates it, and a burn likewise.[61]

The influence of tree species on the nitrification of the humus is marked, the figures for a broadleaved shade-bearer such as the European beech being over ten times as great as for pine, an admixture of beech with the latter having a very pronounced favourable effect.[62] The same thing has been observed with broadleaved trees in the higher Himalayas, where an admixture of broadleaved trees with spruce and silver fir results in entirely different humus conditions, far more favourable to natural regeneration than those found under pure fir forest.

Mycorrhiza

The roots of many forest trees including conifers are associated with apparently symbiotic fungi (mostly *Hymenomycetes* of such genera as *Boletus*, *Amanita* and *Lactarius*) known as *mycorrhiza*,[40] which it has been claimed render available to them the more complex forms of combined nitrogen which they cannot absorb directly (cf. p. 120). In fact it has been shown in some cases that nursery and afforestation work may fail in the absence of the appropriate fungi from this cause alone (pines in several parts of the world). Owing to this indirect method of obtaining nitrogen, addition of inorganic nitrogen compounds would probably affect trees and field crops differently.[62]

Bacterial nodules

It has long been known that most leguminous plants actually increase the nitrogen content of the soils in which they grow through the agency of bacteria (*Rhizobium*) living symbiotically in nodules on their roots, these bacteria being able to fix nitrogen from the air when in association with the higher plant—and not otherwise.[63] It appears that they actually excrete organic nitrogen compounds into the soil as well as contributing nitrogenous matter on their ultimate decay.[64] There are many different strains of *Rhizobium*, some associated with a wide range of hosts and others with very few. Acid soils are unfavourable to their development,[65] and it has been found that they are relatively few and unimportant in wet tropical forest where nitrogen equilibrium prevails, the slight loss by leaching being made up by that added by the rainfall. It is of interest to note that leguminous trees and weeds are relatively uncommon in the moister Indian tropical forests. There are other small groups of trees with similar relationships, notably the alders and *Casuarina* growing on sites poor in nitrogen, and also a few such as *Pavetta* in which similar bacteria live in the leaves. Rice roots contain nitrogen-fixing bacteria which function even when isolated in culture, and there is evidently much more to be discovered in this field.

It is important to note that the requisite bacteria are not necessarily present in the soil and cases have occurred in India with both *Casuarina* and *Leucaena* in which the bacteria have had to be imported to the new sites in order to produce normal growth of the species.

MANURING

Use of manures

It has been mentioned that forest soils generally contain the essential food material for adequate growth so that the addition of inorganic manures would not be expected to lead to much response. The addition of lime is on a somewhat different footing in that an effect would be looked for, not from its meeting requirements for mineral food, but from its effect on the soil conditions. By neutralizing soil acids, both humus and clay, it replaces sticky alkali clays by calcium clay with superior crumb structure, whilst calcium humate is less resistant to bacterial decomposition and so more favourable to plant growth.[66] Lime addition, however, if overdone, may cause more harm than good by causing the leaching out of other necessary food materials, or by an undesirable reduction in acidity.[67] A liming experiment in Nilambur teak (Expt. 109) gave no result though done on an alluvial soil deficient in lime. Many European foresters consider that liming is advantageous and justifiable, but except for a few spectacular results with spruce (acid humus) very little response has been shown in the numerous experiments which have been recorded, though it is true that most have been made with *Pinus sylvestris* which is exceptionally unresponsive in any case.[62] Occasionally good results have been obtained with phosphatic manures, notably on peat soils, but interplanting with leguminous plants such as lupins seems more effective than any directly applied manure.

Improving saline soils

Gypsum and sulphur have been successfully used in agricultural and horticultural practice in breaking up sodium clay formed in the presence of excessive alkali,[68] but recently molasses have been found to be far more effective, especially if lime is also added, and this substance offers the additional advantage of raising the nitrogen content.[57]

Manuring nurseries

Only in the case of permanent nurseries does the question of manuring usually arise, and here organic manures such as farmyard manure or a good leaf compost are the most suitable materials to use, simultaneously providing the necessary foodstuffs and improving the texture of the soil. The preparation of compost of 'artificial farmyard manure' from green vegetable waste is a practical proposition and should find a place at all permanent nurseries.[69] Use of the proprietary ADCO in a proportion of 1 : 40 by weight is the simplest method, applying it in layers in square flat-topped heaps which must be kept thoroughly wetted. (Cost about Rs. 7-8 per cwt. It contains 3·2 per cent nitrogen and 6·0 per cent phosphoric acid.) Where leaf mould is not available in the forest for direct carriage to the nursery, as is very often the case, a large pit should be dug and filled up with leaves whenever they are available in quantity, avoiding thick hard leaves such as sal ; in N. India, mango, *tun*, etc., are quite good. When artificial manures are applied, normal quantities are 60-120 lb. per acre for ammonium sulphate and sodium nitrate, potassium nitrate or potassium sulphate, and 200-400 lb. for phosphates and bone meal.

Green manuring

In the sense of digging a green crop, usually leguminous, into the soil, this is likewise only a practical proposition in the nursery, where such species as *Crotolaria juncea* will be found very useful.

(Lupins are used in European practice.) They should be dug in shortly before flowering. The use of green soil cover crops left to decay *in situ* will be discussed later, as also the villagers' practice of lopping the forest for green manure for rice cultivation. The relative value of non-leguminous green manures seems to vary, but hemp has given as satisfactory result as *Cortolaria*, and the chief factor may be the improvement of the physical texture of the soil rather than nitrogen addition;[70,71] similarly for *Oxalis* used in tea gardens[72] and *Cassia tora* which is without nodules. In Britain and Europe, useful results have been obtained by sowing a leguminous cover (such as lupins, furze or broom) with or before the tree plants.[73]

Influence of soil on vegetation

Whereas climate determines the broad outlines of the distribution of the main types of vegetation, soil variations usually determine the detail. With more or less uniform climate, one variety of a main type will give place to another with a change of soil: thus in the moist mixed deciduous forest, the change from the subtype with dominant sal to subtype with prevalent teak appears to be determined by a change of soil. The change of subtype and species with varying moisture content of the soil is similarly apparent along every watercourse. This subject is considered in detail in Chapter IV.

Topography

Influence of topography on soil

The configuration of the land surface influences the vegetation in three chief ways, *viz.*, through drainage, aspect and altitude. Drainage is closely bound up with soil aeration, and fine textured soils which easily become wet and badly aerated on flat or nearly flat ground may, if situated on a hillside, be well enough drained to carry vegetation much more exacting in this respect, as in the example of *Pinus longifolia* mentioned on p. 148. On the other hand, light sandy soils on slopes may drain out too rapidly and completely to carry the vegetation they could support on level ground. The mechanical shift of the finer soil particles down a hillside is a well-known phenomenon, and their redeposition as the gradient eases off near the foot as 'wash' soils often results in the finest forest development on such sites, often only a shallow sandy soil being left on the slopes. A cap of deeper soil often remains on the tops, but it may differ markedly from the valley soil and is generally much inferior. The reverse of this does occasionally occur as for example in the Bori valley of the C.P. where the best teak occurs on the low hill tops and the poor forest at the bottom. This is however due to the local geological structure. The percolation of moisture down a slope may often have a marked effect in favour of the lower slopes to an extent depending on the permeability of the strata present and the presence of porous water-holding rocks. The minor variations in topography affect growth partly in this way, but more as next to be described for aspect and altitude.

Topography and rainfall

Sometimes the topography is such as to concentrate the rainfall (debouchment of the big Himalayan rivers on to the plains) or mist (Ghum ridge at Darjeeling), but these differences may be viewed as climatic, as likewise the abrupt falling off of rainfall east of the W. Ghats.

Aspect

Aspect and vegetation

Aspect really affects the climate of a site to an extent dependent on its relation to the sun's course and to the prevalent winds. In India all southerly aspects are exposed to an insolation corresponding to a more southerly latitude than the actual, and this to a greater extent as one goes northwards, from very little in South Madras to a really effective extent in the Himalayas. Similarly northerly aspects are cooler than corresponds to the latitude.

Aspect and insolation

Easterly and westerly aspects, though receiving an equal amount of insolation, differ in their temperature conditions in several important respects. In the east, the angle of incidence is greatest in the morning before the air temperature has fully warmed up and perhaps while the dew is still on the vegetation or has only recently gone ; and tissues frozen during the night may be rapidly thawed out with destructive effects. In the west, the sun strikes hardest after the air has heated up and any dew dried off : hot winds too may have been generated, intensifying the descicating effect ; but frost damage is at a minimum. SE. and SW. aspects will fall between these extremes, the SSW. being the hottest and driest of all.

Aspect and temperature

Northern aspects in the Himalayas are so much cooler than the southern that there is nearly 1,000 ft. difference in the altitudinal range of species and types, and completely different types of forest may prevail on the two sides of an E. to W. ridge. Some tender species seem to avoid southerly aspects completely (*Abies pindrow* in Kumaon, United Provinces). It is a general characteristic of the Western Himalayas that southern slopes are bare of forest while northern slopes are covered with forest. Hence looking north from Simla the hills appear to have no forest, whereas looking south from the inner ranges the whole country appears covered with forest. The temperature effects are of course combined with the moisture differences they condition, and in South India the differences are, as expected, not so marked and tend to be more marked by the influence of wind direction.

Aspect and rainfall

In most of India, it is the moisture-bearing SW. monsoon winds which most influence the vegetation. The effect is naturally more marked on the windward and leeward sides of large hill masses than on the corresponding subaspects of the smaller ridges and spurs. In the higher hills of S. India, however, the NE. monsoon is also influential, *e.g.*, in the Nilgiris there are marked differences in rainfall and moisture at places only a few miles apart, primarily depending on the relative degree of exposure to the two monsoons.

It must be remembered that the influence of aspect on forest practice in India is fundamentally different from what it is in Europe.

Altitude

Altitude and temperature

It has been mentioned (p. 7) that with ascending altitude there is normally a regular fall of temperature, which has been considered as meaning a definite change in climate. Ascending altitude is generally associated with increased rainfall, but this of course assumes equal exposure to the rain-bearing winds—the inner Himalayan ranges become successively drier as more and more moisture is drained from the monsoon currents. The influence of altitude on forest type is brought out in the classification given on pp. 145 ff.

PLATE 3. Air photographs showing the effect of aspect. (*Above*) A northern aspect on the left bank of the Indus. (*Below*) A southern aspect on the right bank of the Indus. Both photographs, Hazara tribal territory, N. W. F. P.

Facing p. 48

Biological Factors

The importance of the activities of the living organisms in the soil has been discussed above, and it remains to consider the direct and indirect influence of the larger animals, particularly man and his domestic animals[47].

Fire

The chief such factor, is fire which though doubtless sometimes a natural happening, is in practice intimately and mainly connected with human activities. Its effects on the soil have been mentioned on pp. 40 and 43.

Litter removal

The removal of litter where intensive, acts in a similar way to fire by depriving the soil of its normal additions of organic matter and so must be detrimental. An example of this adverse effect on the quality class of the forest may be observed in some of the forest bordering intensive rice cultivation on the left bank of the Kulu valley. The removal of grass, green fodder and loppings, and to a less extent of timber and fuel, will again produce the same results.

Grazing

Forest grazing influences the soil in a variety of ways ; the direct removal of carbon and proteins is probably of no special importance, but the physical effects of the trampling of the soil may be very far reaching both on the soil and the vegetation it can carry. By breaking the vegetative cover, it is very liable to cause increased erosion by water and wind, and it is unquestionably responsible for the terrible erosion in the Siwaliks, the Chambal ravines and other similar places.

SITE MAINTENANCE

Operations for maintenance of site quality

General.—In the foregoing sections, individual site factors have been examined and their effect on various operations has been considered. It is necessary now to summarize the available information from the opposite point of view of methods to be adopted for what has already been spoken of as the first duty of the forester, *viz.* the maintenance of the productive capacity of the site. The operations requiring consideration are those directly affecting the soil, such as soil working, drainage and litter removal, and those affecting it through the vegetation, such as different systems of management, choice of species, and the use of soil cover crops or manures. Details will be given in later chapters.

Soil working

When a soil has been compacted or hardened from any cause, it sometimes presents mechanical resistance to penetration by seedling roots, but the chief defect is reduced aeration which reacts on the soil by increasing its acidity and reducing humification and nitrification. Moisture conditions may be rendered unfavourable both by checking penetration (thus increasing run-off and erosion elsewhere) and facilitating drying-out by evaporation. Soil working in hardened or heavy soils accordingly improves growth conditions, and may be very beneficial to regeneration. Particularly in plantations the soil is liable to become packed and badly aerated during the rains, and a soil working towards the end may prolong the growing season appreciably. Where there is a significant mat of leaves or needles on the soil surface, soil working permits access of seedling roots to the mineral soil, reduces acidity, and may improve the soil as a whole by mixing mineral and humus layers. Soil working as a moisture-conserving measure underlies all dry farming and is equally important in forestry on dry sites.

Litter removal

The effect of litter removal varies with conditions. Where vegetable detritus accumulates faster than it can be incorporated with the soil and so becomes deep and acid, its removal is beneficial or even essential to regeneration, as in the fir forests of the higher Himalayas. A thinner layer may likewise be harmful in preventing germinating seed from rooting, either mechanically or through generated acidity. Where such accumulation does not occur, litter removal if persisted in works most harmfully in reducing the humus content of the soil and, with it, the chief source of fertility.

Drainage

Bad soil drainage means waterlogging and bad aeration with the results already mentioned, and most trees are sensitive to it

Ridging and mounding

In poorly drained soils, much better plantation results are often obtained if the sowings are done or the seedlings planted on ridges or mounds raised somewhat above the general level. This ensures better aeration during the wet season though it involves risks of surface erosion and root exposure which must be countered. In dry climates mounds have been reported to remain moist when the surrounding soil has dried out, owing to condensation of atmospheric moisture in the soil.

Contour trenching (*Catch drains*)

In dry hilly country where water conservation is of great importance, as in the hilly and ravined tracts in the Indo-Gangetic plain and the N.W.F.P. contour trenching helps to catch a maximum proportion of the rainfall and benefits the plants raised on the thrown-up earth. The trenches also serve as silt traps and reduce soil erosion, this being an accepted method in plantation of other economic crops.

Burning

In a general way, burning the soil cover destroys most of the raw material which maintains the essential humus content of the soil, and a continued burning regime must be very injurious to its fertility. Burning may however give a temporary impetus to growth by causing an increase in bacterial activity and hence in available nitrogen. It may also, through its physical effect on the soil and by removing a mechanically obstructive and possibly harmfully acidic surface layer, temporarily improve conditions for natural or artificial regeneration, or even be an essential condition for it.[80]

Grazing

Grazing is effective chiefly through the trampling of the soil rendering it harder and less aerated, but it is also accompanied by some degree of incorporation of the vegetable detritus with the mineral soil and indirect effects on the composition of the ground vegetation. The nitrogenous manuring of the soil by the droppings appears unimportant except where concentrated on standings and near drinking places, and there favours herbaceous weed growth rather than tree growth.

Species

It is generally accepted, and borne out by all appearances, that shade-bearers protect and improve the soil more effectively than light-demanders, though no precise data are available from tropical forests. Pure crops of light-demanders such as teak are accordingly to be deprecated unless soil protection is cared for by a suitable underwood. There are also indications that humus conditions are usually more satisfactory with a mixed crop than a pure one.

Silvicultural system

(*a*) *Clear-felling* results in a complete if only temporary change of soil climate, insolation temperature and moisture, the conditions being suddenly and fundamentally altered. If the clearing is followed by a burn, the change is even greater.

The immediate effects of clearing may appear beneficial through a rapid mobilization of the humus and nitrogen under the exposed conditions, and the burn supplies soluble mineral salts, and may increase nitrification by reducing the protozoan population of the soil ; but even apart from the inevitable surface erosion on sloping ground, if the cover is not soon reformed, a loss of fertility follows and may be very great. Hence where conditions render clear-felling necessary as the only satisfactory method of regeneration, it is important to restore a vegetative cover to the soil as quickly as possible, and to restore the original forest conditions, with protection from excessive insolation and with a renewed supply of raw materials for humus formation. There is no evidence that one season's partial exposure need result in any permanent harm.

(*b*) *Selection fellings* provide the ideal conditions for soil conservation, except occasionally, where there is too marked a tendency to acid humus formation, and even here the group selection system will usually meet the position.

(*c*) *Shelterwood systems* are generally satisfactory from the point of view of soil management, and offer the additional advantage of permitting the temporary modification of surface conditions to those suitable for regeneration of the forest without undue or sudden exposure. Clear-felled strips may also effect this if suitable in width and orientation.

Manuring has been shown above to be rarely either necessary or a practical proposition in forestry, except in nurseries. The demands of trees on the inorganic foods in the soil are relatively very low, and the trees themselves are the great contributors of humus.

Plantation technique also influences the soil, chiefly in that different methods vary in the degree of exposure and so in the extent of deterioration of the soil during the period of establishment. Methods resulting in much direct erosion of the finer constituents are obviously undesirable and this includes open cultivation for more than the minimum possible time. The drain on the food material of a forest soil by one season's field cultivation is rarely important. A grass cover provides an effective check on surface erosion, but also checks tree growth, often seriously. In dry climates, moisture conservation becomes a vital factor, and dry farming methods involving deep cultivation to encourage deep rooting and maximum absorption of rainfall, the maintenance of the humus content of the soil, and an effective dust mulch by frequent surface cultivation, all become desirable.

Cover crops in plantations provide an effective means of minimizing the period of exposure of the soil to insolation and desiccation, and are also valuable both in checking surface soil erosion and in restoring humus and nitrogenous material.

The introduction of a soil-protecting or improving understorey in plantations or regular high forest of light-demanding species is similarly a desirable measure. The usual cover crops are short lived and need to be succeeded by a more permanent underwood, which may be allowed or encouraged to develop either from mixed natural regrowth, both seedlings, rhizomes or coppice, or intentionally introduced in the form of an admixture from the start, or by undersowing or underplanting. Available evidence shows that nearly all such admixture takes something from the growth of the main crop, but there is every reason to believe that it must be beneficial in the long run.

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II

GROWTH AND FORM OF TREES AND CROPS

TREE MORPHOLOGY

THE CROWN

Crown form

Typical crown shapes. The closest co-ordination and balance exists between the crown, bole and root systems of a tree, each influencing the form, health and growth of the others. The shape and size of the crown, *i.e.* the branch system with the foliage it bears, vary greatly with species and growth conditions (*see* Diagram III). Palms, tree-ferns and cycads have a single bunch of large leaves at the top of an undivided stem, and their shape is the same whether growing isolated or among other vegetation. Dicotyledonous trees and conifers develop a branch system carrying the foliage, and though specific characters are still evident, the crown form is much influenced by environment. Isolated trees generally carry branches over most of the length of the stem, and the individual branches are much larger than on the same trees growing in the forest. The typical outline is an elongated cone becoming broader and more rounded with increasing size or age, the final shape ranging from almost cylindrical (*Abies*), through more or less oblong (perhaps most trees) and spherical forms, to broad flat-topped or umbrella shapes (*Acacia planifrons*). Diagram III shows the range of forms.

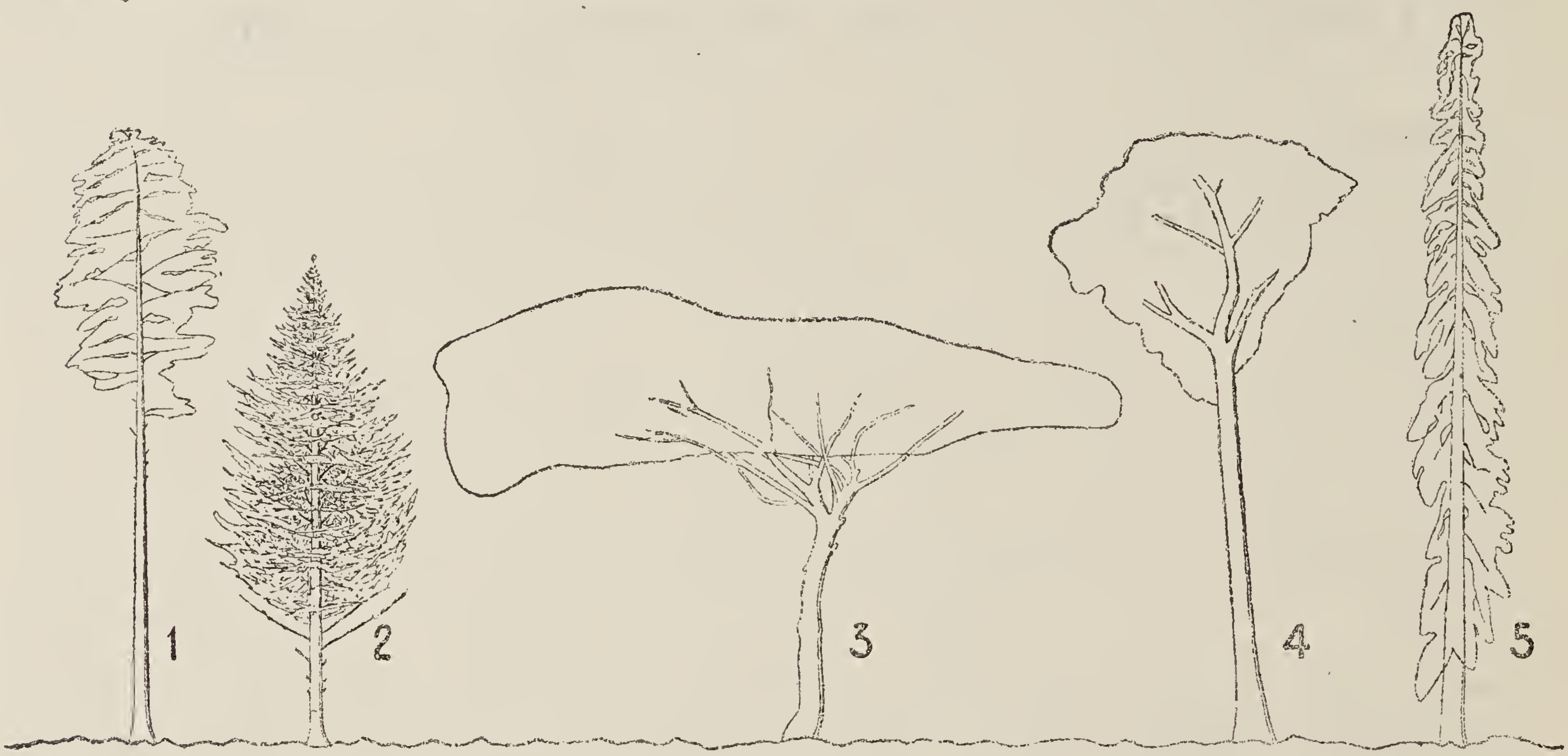

Diagram III. Typical Bole and Crown Forms

1. Mature deodar. 2. Immature deodar in a rather open Crop. 3. *Acacia planifrons*. 4. *Dipterocarpus*. 5. *Abies pindrow* (outlines traced from photographs).

The general effect on trees of growing in a more or less closed canopy is to eliminate the lower parts, to condense the shape in a vertical plane, and to restrict the crown to the upper fraction of the total height so that ultimately the flat-topped type tends to predominate—*e.g. Pinus longifolia*, and most species of the tropical evergreen forest including *Dipterocarpus*.

Frondose habit

In many young trees exemplified by the *Terminalias*, *Pterocarpus* and *Prosopis*, the development of a fully vertical axis and symmetrical crown is delayed several years, during which the upper part of the main stem bends to one side, and the crown tends to be flattened laterally, giving an appearance suggestive of a fern and so called frondose.

The relations between crown length, crown width, and total height in closed crops are much influenced by the treatment and will be further discussed in Chapter VIII.

Mode of branching

The mode of branching is a specific or even a generic or family characteristic. In the majority of trees it appears completely unsystematic owing to the development of a few only out of an infinite number of buds[1]. In trees with opposite leaves such as teak and *Adina*, the branches also tend to develop in opposite pairs, but one of the pair usually gets ahead so that the feature is only noticeable in the ultimate twigs. Whorls of branches are met with in a number of trees with alternate leaves, *e.g.*, *Bombax* and *Pinus excelsa*, and in them are ascribable to an inherent tendency to develop a series of buds at about the same level and time at a certain season—it may be once a year or more or less frequently.

The direction of the branches relative to the main axis may also show specific variations. In most trees, the branches leave the main axis at a moderate angle of 60° or 70°, but in some species, sports have arisen with a much steeper angle of 20° or 30°—as in *Populus nigra*, *Cupressus sempervirens* and the *ramkantha* variety of *Acacia arabica*. Quite a number of trees have the branches conspicuously horizontally set as in *Homalium* and *Casearea*, and others have them with a downward direction, this being a characteristic of high level forms of conifers exposed to heavy snowfall and sports with drooping habit.

Degree of branching

There is again much variation in the degree of branching of the main branches, ranging from dense twiggy crowns as in many of the southern temperate rain forest trees, through only mederately branched crowns, (usually with thick twigs) such as teak, to crowns consisting of relatively few, long, hardly subdivided main branches as in *Duabanga*. Trees much exposed to the wind very commonly have a dense twiggy crown even in species normally fairly loose, the internodes being conspicuously shorter than usual.

Flexibility of branches

There is also much variety in the flexibility of the branches, from the stiff unyielding branches of teak to the thin whippy ones of *Betula utilis* ; this is sometimes of significance in cleaning and thinning operations. Many trees sometimes have small ‘ epicormic ’ branches all down the bole, a phenomenon further discussed on p. 60.

Deciduous and evergreen habit

The most important variation in tree foliage is its deciduous or evergreen habit. The deciduous tree is leafless every year for a period which varies from a week or ten days in the case of *Shorea robusta* to over six months in *Hymenodictyon*. The period also varies considerably for any given species according to the climate and conditions in which it is growing ; thus teak and *Cedrela toona* are practically evergreen in favourable moist and warm localities, the old foliage persisting till the new buds unfold.

A curious case is that of sandal wood (*Santalum album*). This species is an obligatory root parasite and is usually deciduous or evergreen according to the habit of the host on which it is parasitic.

Persistence of evergreen leaves

The old leaves of evergreens may only persist slightly longer than in trees such as *Cedrela toona*, but long enough for the new foliage to be fairly well developed before there is an appreciable fall of the old ; this appears to be the case for *Hopea* and perhaps the majority of species of the moist tropical forest. *Pinus longifolia* and *Eugenia jambolana* in dry localities provide good examples of trees which are just evergreen. In general however the life of evergreen leaves is considerably longer, commonly 2 or 3 years, and even up to 7 years or more for conifers at high elevations. In relation to their longer life, evergreen leaves are usually thicker and stronger than deciduous leaves and cast a heavier shade ; they tend also to form a denser canopy, though in dry evergreen forest this is not the case and many deciduous trees cast a very heavy shade during the period they are in leaf.

Twig shedding

A few trees regularly shed their smaller twigs with the leaves ; such are *Cryptomeria*, oaks, and *Emblica* (and strictly speaking, all pines), and many others can do so on occasion *e.g. Bombax*.

Leaf texture

There is an enormous variation in the size and shape of leaves but it is not of importance to silviculture and so will not be described[46]. The texture of leaves is however of some importance because when they fall they form a soil covering, the nature of which has a great influence on soil formation and fertility (cf. pp. 38-41), and on natural regeneration. Large coriaceous leaves, slow to break up and decompose, such as those of sal, tend to be harmful, as also coniferous needles, whilst thin fragile leaves are rapidly broken up and incorporated with the soil and, if mixed with the more resistant types, hasten the decomposition of the latter.

Drip

Large entire leaves like those of teak and *Dipterocarpus tuberculatus*, or even sal, are liable to be harmful to small regeneration through their action in collecting moisture in large drops, the fall of which splashes mud over the seedlings. This drip action often results in the death of the seedling. In some trees, there seem to be adaptations for draining water off the leaves as quickly as possible—as in the ' drip tip ' of *Ficus religiosa.*

The Stem

Variations in shape

The main stem of a tree is a good deal influenced in its shape by the variations described above for the crown it carries. The lower portion of the stem up to the point where the main branches are given off is known as the *bole*. Some trees have an inherent tendency to form a tall erect straight bole with relatively small branches and will do so even when growing in the open—this the forester could wish were a commoner property. Such is the case with most conifers, many species of *Dipterocarpus* and *Eucalyptus*, *Bombax* and *Michelia champaca*, in all of which the tendency usually persists till a fairly long bole has been developed, more or less free of branches. Teak seedlings have no branches till their third growing season. Many other trees exhibit the same tendency at first but it does not persist so long, and the length of bole free of branches is relatively short unless the lower branches are killed off by shade—sal and *sissu* provide examples. At the opposite end of the range is *Lagerstroemia flos-reginae* which is very prone to low and repeated branching.

Forked stems

It is not uncommon for the main stem to fork more or less equally, and grow with two leading shoots, giving usually a larger crown but, from the forester's viewpoint, a most unsatisfactory bole ; this may happen equally with opposite leaved trees such as teak, and alternate leaved species such as sal. The so-called *candelabra* form with a number of leaders is due to injury, usually repeated injury, and is met with in many species, especially in village forests, deodar providing a good example. Forking is often caused by injuries such as those resulting from hail storms or defoliation.

Development of a clean bole

The death and shedding of the side branches as a tree grows up is of great importance to the quality of the timber produced. It has just been mentioned that during the period of bole formation in some trees, no side branches of any size are developed and the small ones formed soon die and drop. In most species, however, side branches are formed and persist for varying periods, but their growth tends to cease as they are shaded by the rest of the crown above them. *See* Plate 4. Rarely they are cut off from the rest of the tree by a definite abscission layer (*Bombax*), but more usually they gradually starve and die and finally are broken off by wind, etc., and the point of insertion grown over. A short length at the base of a branch usually remains alive and goes on growing slowly, so that in the end the wound is covered over without enclosing a dead piece of branch. This process is exceptionally slow in species such as *Pinus excelsa* and is usually a long process if the branches have once grown beyond a certain size ; it will be discussed again later on (p. 72). Some of these variations have been shown to be fixed in certain strains of a species and to be inherited through the seed.

Epicormic branches

Not infrequently a tree will produce a large number of small branches, on a bole that has hitherto been clear of them. This phenomenon of *epicormic* branching has been shown to follow almost any form of shock to the tree, such as frost, fire, drought, defoliation, and sudden exposure from heavy thinning. It is undoubtedly often caused by a deficient water-supply being associated with more or less stag-headedness, but any lack of balance of roots and crown seems sufficient to cause it, including that caused by overcrowding or underthinning[2]. Sal and teak both readily develop epicormic shoots from the causes mentioned.

Taper, form factor, and form quotient

Apart from its branchiness, the bole form varies a good deal in other particulars, which are studied in detail under forest mensuration. It has been shown that in general the shape is that which is best suited to meet the strains due to wind pressure on the crown, usually centred on the lower third of the latter, and to transmit them to the root system anchoring the tree in the soil, though above the so-called *root swell* the shape may closely approximate to a truncated cone or paraboloid. The taper of the bole is commonly expressed as the *stem form factor*, which is the proportion which the

PLATE 4. *Vateria indica* growing in high forest, Wynaad, Madras (*L*), and in a roadside avenue, Mangalore, Madras (*R*)

Facing p. 60.


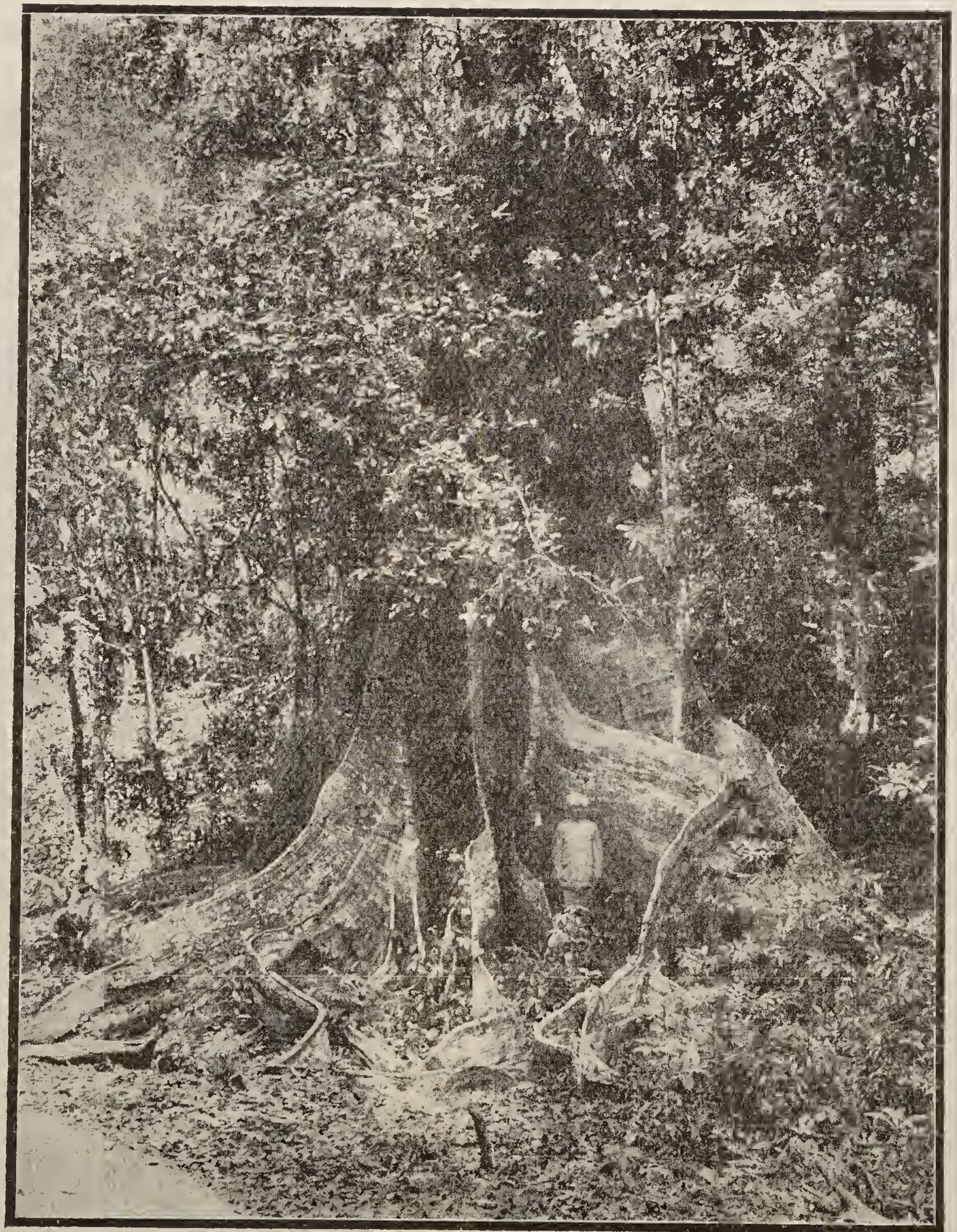
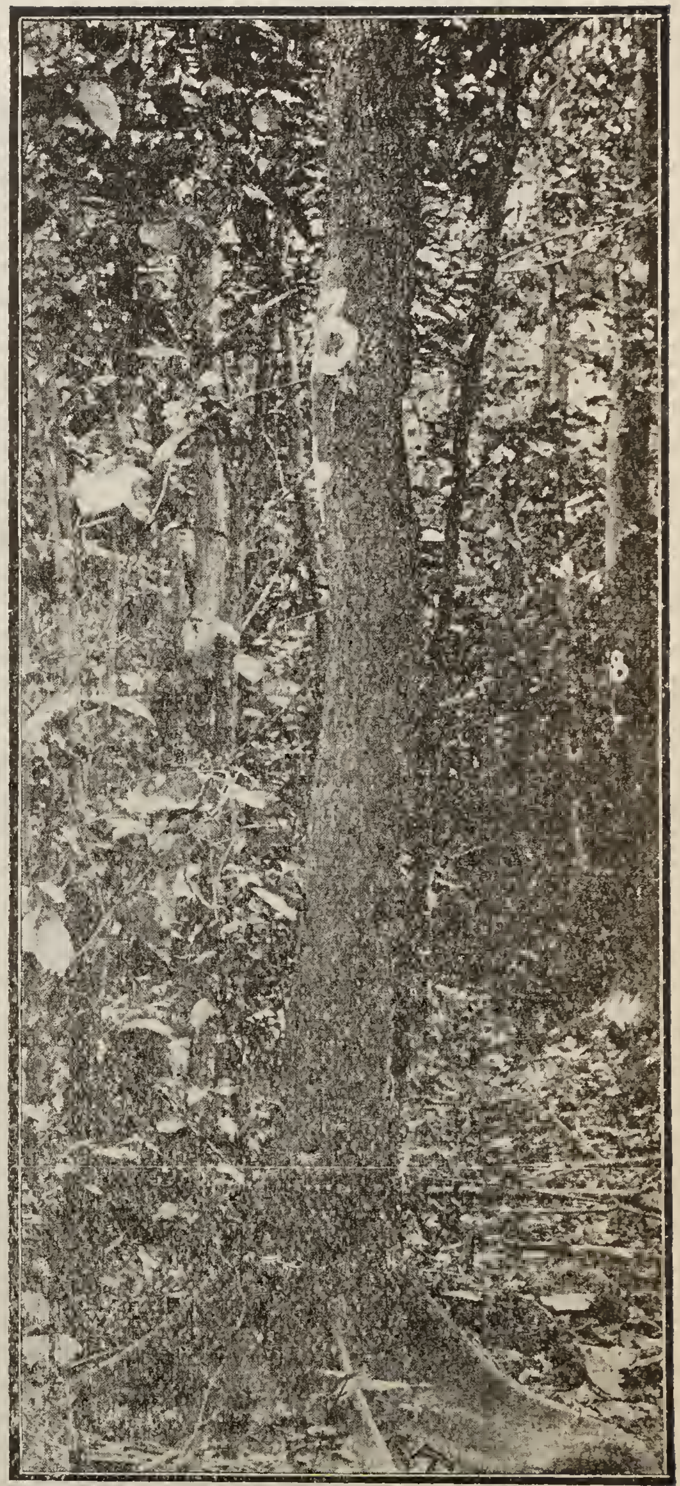

PLATE 5. Buttressed stems. *Centre* : *Elaeocarpus tuberculatus* with thin buttresses extending 20 ft. up the bole, Mysore. (*L*) *Tetrameles nudiflora*, Coorg. (*R*) Young *Pterocarpus dalbergioides* plantation with buttress formation commencing, Andamans.

Facing p. 61.

actual volume bears to the volume of a cylinder of the same height on the same base (taken as that at breast height or 4½ ft. above the ground). A more generalized measure is the *form quotient*, for which works on mensuration should be consulted.

Buttressed stems

In many trees of the wet tropical forest (*Buchanania lancifolia*, *Sterculia* spp., *Pterocarpus dalbergioides*, *Terminalia myriocarpa*, *Bruguiera*) and a few in the drier tropics (*Bombax*, *Holoptelea*, *Tectona*), the swelling at the base is far more pronounced and takes on a buttress form which may extend 15 feet or more up the stem. *See* Plate 5. In extreme cases these buttresses are in the form of wings thin enough for planks to be hewn directly out of them (*Elaeocarpus tuberculatus* and sometimes *Bombax*). A further infrequent development is met with in *Rhizophora* and a few other genera (*Dillenia*, *Elaeocarpus*), comparable with the flying buttresses of architecture, the base of the stem being supported by strut-like outgrowths (' stilt roots ').

Fluted stems

The bole above the basal swell may be smoothly round in section or it may show irregular involutions and swellings—usually referred to as *fluting*, and a serious defect for timber production. Sometimes the fluting seems related to buttress formation, but it is often independent. Teak is particularly liable to this peculiarity, which it has been attempted to refer to epicormic branching, insect attack, faulty thinning, unsuitable site, defective racial strain and other causes, without conclusive results[2]. The phenomenon may be met with as an abnormality in a great many other species, but is definitely characteristic of some trees like teak itself and *Mitragyna parvifolia*. In plantation teak the proportion of the stem (by volume) occupied by the flutes has been shown to be independent of the quality class.

Size of Trees

Stages of development

Different terms are used for the different stages of development of forest trees, and for convenience in reference, the usage of these terms has been standardized for India[35] as follows :—

Seedling, from germination up to a height of 3′.

Sapling, from the time the young trees reach 3′ in height till the lower branches begin to fall. A sapling is characterized by the absence of dead bark and by vigorous height growth.

Pole, from the fall of the lower branches to the time when the rate of increase in height begins to fall off and crown expansion becomes marked.

Tree, after passing the pole stage.

It is obvious that no sharp distinction is possible on these definitions between sapling and pole, and still less between pole and tree stages, but in practice they are serviceable enough.

Maximum diameter

From the point of view of size, the trees of India cannot compete with the Sequoias of California or the Eucalypts of Australia, which attain girths of about 120 ft. and 100 ft. respectively. Records of exceptionally large trees in India include the following, but very few records seem to have been published[3].

Species	Girth at breast height	Locality
Terminalia myriocarpa	46′	Lakhimpur, Assam.[4]
Platanus orientalis	41′	Srinagar, Kashmir.[5]
Cedrus deodara	38′ 9″	Mohu Mangat, Jammu.[5]
	36′ (at 6′)	Kuarsi, Ravi V.[6]
Dipterocarpus turbinatus	28′	Thaungyin, Burma.[7]
Tectona grandis	26′ 7″	Pahok, Burma.[8]
	20′ 6″	Parambakulam, Cochin.
Shorea robusta	25′ 8″	Ramnagar, U.P.
Picea morinda	24′ 8″	Ramban, Jammu.[5]
Quercus semecarpifolia	22′ 8″	Ramban, Jammu.[5]

Maximum volume

The biggest volumes of timber from individual trees of which records have been traced are :—

Tectona grandis	Bhamo[8]	1,367 cu. ft.
Cedrus deodara	Kashmir[5]	1,020 ,,
Shorea robusta	Assam	227 ,,
[*Agathis australis*]	New Zealand	31,400 ,,
[*Sequoia sempervirens*]	California	31,100 ,,
[*Sequoia gigantea*]	Do.	50,000 ,,

Maximum height

The biggest trees are by no means always the tallest. On the available records, it would appear that in India the conifers considerably surpass the broadleaved trees in maximum height attained, as indicated by the following figures[3] to which a few outstanding foreign entries are added. There are however very few records from the tropical evergreen forest.

		ft.
Cedrus deodara	Sutlej Valley, Punjab	240
	Dungri, Kulu	240
Picea morinda	Jaunsar, U.P.	215
Abies pindrow	,, ,,	206
Pinus longifolia	Tons Valley, Tehri-Garhwal	180
Pinus excelsa	Pabar Valley	176 (F.R.I.)
(*Sequoia sempervirens*)	California	364.[3a]
(*S. gigantea*)	,,	325.[3a]
Tectona grandis	S. Malabar	192
Dipterocarpus turbinatus	Thaungyin	150 (well over)
Shorea robusta	Chorgallia, Haldwani, U.P. (S.P. 6, tree 2)	149
	Nepal	168
Eucalyptus globulus	Mutinad, Nilgiris	234
Eucalyptus regnans	Australia	347

(Some figures for age attained are given on p. 99.)

Stem Structure

The main stem and branches of a tree consist of the central wood, the cambium and the bark. We are primarily interested in the wood (*xylem*) core which constitutes the timber, which is separated from the living and dead bark by the delicate thin *cambium* layer.

Thickness and texture of bark

The outer bark consists of dead corky tissues forming an insulating coat of considerable biological importance in the more extreme climates (*Betula utilis*) and in areas liable to be swept by fire (chir pine) ; under such conditions the layers tend to be thicker and more persistent than under moister and more equable climates. In wet tropical forest, rough corky outer bark is rarely met with, and the bark as a whole is thin and delicate and so particularly sensitive to exposure or fire.

Bark variations in appearance, colour and smell are a great help in identification, particularly in wet tropical forest where the foliage and flowers are not accessible ; but they cannot be discussed here.

Cork

In a few trees the outer bark can be stripped off in slabs without damage, rupturing at the *bark cambium ;* the cork of commerce is obtained in this way from *Quercus* spp. The bark of some species of *Betula* and other genera can be peeled off in paper-thin layers. Bark thickness has been studied in detail for a number of important timber species. It is found that the thickness increases with stem diameter but at a decreasing rate, and it decreases for a given diameter as the height above the ground increases. The thickness and water content of the bark are influential factors in determining the extent of the damage done by lightning striking the tree ; rupture will occur if the conducting power is low.

Inner bark

The inner layers of bark differ in being alive and in taking an active and important part in the nutritional processes of the tree. In general terms, the living bark distributes the food products elaborated in the leaves and conducts them to all growing parts including the root system.

Latex

The latex-bearing system of latex-producing trees is also mainly situated in the living bark as in many *Euphorbiaceae* (e.g. *Hevea*, Para rubber), *Apocynaceae* (*Alstonia*) and *Ficaceae* (*Ficus elastica* and other figs). The latex system usually consists of long much branched tubes, but in some plants such as *Hevea*, the Para rubber, the latex occurs in vessels which are very much branched and which, unlike the tubes, anastamose freely ; they retain their protoplasm and nuclei for a long period. During the recent war much data has been collected of Indian latex-producing trees and shrubs.[47, 48, 49]

Bark resin, etc.

Resin is found in the bark of many conifers (*Abies*) though the resin tapped from pines comes mainly from ducts in the wood ; oleo-resins also occur in the bark of *Boswellia*. Alkaloids are extracted from the bark of *Cinchona*, etc.

Girdling

Bark girdling consists in removing a strip of bark down to the cambium all round the bole. Experience has shown that some trees, such as *Buchanania latifolia*, are killed very easily in this way ; some die certainly but slowly, *e.g. Pinus longifolia*, *Boswellia* ; others tend to recover, whilst yet others seem to be but little affected, even excluding those such as *Adina cordifolia*, *Dillenia* and *Ficus* spp. in which complete girdling is impossible owing to fluting. Mention must also be made of trees with abnormal structure in which strands of phloem tissues occur among the woody tissues, *Dalbergia paniculata* providing an example among the commoner trees. This character is one usually associated with the climbing habit, and such trees are naturally resistant to girdling. The thin-barked trees of the dense wet tropical evergreen forest tend to be more sensitive to girdling than the thick rough-barked trees of drier types. Girdling into the wood and the application of poisons are of course different propositions from simple girdling of the bark only (cf. p. 318).

Cambium

The cambium is a layer of living tissue, theoretically only one cell thick, which forms both cortex and wood by repeated division of its cells and the differentiation of the daughter cells into the various elements which build up these tissues. The cambium cells being thin-walled and soft are easy to rupture, particularly when active division is in progress at the beginning of a growing season. To the cambium, too, falls the task of healing over wounds (occlusion). In palms, bamboos and ferns the mode of growth is very different, and this cambial sheath is absent.

Wood structure

The wood is of more uniform appearance and texture than the bark. An annular structure results from its mode of formation on the inside of the expanding cambial sheath, and is apparent in varying degree. In temperate climates and deciduous trees, the annual periodicity of growth is evident in the wood, but in the moist tropics, especially in evergreens, this feature is often not apparent. The formation of annual rings is described on p. 95. For details of the structure of timber, reference should be made to the many available publications on the subject.[9,10].

Heartwood

There is also often a differentiation into an inner core of *heartwood* and an outer ring of *sapwood*, the former being often a darker colour and harder and denser than the latter ; no heartwood is discernible in mango, silver fir and many other timbers. Microscopic and chemical examination reveals the facts that the heartwood also differs in containing no living elements, in having the pores more or less blocked with cellular growths (*tyloses*) or deposited materials, and in having the walls more highly lignified and infiltrated with tannins and coloured substances which may still further darken on exposure to air ; physiologically, the heartwood has ceased to play any important part in water conduction and serves to lend rigidity and support to the ever increasing weight of the tree. The sapwood on the other hand includes living and functional cells, particularly in the so-called medullary rays, which are transverse strips or wedges of tissue running radially across and between the mass of longitudinally orientated wood elements through which passes most of the upward stream of sap from the absorbing root system to the transpiring leaf surface. The colour difference between heartwood and sapwood is liable to become obscured when the latter darkens on exposure, as is the case with sal. The change from sap to heartwood is dealt with later on p. 97.

Resin in wood

Resin ducts are found in the wood of conifers, *Dipterocarpus* and some other trees. They are formed by the drawing apart of neighbouring cells to leave a central intercellular space into which the lining cells (epithelial cells) secrete the resin. There is often a surrounding sheath of dead air-filled cells. In conifers there are narrower horizontal ducts along the medullary rays connecting with the longitudinal ones in the wood, but no medullary ducts have been found in the Indian Dipterocarps. Callus tissues formed in response to wounding have two or three times as many ducts as the normal wood, an important fact for tapping processes. The ducts are usually 1′-2′ long but may be even longer. In *Pinus longifolia* wood there are 30 to 100 ducts per square inch of cross section, the more the narrower the annual rings.

THE ROOT SYSTEM

Forms of roots

Owing to the difficulty of studying and experimenting with the roots of trees, our knowledge is still very inadequate. In general terms, the root system can usually be differentiated into a downward penetrating portion, the *tap-root* and *sinker* roots which reach down towards the permanent subsoil supply of moisture, and a horizontally distributed portion which anchors the tree to the soil taking up the mechanical strains transmitted from the exposed bole and crown, and bearing the feeding rootlets which absorb the nutrient soil solution from the upper soil layers.

Tap-root

The tap-root is normally derived directly from the radicle of the seedling. It sometimes penetrates to great depths, and *Prosopis spicigera* and *Acacia arabica* are recorded as reaching down to 100 ft. or more. The tap-root of *sissu* in the Chichawatni irrigated plantations has been found to extend down to the permanent water level at a depth of 30-47 ft. in 10 years, but only penetrates a few feet where, as in Terah, a *kankar* pan exists : here a shallow spreading root system is developed instead.[11]

Seedling roots

The roots of seedlings penetrate much deeper than is imagined owing to their thinness and the ease with which they are broken when it is attempted to extract them ; unless the actual growing tip is found it is impossible to determine the depth with any accuracy. Sal seedlings in Dehra Dun *taungyas* were found to get down to 39″ in their first monsoon, a figure which is doubtless much exceeded under more favourable conditions, but which is double the average found for forest seedlings of the same age.[34] *Terminalia tomentosa* seedlings penetrated to a depth of 11½ ft. in less than two growing seasons. When the tap-root is injured or checked in any way, its function is often taken over by one or more lateral roots which grow down into the soil as sinker roots of similar appearance.

Horizontal roots

Very little is known as to the extent of the horizontal root system of Indian forest trees, though it has been found that it is usually only to a radius of 2-8 ft. and rarely up to 12 ft. in irrigated *sissu* plantations about 10-12 years old.[11] It appears that for some trees, the roots are generally confined to the area covered by the crown, but for others (such as the pine and spruce in Europe) they extend much further and so extensively overlap the roots of the surrounding trees. Trees growing along the edges of a clearing spread their roots a long way out into it, 100 ft. or more especially in worked soil, and act detrimentally on field or seedling crops raised on the ground so occupied. This is evidently one of the reasons why trees which have long been isolated are much more wind firm than trees freed by the felling of those around them. There are indications that in youth a pine explores a large area, whilst later in life it exploits the area occupied more thoroughly.[12] Most workers have reached the conclusion that though the form of the root system of a tree is probably determined to some extent by the hereditary growth characters of the species, the reaction to soil conditions plays a greater part.[13,13a]

Mangrove roots

The special adaptations of the trees of tidal estuaries to their environment are particularly apparent in their root systems, the modifications evidently primarily serving to meet inadequate aeration consequent on a waterlogged or even submerged soil. As examples, the Rhizophoras are supported on a system of aerial stilt roots, the Bruguieras send up peglike projections from their roots, and the Heritieras develop aerial knees. These breathing roots or *pneumatophores* consist of soft spongy tissue and are also sometimes met with in fresh-water swamps.

Roots of figs

A few trees, notably the figs, commence life epiphytically but may ultimately become independently fixed in the soil. The prop-root system of the banyan is a further development in the same direction.

Bamboo roots

In view of their forest importance, brief reference is due to the very different root system of the bamboos, which are of course Monocotyledons. The bamboo stem stands on a branched underground rhizome (stem) system which carries a dense mat of thin usually undivided adventitious rootlets which show no secondary thickening and are replaced by new ones as they die off in the course of time.

Adaptability of roots

The extent to which the root system of a tree can adapt itself to a change of conditions seems to be a specific character. A rise in water level causing the death of the deeper roots may lead to the death of the tree (as with sal), or adjustment may take place. Similarly most trees die if a deep layer of silt is deposited over the soil, but some are able to produce a new series of adventitious roots higher up the stem and survive. A few species when planted too deeply as seedlings behave in this way and take no harm. Rupture of roots by wind or felling damage often results in the death of an exposed tree before enough new roots can be formed to meet the continued demands of the transpiring crown, and this is a frequent cause of death in the overwood left in uniform regeneration fellings.

Seasonal changes in roots

Young teak plants form abundant fine absorption rootlets in the uppermost soil layer during the monsoon period, which largely die off in the dry season, when they are in part replaced by new ones developed in the deeper layers provided aeration is adequate.[13a] It is probable that many other species behave similarly.

The regeneration of the root system on root and shoot cuttings is described on p. 106. During the first growing season on good soil, the new sinker roots were 3½ ft. long in teak, and up to 6 ft. long in *Acacia catechu* at Dehra Dun.

Mycorrhiza

Close behind the growing tip of the normal plant root, the epidermal cells are thin-walled and closely set with fine hairs, the *root hairs* (through which the absorption of the soil solution takes place). Many trees of temperate climates which have been examined do not possess these root hairs, but the fine root extremities are closely enveloped and often actually penetrated by a mycelial fungoid growth known as *mycorrhiza*,[14,14a] an apparently[15] symbiotic relationship serving the same ultimate function. The fungus may cause the development of coralloid swellings in the roots, as is well seen in *Podocarpus*. The only Indian tree on which mycorrhiza has been recorded is *Trewia nudiflora*, but it occurs on all *Podocarpus* and will probably be found on many species when systematically studied. Hyaline fungal hyphae have been found in close association with the feeding roots of sal, *Cedrela toona*, *Quercus incana*, *Cedrus deodara* and mango without doing them any visible injury, and are quite possibly of mycorrhizal nature. Mycorrhiza has also been reported on teak roots in Java.[13a]

Root nodules

The root nodules of leguminous plants, already mentioned (*vide* p. 44) as containing nitrogen-fixing bacteria, are found on the majority of leguminous trees, shrubs and herbs, and are definitely recorded[31] for *Dalbergia*, *Bauhinia*, *Erythrina*, etc., as well as on frequently used shrubby cover crops such as *Tephrosia*, *Crotolaria*, *Indigofera* and *Leucaena*, though the common weed *Cassia tora* is without them. The large bacteria-bearing root nodules of *Casuarina* are noteworthy ;[16] *Tamarix* growing sandy in similar soils does not possess nodules. Podocarpus has apparently both mycorrhiza and bacterial nodules.[14a] It may be noted that *Bambusa aru dinacea* has the roots for several inches behind the root cap coveren with a mat of very closely set hairs with empty cellulose wall and of unknown function.[17]

Parasitic roots

A few trees, notably the sandalwood, have haustorial connexions with the roots of other plants, on which they are parasitic in varying degree. The actual roots of the sandal itself merely function to support the tree in an upright position.

CROP MORPHOLOGY

Crown and Canopy

Canopy classes in even-aged crops

For forest practice, a standardized classification of the trees composing a crop is required and will be dealt with in detail in Chapter VIII. It may be noted here that in more or less even-aged crops, it is convenient to differentiate the following :—

(1) *Dominant* trees which form the uppermost canopy and include *predominants*, the tallest trees determining the general top level, and the rather shorter *codominants*.

(2) *Dominated* trees, about three-quarters the height of the predominants, filling up the minor holes in the dominant conopy.

(3) *Suppressed* trees which are little more than half the height of the predominants and stand under the shade of the taller trees.

Storeys in tropical evergreen forest

In virgin forests and in uneven-aged forests approximating to them in form, it has long been customary to refer to various canopy layers or storeys. Thus in moist tropical evergreen forest, there is often a scattered top storey of giant trees (*Dipterocarpus* spp. are commonly found thus) definitely projecting above the general top level formed mainly by different species ; below may be a third storey, again mainly of different species which do not usually attain the ceiling, and, being more shade-bearing, fill the role of the dominated class of the regular crop. Below these again may come a fourth storey of relatively small trees, and finally a ground vegetation. Very few special studies have been made of the matter, however, and those that have,[17a] suggest that such differentiation may easily be subjective, especially where the lower storeys include much regeneration of the species of the upper storeys.

Crop height

The height attained by the dominant trees of a crop depends primarily on the quality. This height is called the *top height* and is used as a measure of the site quality. Some 15 years ago the *crop height* was calculated by Lorey's formula, mean height $\frac{\Sigma Sh}{\Sigma S}$, where S is the basal area of a group, and h the height corresponding to the mean diameter of the group and this is still the practice in Indian sample plot technique. In 1936 however the International Union of Forest Research Organisations considered this mean value as not of great significance as it does not adequately express the quality class. (This fact is obvious from a study of the deodar multiple yield tables in which the crop height is found to vary, for the same quality, with the intensity of thinning.)

Top height is however a standard for young and middle-aged crops, and by definition it is the height corresponding to the mean diameter of the 100 biggest diameters per acre as read from the height/diameter curve. When the number of trees falls below 50 per acre, top height becomes synonymous with crop height.

Some figures of crop height for Indian species are given below. These figures are all for C-grade thinning.

Species	Quality class	Crop age in years	Crop height in feet
Cedrus deodara	I	140	140
	II	140	119
	III	140	97
	IV	140	78
Pinus longifolia	I	160	141
	II	160	116
	III	160	107
Pinus excelsa	I	120	139
	II	120	119
	III	120	99
Shorea robusta	I	150	139
	II	150	114
	III	150	89
	IV	150	63
Tectona grandis	I	80	140
	II	80	120
	III	80	100
	IV	80	78
	V	80	57

Crop bole form

Within limits set by species, the shape of the individual bole is determined by the conditions of growth and crown form. Accordingly, form factor varies appreciably with size of crown and diameter, and this latter relationship is determined as a step in the Indian standardized method of measuring crop volume. The sal yield tables show the crop form factor as rising right to maturity, though slowly towards the end, the stems becoming more and more cylindrical. The multiple yield tables for deodar, however, show a rise to a miximum in upper middle age followed by a gradual fall, and for a given quality and diameter, a higher factor for the heavier grades of thinning, implying better balanced crowns.

Branchiness in crops

Free standing trees with long crowns implying branchy stems are very unsuitable for yielding clean timber. Trees standing in closed crops have boles more or less free of branches, and of a relative length varying with species and increasing with the density of the crop, till finally a point is reached at which the crown becomes too small for continued healthy growth ; the bole itself, owing to the smallness of the crown, then becomes too long and slender to support the crown under adverse conditions of wind or snow pressure (*whip* trees). The branches are very persistent in *Pinus excelsa* and many hardwoods, whilst deodar, sal and *Terminalias* are examples of species which form good clean boles if standing in reasonably dense canopy. Branchiness of single trees or groups of trees in crops has often been considered to be a hereditary character.[50]

Diameter-Classes in Crops

Even-aged crops

Even in even-aged crops, owing to the different opportunities of growth and crown size, there is always a wide range of diameter, and a study of the frequency distribution about the mean value is of both interest and importance. Examples are taken from published tables for crops of average diameter 20″. A sal crop of average diameter 20″ is thus likely to include trees from 10″ to 30″, 39 per cent being over 20″ ; 9 per cent over 24″ and 23 per cent under 16″. The corresponding figures for deodar are 38 per cent over 20″ ; 10 per cent over 24″ and 22 per cent under 16″, and include trees from 12″ to 29″. Thus they are almost the same as for sal, though the mean annual increment curve for deodar

DISTRIBUTION OF DIAMETER-CLASSES IN EVEN-AGED CROPS OF 20″ CROP DIAMETER

	Diameter-class in inches																					
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
	Percentages																					
Sal																						
In each class .	1	1	3	4	7	7	9	10	10	9	10	8	7	5	3	2½	1	1	½	½	½	*Indian Forest Records*, Vol. 4-A No. 4, pp. 242-3 (1943).
Cumulative .	100	99	98	95	91	84	77	68	58	48	39	29	21	14	9	6	3½	2½	1½	1	½	
Deodar																						
In each class .		3	3	4	5	7	9	10	11	10	9	8	7	4	3	3	1	1	1	1	..	*Indian Forest Records*, Vol. 15 part 8, pp. 78-9 (1933).
Cumulative .		100	97	94	90	85	78	69	59	48	38	29	21	14	10	7	4	3	2	1	..	
Chir pine																						
In each class .	1	1	2	3	5	6	8	10	10	11	9	9	8	7	4	2½	1½	1	½	½	..	*Indian Forest Records*, Vol. 2 No. 3 pp. 62-3 (1936).
Cumulative .	100	99	98	96	93	88	82	74	64	54	43	34	25	17	10	6	3½	2	1		..	

culminates at 19″ instead of 17½″. It should be remembered however that these figures apply to tended crops in which many trees, mainly of the lower diameter-classes, have been removed in thinnings. A table is given on page 73 to show the distribution of diameter-classes in even-aged crops of 20″ crop diameter.

Uneven-aged forest

In this form of forest the proportions of trees of different diameter varies unsystematically from spot to spot, but it may be mentioned that in the so-called normal forest under sustained yield management, the proportion of trees of the larger diameter-classes is considerably higher than in normal even-aged forest.

Crop Volume

Typical crop volume

Yield tables provide data for the volume standing in an acre of fully stocked more or less even-aged crops at different ages on sites of different qualities. The following examples are for timber volumes on Quality Class II sites, timber being everything 8″ and over diameter over bark.

Species	Age in years			
	40	60	80	100
	Timber volume in cubic feet			
Sal	730	2050	3010	3660
Teak	1990	3270	4390	5335 (estimated)
Chir pine	340	2560	4400	5460
Deodar	450	4090	7260	9840

Records of maximum crop volume

The following figures for the maximum standing volume per acre recorded for several species are taken from sample plot records. Few areas of any extent carry more than about half the full stocking possible, and most of our forests still less. Figures for tropical evergreen forest might be higher but no reliable data are available.

Species	Crop averages after thinning			Volume per acre before thinning		Locality
	Height	Diameter	Age	Timber	Timber and smallwood	
	ft.	*inches*	*years*	*cu. ft.*	*cu. ft.*	
Cedrus deodara . .	132	23·5	167	29028	30618	Temporary S. Plot 5, L. Bashahr, Punjab.
Pinus excelsa . .	123	22·3	130	25294	26349	Temporary S. Plot 11, Kulu, Punjab.
Teak	153	24·6	73	9116	10293	S.P. 2, Ataran, Burma.
Sal	116	19·8	118	6655	8697	S.P. 29, Haldwani, U.P.

Root distribution in crops

Very little information indeed is available as to root conditions after the seedling stage of tree crops is passed. The roots of adjoining trees overlap to a considerable extent and even not infrequently become grafted together, as may be indicated by the healing over of the stumps of felled trees. As different species tend to concentrate their roots at different depths in the soil,[13] the appearances may be presented of very little competition between them, but it must be remembered that the roots occupying the upper layers will absorb moisture which would otherwise sink to the lower : in this way a soil-covering underwood may be harmful to the overwood for the benefit of which it may have been introduced, as has been found to be the case in some localities for the classical case of beech under oak. On the other hand, a cover crop of *Leucaena* spreads its roots mainly below the feeding roots of teak.[13]

FLOWERING AND SEEDING

Flowering

The frequency and profusion with which trees flower varies greatly with species, weather, age and size of tree, and with canopy and crown class.

Age at commencement of flowering

Some species normally start flowering from a very early age (*e.g. Dalbergia sissoo, Bauhinia purpurea* and *B. variegata* at 3 or 4 years), but most timber trees do not produce flowers till they are much older, at least until the early burst of vegetative growth is slackening, although occasional deviations occur, as in cases recorded of teak flowering in its second or even its first year. Many trees when growing in the open begin to produce flowers when 10-15 years old (*Pinus longifolia* and *Shorea robusta* at about 15 years), but in closed crops, flowering typically commences much later, and is restricted in amount even on trees with good crowns till height growth is largely finished, sal and chir again providing good examples. Sometimes the age of the tree appears to be more influential than the size and both these factors less important than position, but there appears to be no general rule on these points. Unduly early flowering in plantations sometimes appears to be a symptom of unhealthiness or unsuitability of the site.

Stimulation of flowering

Heavy pruning of branches or roots may hasten the flowering of young trees, including conifers.[18] In making regeneration fellings with most species, dominant trees with the more flattened crown typical of maturity can alone be counted on to flower freely.

Season of flowering

The season of flowering also varies a great deal. Among deciduous trees, some flower when they are leafless in the dry season : such are *Sterculia* spp. and *Lannea grandis*, whilst in *Butea frondosa* and *Bombax* the upper flowering branches are leafless while the lower branches still carry more or less foliage. Many others flower as they come into leaf in the earlier months of the year, like *sissu* and sal, whilst some, such as *Adina cordifolia*, *Lagerstroemia flos-reginae* and Terminalias, only flower when they are in full leaf. Relatively few species, such as *Kydia calycina* and *Bauhinia purpurea*, flower at the end of the monsoon or shortly after it has stopped.

Evergreen species show a similar range, though it is perhaps less conspicuous and the flowering period is spread over a longer period corresponding to the less well marked seasons of moist evergreen forest. The conifers nearly all ‘ flower ’ early in the spring, but deodar flowers in the autumn.

Amount of bloom

The profusion of blossom produced varies a great deal from year to year quite apart from any direct injury to the buds, and in many species there may be a good blooming only once in several years. The conifers and Dipterocarps are all well known to behave in this way, and the fact is of considerable importance in forest practice. All flowering years are of course not followed by good seed crops as various injurious influences may prevent the seed from setting. Examples of succession of seed years will be given later (p. 80).

Conditions for flowering

The precise conditions which bring about a good flower or seed year are not clearly understood, but it seems likely that the weather conditions experienced during the preceding period are chiefly concerned, a dry year tending to be followed by a good flowering. It is known that reduction of nitrogen supply and increase of phosphorus supply stimulate flowering and fruiting.

Periodic flowering of shrubs

In one or two groups of plants—not including timber trees however—conditions are different, and profuse flowering occurs in certain years with a definite periodicity which is practically independent of weather conditions, only sporadic flowering or even none taking place in the intervening years. *Strobilanthes* is the best known genus which behaves in this way. A 12-year flowering is well established for *S. wallichii* and *S. atropurpureus* in the W. Himalayas, and for *S. kunthianus* in the Nilgiris,[19] and other species apparently follow cycles of 17, 7, 3 and 2 years.

Flowering of bamboos

Still more striking is the behaviour of bamboos, though here also the whole range is encountered, from a long cycle with practically no flowering between times, to flowering so irregular that some flowers can be found every or nearly every year. This periodic flowering affects in the same year practically all the plants of the species growing over a tract of country of varying extent, the remainder usually flowering during the next year or two. The whole range of the species is not however affected in the same year, and the flowering usually proceeds in wave form across it. After such gregarious flowering, the plants with rare exceptions die off and a new seedling crop replaces them. Vegetative propagation does not postpone the flowering, as has often been demonstrated with bamboo offsets. The records of gregarious flowering are extremely inadequate, particularly in the lack of precision as to exact locality. Some species of *Arundinaria* and *Ochlandra* flower practically every year without the death of the plant. *Bambusa arundinacea* is perhaps the best example of well defined periodicity at 30-40 years. A 60-years cycle has been suggested for *B. polymorpha*, which in 1936 began to flower in parts of Burma. The cycle for *Melocanna* is variously put at 30 years (Gamble) and 45 years (Troup), but data are inadequate for this bamboo, as also they are, surprisingly enough, for *Dendrocalamus strictus*, though a 20-22 years' cycle is most likely and there is some evidence indicating that regulated fellings may prolong it.[20]

Monocarpic flowering of palms

The procedure is different among the palms, in some species of which a tree suddenly ceases vegetative growth and exhausts itself in the production of a terminal mass of bloom. Although there may be much more general flowering in some years than others, it is brought about by factors other than the periodicity of the *Strobilanthes*. Such *monocarpic* species are the talipot and sago palms (*Corypha* and *Metroxylon*).

Unisexual flowers

Most trees have bisexual flowers, but in quite a number there are separate male and female flowers—*e.g.* mango and other trees of the same order *Anacardiaceae*, as well as *Euphorbiaceae* (e.g. *Trewia*), *Cupuliferae* and *Coniferae* generally. The male and female flowers may be on the same inflorescence (mango), different inflorescences on the same tree (pines), or on different trees (willows). Some trees normally ' monoecious ', like *Pinus*, occasionally appear to be ' dioecious ' like *Salix*, *Cedrus deodara* being an example. Still more complicated are the relations occurring in the figs. This separation of the sexes is connected with the advantages derived from cross fertilization, and even where the stamens and ovaries are in the same flowers, they may mature at different times with the same result.

Pollination

In any case, transference of pollen from the stamens to the stigmas has to be effected. Relatively few trees depend on the wind for this, *e.g. Pinus* and *Bambuseas*, and some (usually with brightly coloured, large or aggregated flowers) relay on flower-frequenting birds, *e.g. Erythrina*, *Bombax* and *Butea*, or even on bats as in *Oroxylum*, but the majority including teak, sal nad *sissu* depend on insect visitors. Some species or cultivated varieties of fruit trees are sterile to their own pollen and require cross fertilization either with the pollen of another individual or another variety. Botanical works must be consulted for further details, but extremely little is known about the pollination of even our commonest tree species.[21]

Seed Production

Interval between flowering and fruiting

In the absence of abnormal weather conditions and of epidemic attack of insects or disease, flowering is followed by the seed crop after a longer or shorter period. Sal flowers in March and the seed ripens three months later ; chir pine also flowers in March but the seed only ripens 24 months later ; *Quercus incana* flowers in April and the seed ripens after eight months.

Annual seed production

How greatly the seed production of given trees may vary from year to year is shown by the following figures for two common species in North India.

Species	Tree No.	Year	Total seed crop in lb.	Number of seeds in 1 lb.	Germinative capacity
Shorea robusta . .	11	1931	5½	234	100
		1932	0	..	..
		1933	46	241	100
		1934	0	..	..
		1935	10	237	99
		1936	0	..	..
Shorea robusta . .	15	1931	1	204	100
		1932	0	..	..
		1933	33	202	100
		1934	0	..	..
		1935	28	207	83
		1936	36	269	100 ?
Terminalia tomentosa .	19	1929	1	344	?
		1930	0	..	..
		1931	11	447	32
		1932	0	..	..
		1933	0	..	..
		1934	31	352	32
		1935	0	..	..
		1936	0	..	..

The seed crop of four dominant trees of *Anogeissus latifolia* was collected annually for the nine years 1928-36, and amounted to 21, 85, 90, 17, 5, 92, 0 (stripped by hail), 73 and 61 lb. in successive years. For ten trees of *Terminalia tomentosa* for 1929 to 1936, the total yield was 12, 0, 77, 0, 0, 183, 0 and 0 lb. in successive years.

Seed Years

Seed years

Many species such as teak, *sissu*, and *Acacias* seed well practically every year, but as noted above, with other important species a good crop of seed only occurs at intervals of some years. The following are examples for the past 10 years :—

	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
Sal in Dehra Dun division.	G	VP	P	P	M	G	P	G	P	M
Deodar in Chakrata division.	M	M	M	P	M	G	o	M	G	P
Chir pine in Chakrata division.	G	P	P	G	o	G	o	M	G	P
Terminalia tomentosa in Dehra Dun division.	G	P	M	G	G	M	P	P	G	M

G—good. M—moderately good. P—poor. VP—very poor. o—no seed.

Seeding cycle

Taking two moderate seed years as equivalent to one good year, these records indicate a seeding cycle of about 3 years for sal and chir pine and 2 years for deodar and *Terminalia*, when a fairly large unit such as a forest division is taken into consideration, but individual areas are often missed, especially in only moderately good seed years, and for natural regeneration it is advisable to be prepared to wait if necessary a double cycle.

There were also seed years for sal in Dehra Dun in 1923, 1921, 1918, 1913, 1910, 1906, 1900, 1896, 1891, 1890, 1885 and 1883, confirming the above deduction from the recent more detailed records that there are good years on an average 3 years apart with the maximum interval of 6 years. For chir pine in Chakrata over 40 years, similarly, the average period is confirmed as 3 years with a maximum interval of 5 years, and for deodar over 54 years, also a 3-year period.

In years of poor seed production, the damage done by insect and other enemies is concentrated on the small supply and still further reduces it. This is notoriously the case for deodar, *Quercus incana* and *Dipterocarpus* spp., so that it is difficult to find a sound seed in poor years.

Stimulus to fruiting

It has been mentioned above (p. 76) that injuries, including shoot or root pruning, stimulate flowering, and good seed may result especially on young and vigorous trees. Sickly trees sometimes produce an abundant crop of small fruit as a last effort before dying, examples being fungus-infected *Gmelina* (F.R.I.) and pines under heavy tapping for resin.[22] Provided the actual seed is full-sized, it is probable that it is of good quality and quite suitable for use, but it is liable to be small and to show poor germination.

Seed Size

Variation in seed size

Average seed size is a specific character from the large coconut down to the dust-like seed of the *Rohdodendron* and *Adina*. The character tends to go by families so that palms typically have large heavy seeds, *Meliaceae* small light seed, *Leguminosae* fairly large hard seed, *Dipterocarpaceae* large soft seed, and so on, and still more so by smaller groups, subfamilies (*Naucleae* typified by *Adina*) and genera (*Quercus*). It is an interesting fact however that special environment may result in deviations from what is normal for a family, so that for example *Carapa* belonging to the *Meliaceae*, a typically small seeded family, in tidal forests conforms with the majority of trees found in that habitat in having large heavy seeds.

As examples of the range of seed weight, the following figures are given:[23]

Species	Number of seeds per ounce	Plnt per cent (cf. p. 87)	Plants per pound of seed
Adina cordifolia	3,20,000	0·001	6,000
Betula cylindrostachys	3,90,000	0·5	33,000
Casuarina equisetifolia	21,500	..	..
Bombax malabaricum	750	30	3,600
Pinus longifolia	250	37	1,500
Quercus incana (acorns)	15	18	45
Shorea robusta (fruits)	15	66	158
Tectona grandis (fruits)	45	42	300
Terminalia tomentosa (fruits)	15	27	65
Aesculus indica	1	80	15

Seed size as a racial character

Any given sample of seed will show a considerable variation in size. It must be remembered that there may be strains or individuals of a single species characterized by relatively large or small seed (*Shorea robusta*, *Terminalia tomentosa*). The following grading of the seed crop of three sal trees will serve to illustrate the variation encountered in this respect :[24]

Tree No.	Number of seeds out of 1,000 in the diameter-classes shown						
	Diameter-class in hundredths of an inch						
	25-30	30-35	35-40	40-45	45-50	50-55	55-60
1	..	..	44	220	610	126	..
2	466	427	74	33	..	..	..
3	..	..	77	734	80	49	5

Seed Dispersal

Need of seed dispersal mechanism

The continued existence of a species depends on the existence of means to ensure the dispersal of seed from the vicinity of the parent tree.[25] Seed germinating immediately below the tree that produced it very commonly does not get established, and even if it does, the seedlings cannot develop far until the tree is removed.

Heavy seed

Where heavy fruits or seeds drop straight down, it is usually found that they are washed or floated away by water (*Trewia*), or roll away in hilly country, or are carried away by animals, the actual seed being unpalatable and so rejected, or liable to be stored and forgotten (acorns and cones by squirrels).

Winged seed

The simplest device which results in some degree of dispersal of heavy seed is the development of wings on the fruit (most Dipterocarps and Terminalias) which catch the wind as the fruits are blown off the tree and are carried a distance depending on their rate of drop and the velocity of the wind ; this device is very effective in scattering seed all over an area in which the parent trees are scattered more or less singly, especially if the seed ripens during a season when wind storms are prevalent—sal is thus known to be sometimes carried a distance of several miles.

More effective is this same winged device on small light seeds or fruits as seen in most of our conifers, and with fairly large seed in *Holoptelea* (*Ulmaceae*), *Dalbergia* and *Pterocarpus* (*Leguminosae*), the extreme being reached with the small winged fruits of *Terminalia* *paniculata* and *T. myriocarpa*, and the still more minute seeds of *Adina*, *Betula* and *Rhododendron* which drift almost like dust in the wind. Most *Bignoniaceae* have winged seeds which are very light, even if large as in *Oroxylum*.

Hairy seed

Another variation of the same plan is met with in seeds set with long hairs which effectively reduce the falling rate of the liberated seed in still air or a light wind, or even suffice to lift them in a stronger rising current. Examples are seen in *Bombax*, *Populus*, *Salix*, and most *Apocynaceae* and *Asclepiadaceae*. Among weeds, *Eupatorium* (like most *Compositae*) and many grasses (*e.g. Imperata*) have light hairy wind-borne seed.

Dispersal of seed by animals

The seeds of a number of tree species are distributed by animal action, *e.g.* those of *Acacia arabica* and *Prosopis juliflora* which are enclosed in an edible fruit swallowed by goats, etc., but themselves pass undamaged or even stimulated through the animals' digestive tract. Mulberry seed is similarly distributed by birds as also the weed *Lantana*, whilst the destructive parasites *Loranthus* and *Viscum* are also carried by birds, though here the sticky seeds are said to be wiped off the beak, not passed through the bird. Dispersal by animals through the burr mechanism is uncommon among trees, but occurs with many forest weeds such as *Urena* and *Desmodium*, and spear grasses such as *Andropogon contortus* and *Aristida*. Explosive mechanisms are likewise less common among trees, but are met with in many shrubs and woody weeds of the forest floor, including *Parrottia*, *Helicteres*, many *Acanthaceae* and *Viscum japonicum*, and in *Impatiens* among the herbs.

GERMINATION AND ESTABLISHMENT

Germination

Absorption of water

The first requirement for germination is moisture. Water is often absorbed in quantity by dry seeds with considerable resultant swelling of the seed, as occurs conspicuously with leguminous seeds, and in all cases is necessary to the development and growth of the seedling. A moist atmosphere may suffice to start germination of soft seed like sal, but the more general need is for actual contact with damp soil, especially where a resistant seed coat has to be softened (most *Leguminosae*) or even rotted before the moisture reaches the embryo itself. Moisture alone is commonly unable to induce germination unless the temperature is high enough, as illustrated by the many species of north temperate forests in which, despite ample moisture, the seeds do not germinate until the spring rise of temperature. On the other hand, moisture and heat can apparently be excessive at least for many herbaceous seeds which, ripening in the hot weather, do not germinate till the wet hot monsoon period is over—no record for this behaviour in a tree has been traced. Excessive acidity or salinity of the soil moisture may inhibit development.

Respiration of germinating seed

The process of germination involves intensive respiratory activity, so that oxygen supply—aeration—is a third essential.

Light stimulus

For some species, light may also be necessary for germination, as is reported to be the case for seed of *Rhododendrons* or it may be at least helpful (most conifers) though the experiments recorded do not always differentiate between light as such, and the heat generated by it. *Albizzia procera*, *Cassia fistula*, *Pinus merkusii* and *Vitex pubescens* are quoted as species requiring full light for normal germination, and *Swietenia* and *Santalum* as species requiring shade.[26]

Modes of germination

For the details of the mode of development of the germinating embryo, botanical textbooks must be consulted. Typical examples are provided by *Shorea robusta*, *Pinus longifolia*, *Tectona* and *Quercus incana*.

Shorea robusta

The winged fruit lies horizontally on the surface of the soil and the radicle breaks through the top of the fruit, bending over and growing vertically down into the soil as a tap-root without branching. The fleshy cotyledons remain in the seed, but their petioles lengthen considerably so that the plumule is carried out an inch or more from it. The first pair of leaves is opposite, the later ones alternate. The remains of the fruit fall off the cotyledons, which contain some chlorophyll but never develop into foliar structures and soon shrivel and fall.

Tectona grandis

The woody fruit has up to four cells, each with one seed The cells crack open as the seed lies on or in the soil and the radicle emerges and grows down into the soil. The two cotyledons expand, breaking off the woody valves, and spread above ground as a pair of small oval leaves about $\frac{3}{4}''$ long, the shoot then developing from the plumule between them. Up to four seedlings may come from one fruit.

Quercus incana

The single seeded fruit germinates in a very similar way to *Shorea*, but the cotyledons remain inside the fruit and their petioles remain very short ; the seed is usually more or less buried.

Pinus longifolia

The radicle emerges through the seed coat at the point furthest from the wing. The 9-12 linear cotyledons grow considerably in length, their tips remaining together some time in the hard seed coat which is lifted above the ground by the straightening of the hypocotyledonary stem between the radicle and cotyledons. The cotyledons are green and function as leaves.

Germination Period and Dormancy

Dormancy

Some seeds germinate almost immediately after they reach the ground, *e.g. Shorea robusta* and the majority of Dipterocarps, or even before they fall, as best exemplified by some of the mangroves. The minute seeds of *Salix* lose their vitality under ordinary conditions within a week.[27] As a rule, however, seeds remain dormant for some time before germinating ; there are some, perhaps more than we realize, that actually require to do so before they are capable of germinating owing to the necessity for a period of post-maturation, either for the proper development of the embryo as in *Fraxinus*, or for chemical changes known as ‘ after-ripening ’ involving increase in acidity.[28] In *Ginkgo*, even fertilization occurs after seed fall.

Lagerstroemia flos-reginae has been shown to have a doubled germinative capacity after 7 months' storage.[26] This dormant period usually carries the seed over a season unfavourable to germination or seedling development, a common time-table being for fruit and seed maturation to take place towards or after the end of one growing season and germination to take place at the beginning of the next. In temperate climates most seed ripens in autumn and germinates next spring ; in dry countries with monsoon rainfall, seed may ripen any time after the end of the monsoon but germinates at its commencement. In nature, the seed seems always to be adapted to withstand the conditions prevailing during this rest period, but if it is artificially stored, particularly in a different locality, it is liable to lose more or less of its vitality. Thus it has been shown that for *Quercus* acorns, the moisture must not fall below a certain figure or significant losses will occur.[1]

Longevity of seed

Many seeds with thick coverings (either the seed coat as in *Leguminosae* and many exotic pines, or the fruit walls as in *Tectona*) often carry over till a second season without loss or even with a gain in ultimate germination. This seems often to happen with seed buried too deep for germination, which may not occur till years have passed and chance circumstances bring the seed up to the surface. There are authentic records of germination of 100-year-old seed (*Hevea*)[29] and many leguminous seeds seem capable of retaining their vitality for periods of that order if kept thoroughly dry. *Acacia farnesiana*, *Albizzia lebbek* and *Cassia fistula* have all been found to germinate freely after 30 years.[44]

Stimulation of germination

Exposure to the weather has been reported as having a stimulating effect on germination, probably from the fluctuations in light, temperature and moisture conditions. Exposure to fire may also stimulate germination directly or indirectly as is believed to be the case with teak ; (it is well known that the cones of certain American pines often do not open till after a fire). Ash seed, which normally only germinates in the second year, is stimulated to germinate in the following spring if it is collected from the tree while still green. Such delay in germination might appear a disadvantage, but is better viewed as an insurance against total loss if all the seed starts germination directly temporarily suitable conditions set in, becoming liable to heavy mortality from subsequent unfavourable conditions. This is probably true even if the delay implies increased losses from insects and other enemies.

The whole subject of the dormancy, storage and germination of Indian forest tree seeds has been recently written up in detail and to this the reader is referred.[51]

GERMINATIVE CAPACITY, ETC.

Germinative capacity

If a sample of apparently good seed is sown in any suitable medium, germination takes place after a period depending on species and conditions, but only rarely will 100 per cent germination be obtained. The percentage ultimately germinating is termed *germinative capacity*, but usually the percentage germinating in a stated limited period of time, *the germination percent*, is of more practical importance.

Typical examples[23] of germinative capacity are :—

100-90 per cent *Acacia catechu*, *Anacardium occidentale Albizzia lebbek*, *Shorea robusta*.

90-70 per cent *Butea frondosa*, *Ougeinia*, *Pinus longifolia*.
70-50 per cent *Terminalia tomentosa*.
50-30 per cent *Bombax malabaricum*, *Tectona grandis*, *Zizyphus jujuba*.

30-10 per cent *Cassia fistula*.
Under 10 per cent *Betula*, *Anogeissus*.

Plant percent

The number of seedlings resulting at the end of a determinate time is even more significant in plantation and nursery practice, and is known as the *plant percent*.

The relation between germinative capacity and plant percent is illustrated by the following figures from individual tests :—

Species	Germinative capacity	Plant percent
Tectona grandis	44	25
Shorea robusta	75	70
Terminalia tomentosa	40	29

Effect of size or age of the parent tree

The influence of these factors has been repeatedly studied. The usual conclusion reached is that in a given locality, seed from middle-aged or medium-sized parent trees generally gives the best results. Definitely younger or older trees frequently give lower germination and seedling vigour, but this is usually traceable to smaller average seed size, so that if the fruits are of full normal size for species or race, there is no objection to such trees as seed-bearers. The same applies to unsound trees, and trees of coppice or seedling origin are equally acceptable. Initial small differences between seedlings are soon lost, being of little importance compared with innate vigour and individual environment. Provided a plantation has been raised from local seed or from an acceptable outside source of seed, there is no objection to using seed from it.[30]

Effect of dominance in the parent tree has also been examined as a factor possibly influencing the quality of seed, and the conclusion has been reached that although seed from dominant trees tends to give the best results, the reason lies in the greater average fruit and seed size, so that if seed of the same size is compared, dominance exerts very little influence.[30]

Effect of seed size

As a rule, the larger the seed the higher the germination and plant percent[51] and the stronger the seedling at the end of the first growth season—afterwards, site conditions tend to mask this initial gain. An example is provided by the following figures for sal :[24]

Diameter of seed *inches*	Germinative capacity	Plant percent	Height at end of season	Number of leaves
0·60—0·55	75	75	4·0	5·0
0·55—0·50	74	67	4·0	4·5
0·50—0·45	75	69	3·3	4·3
0·45—0·40	73	60	2·6	3·0
0·40—0·35	60	34	2·2	2·4
0·35—0·30	54	19	1·6	2·2
0·30—0·25	28	0	0	0

The marked drop below a diameter of 0·40″ is noteworthy, but it must be borne in mind that these figures only refer to seed from one locality.

In the case of teak, the size of the fruit bears little relation to the size of the seed it contains, and close relationship of fruit size and quality is neither to be expected nor is it found.

Seedling Establishment

Establishment of seedlings

In the case of seed with considerable supplies of reserve food materials, such as sal and oaks, the seedling if kept moist is capable of developing for some time whether it succeeds in rooting in the soil or not, before such reserves, large or small, are exhausted. There is almost always intense competition for space and light on the floor of the forest, and rapid seedling development is of the greatest importance to a species. Only pioneer species colonizing new soils escape this competition and they have to be adapted to their exposed and often relatively sterile environment.

Need for symbiotic organisms

Further development of tree seedlings often depends on the establishment of symbiotic relationships with other organisms in the soil. Indian information on this point is scanty[31] but it has been shown that stagnation occurs in *Leucaena*[32] and *Casuarina*[16] unless inoculation with the nitrogen-fixing bacteria and nodule formation take place, and foreign data show the necessity of infection with mycorrhiza in many other trees, e.g. pines. Ordinarily however these organisms are present with natural regeneration, and growth depends on physical conditions above and below ground level.

Seedling mortality and seedling years

In Chapter I it has been seen how different soil conditions affect growth. Seedlings are particularly sensitive to adverse conditions in the surface layers, which may effectively prevent establishment, as often happens with sal, spruce and deodar for instance, the seedlings developing up to a point and then dying off.

Apart from soil conditions, unfavourable weather may kill off seedlings wholesale ; this is usually a result of drought, but excessively damp hot conditions may so encourage parasitic fungi that cause 'damping off' diseases as to destroy most of a seedling crop. There may also be so strong a growth of herbaceous vegetation as to smother the relatively small tree seedlings even if they have made an earlier start. Variations in these respects necessitate in forestry the differentiation of a *seedling year* from a *seed year*, and it is becoming increasingly apparent that in many dry localities, successful establishment of new seedling growth requires the rare coincidence of a good flowering, seeding and seedling year. Gregarious flowering of bamboos and *Strobilanthes* may periodically permit the establishment of the seedlings which their cover normally prevents.

Dying back

There are some species, among which sal is notorious, in which the seedling usually remains a number of years without making much above-ground growth. Growth on the original shoot more or less stops, and in the next season thin whippy new shoots little or no bigger grow up from ground level or deeper, the process continuing even 20 years without the development of a permanent leader ; gradual growth of the root stock does however take place, and eventually a stage may be reached when a single erect shoot grows up and develops into a tree. That this behaviour is due to faulty growing conditions is shown both by the normal development under the favourable conditions of weeded plantations in the open and the response to light and air ; and the fault lies partly in bad soil conditions induced by a cover of sal leaves, partly in excessive weed competition, and often partly in inadequate light due to excessive overhead shade.[33,34] Similar behaviour is met with in *Terminalia tomentosa*, but it has not been studied in detail. In other instances such as *Bombax*, the dying back of the seedling may be simply ascribable to one or more of the factors, frost, drought and burning, the root stock persisting and growing till ultimately the annual shoot it produces escapes damage and succeeds in getting established. The mortality before establishment is reached is enormous, especially for small seedlings. For sal, a mature tree occupies about 600 sq. ft., which might carry about 300 established seedlings : it is estimated that on an average about 4,000 viable seeds may be dropped on that area each year.

Seedling establishment period

The time required for the establishment of reproduction will obviously vary with species and conditions and is defined[35] as the time lapsing from germination till 'it is unlikely to disappear from adverse influences such as frost, fire, drought, or weeds'.

Seedling foliage

There is frequently considerable difference between the seedling leaves and the foliage of the established tree, sometimes rendering recognition difficult. Thus in species with compound leaves, the first few leaves produced by the seedling are simple (*Lannea*, *Canarium*), whilst in some with simple more or less entire leaves, the seedling leaves tend to be deeply lobed or divided (*Artocarpus* spp., *Morus* spp.). Even with simple entire leaves there may be marked differences, as in *Terminalia tomentosa*. In not a few trees, there are two quite different leaf forms known as *juvenile* and *adult*, the former tending to be the less specialized type : examples are *Pinus* (here the adult foliage is borne on dwarf shoots) and *Eucalyptus*. In many *Mimosae*, only the seedlings bear pinnate leaves, the adult form having phyllodes only. In most of these instances, the juvenile forms tend to be reproduced on the post-seedling stages after injury in any form—burning, coppicing, etc.

GROWTH

Seasonal Changes in Trees

The growth of the established seedling to the timber tree has next to be considered. Growth does not take place continuously and evenly but varies with conditions of temperature, moisture, food supplies, etc., which are largely determined by the season. The seasonal progress of the development of the foliage and flowering, as well as that of growth in height and diameter, has been studied for a number of our common trees, and in much greater detail for allied trees abroad, this branch of science being known as *phenology.*

The seasons are well marked in the temperate hill regions, and the time-table of many of the trees is closely similar to that of the North Temperate Zone, depending on the fact that moisture is generally adequate and temperature is the factor determining the date of commencement of growth in the spring and its cessation in the autumn. Seasonal changes are also well marked in all the drier parts of the country where summer deciduous species are common, but are less so in the moist tropical, though they are usually easily discernible.

Foliage Changes

Leafing leaffall

The time of development of the new foliage depends on species, locality, and the weather of the year ; there are also late and early leafing strains or individuals within a species which may be of considerable practical significance especially where frosts occur (*Picea excelsa* in Europe).

Among tropical deciduous species, the following dates have been recorded at the Forest Research Institute for the beginning of leafing

Species	Date of commencement of new leafing			Date of completion of leafing		
	1934	1935	1936	1934	1935	1936
Sal (1)	Mar. 24	Mar. 3	Apr. 5	May 5	July 26	June 23
(2)	Mar. 16	Apr. 16	Apr. 11	May 5	July 20	June 6
Teak	May 12	May 22	May 18	July 8	July 15	..
Bombax	Mar. 23	Mar. 23	Apr. 3	May 6	May 23	May 26
Sissu	Feb. 15	Mar. 2	Mar. 5	Apr. 10	Apr. 24	Apr. 24
Cedrela toona	Feb. 14	Feb. 11	Feb. 7	Apr. 6	Apr. 5	Apr. 1

and the attainment of full leafy canopy (averages for 5 trees growing in normal situation). Considerable variation is apparent.

The variation among individual trees is exemplified in the following table for the dates of commencement of new leafing in 1936:—

Species	Tree number					Range in days	Average date
	1	2	3	4	5		
	Date of commencement of new leafing						
Sal	Apr. 1	Mar. 31	Apr. 1	Apr. 6	Apr. 15	16	Apr. 9
Mango	Mar. 15	Mar. 31	Mar. 30	Mar. 30	Mar. 29	14	Mar. 22
Cedrela toona	Feb. 2	Feb. 5	Feb. 16	Jan. 28	Feb. 16	19	Feb. 6
Eugenia jambolana	Mar. 10	Mar. 9	Mar. 9	Mar. 8	Mar. 7	3	Mar. 9

The trees for which data are given above all come into leaf about the end of the cold weather, but quite a number of common trees of the tropical deciduous forest such as *Terminalia tomentosa*, *Hymenodictyon*, *Sterculia* spp., etc., remain leafless during the hot weather, only producing new foliage at or shortly before the arrival of the monsoon rain.

Winter buds.

Temperate deciduous species come into leaf between April and June and drop their leaves in September and October as in Europe. Many of them have well developed winter buds, a character not so frequent in the tropical forests, though it is met with in both deciduous (*Bombax*) and evergreen trees (*Lauraceae*, *Magnoliaceae*, *Ochna*).

New leafing in evergreen forest

Among evergreens, the temperate conifers commence shoot extention about the same time as the deciduous trees are producing new foliage. The evergreens of the predominantly deciduous forest such as mango, *Eugenia jambolana* and *Schleichera* all produce the new foliage at the commencement of the hot weather, about March and early April. The new foliage of the temperate evergreens of the S. India hills is very conspicuous from its red or pink colour and appears most prevalent in March and April. Very little is on record for the leafing of the trees of the moist tropical evergreen forest, though here too the new foliage is often conspicuous. Many seem to come into new leaf with the flowers about December/ January (*Hopea*, *Mesua*, *Cinnamomum*), but the maximum new foliage production occurs in March/April, the necessary stimulus being more likely to be changes in the soil moisture after the monsoon season than changes in temperature. Leaf fall has already been considered on p. 58.

Seasonal Progress of Height Growth

Height growth in trees

Studies of the seasonal progress of height growth[36] reveal wide variations with different species, from a simple curve correlated mainly with the temperature curve (*Adina* and teak) or the rainfall curve (*Bombax*), through curves with double maxima when temperature and rainfall seem equally influential (*Acacia catechu*), to complicated curves with several maxima. In the last-mentioned type, a peak usually occurs (sal, *sissu*) early in the season. This is apparently conditioned by a response to rise in temperature followed by exhaustion of food reserves, as detailed foreign investigations in temperate climates show correlation between the growth of the year and the precipitation during the period of rapid growth in combination with the weather conditions and reserves accumulated during the previous summer. This spring maximum is so strong in chir pine as to dwarf all subsequent growth. Typical curves are shown in Diagram IV.

This subject has recently been gone into in some detail for teak in several different types of climate in south India and for a number of the timber trees of Malabar. The rate of height growth has also been correlated with the leaf surface of the young trees and with the size and arrangement of the stomates on the leaves.[46]

Whorled branching

The varying rate of growth during the season is often indicated by the length of the internodes, a fact which often makes it possible to determine the age of a plant by counting the number of levels with pronounced crowding of leaf scars as in teak, magnolias and blue pine ; a mistaken conclusion may be reached if there has been more than one spurt of growth during the year. Contrary to the prevalent idea that trees tend to be drawn up by growth in a crowded stand, it has been shown that height increment is definitely superior when the trees have adequate growing space (as with C-grade thinning, cf. p. 295), though it may fall off a little when the trees are standing in still more open canopy.

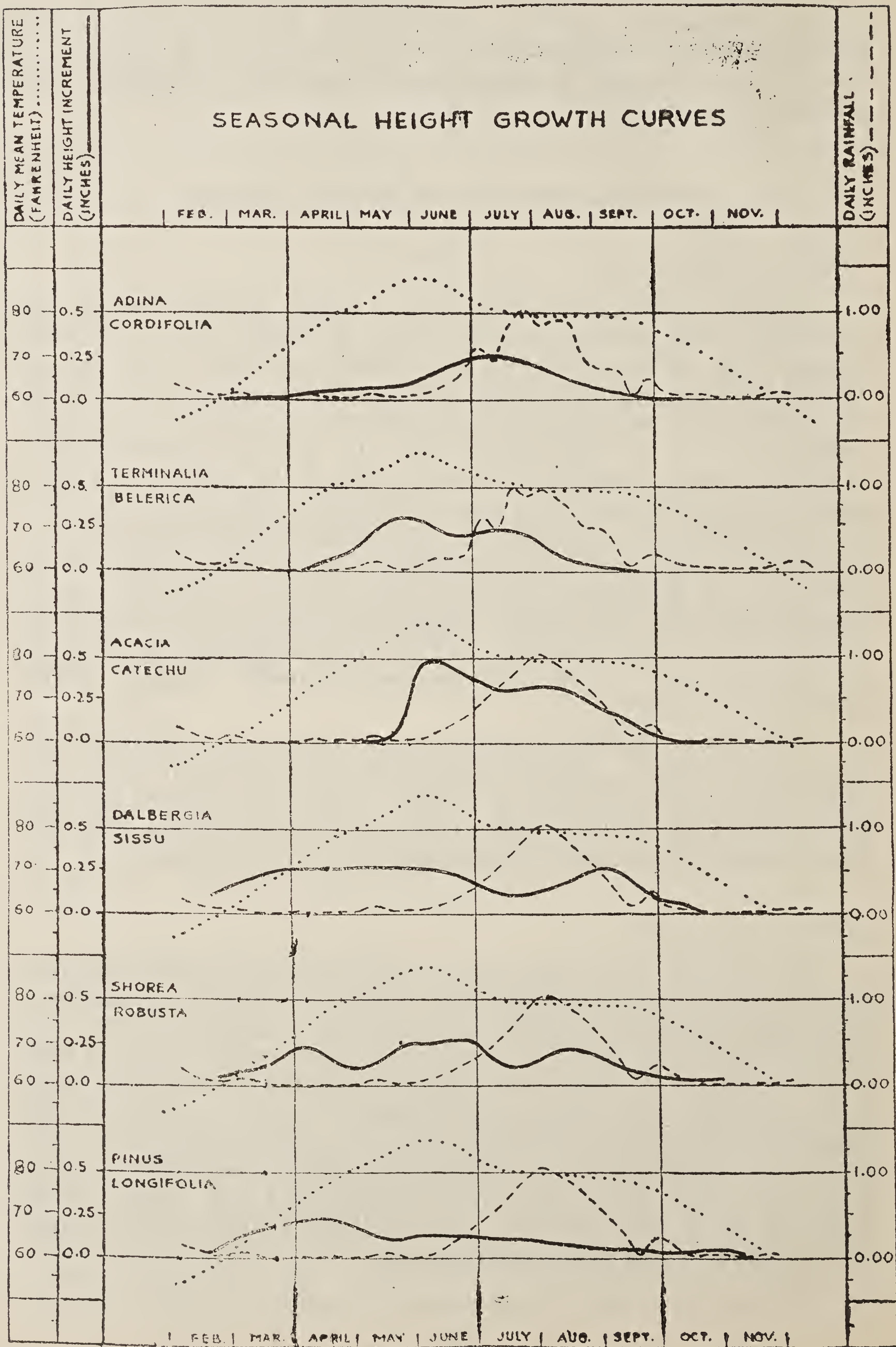
SEASONAL HEIGHT GROWTH CURVES
DAILY MEAN TEMPERATURE (FAHRENHEIT)
DAILY HEIGHT INCREMENT (INCHES)
DAILY RAINFALL (INCHES)
FEB. MAR. APRIL MAY JUNE JULY AUG. SEPT. OCT. NOV.
ADINA CORDIFOLIA
TERMINALIA BELERICA
ACACIA CATECHU
DALBERGIA SISSU
SHOREA ROBUSTA
PINUS LONGIFOLIA
80
70
60
0.5
0.25
0.0
1.00
0.00

Diagram IV

Height growth in bamboos

The process of height growth of bamboos is quite different.[20] Typically, the new shoots appear above the ground only after moist conditions are well established, and then grow at a very rapid rate till their full height growth is attained in a few months; there is no further growth thereafter unless abnormal conditions have caused a check, which may result in a little growth during the next season. This growth, which is mainly by internodal not terminal extension, has been shown to be conditioned by turgidity and hence humidity.[56]

SEASONAL PROGRESS OF DIAMETER GROWTH

Diameter growth

The increase in thickness of stem and branches is brought about by the division and growth of the cells of the cambium which ensheath the wood. These cambial cells are typically narrow and elongate, and divide in the tangential plane, the daughter cells on the inner side being differentiated into wood elements and those on the outer side into bark elements; they also appear to divide radially, but the actual division is probably transverse and followed by sliding growth which results in the daughter cells finally attaining a side by side tangential position, and so providing for the necessary enlargement of the cambium seath.[1] For details of the differentiation of the different tissue elements, wall thickenings, etc., botanical works must be consulted.

Annual rings

The cambial activity varies in both kind and degree under internal or external stimuli, laying down now one kind, now another, of tissue elements at varying rates. In the simple wood of the conifers consisting almost entirely of tracheids, there is a sharp change from the thick-walled tracheids formed in the summer and later part of the year, to the thin-walled tracheids formed in the spring, the converse change being less marked and often inconspicuous. Any other stimulus which results in a sudden change of rate of growth (such as frost, drought, injury) may cause a similar change, but as a rule the darker circular markings seen on a cross-section of coniferous wood correspond to summer wood, and each is an annual ring. Similar appearances occur in the more complex wood of many broadleaved trees, though the annual rings are not usually so easily discerned, except perhaps in *ring porous* woods like teak and chestnut in which renewal of growth is associated with the differentiation of large vessels, such vessels occurring only sparingly and irregularly in the later wood. In many species, of which sal and mango may be taken as representative, a zoning of different tissue elements of different appearance (due to varying refractive power) is evident enough, but these apparent rings are difficult to follow right round the circle and cannot be correlated with an annual periodicity of growth. It is generally easier to discern rings in the pale sapwood than in coloured heartwood (e.g. in *Pterocarpus dalbergioides*).

In yet other timbers such as *Dipterocarpus*, *Guttiferae* and some *Diospyros*, little or no trace of annual rings is to be seen. Although it would be expected that the formation of definite annual rings would be the rule wherever the climate shows marked seasonal variation with a period unfavourable to growth, whether from cold or drought, and similarly for all deciduous species, it seems to be considerably influenced by specific affinities—thus the timbers of *Magnoliaceae* show rings whether deciduous or evergreen, temperate or tropical whilst those of Dipterocarps and fig trees do not. However, in contrast with the European oaks, most of the Indian oaks have very indistinct rings, *Q. incana* (indistinct) and *Q. serrata* (distinct) illustrating the two extremes. Cambial growth has been reported to commence long before the opening of the buds (*Quercus robur*),[1] shortly before (*Picea excelsa*) or even up to a month later (beech); it often continues longer than active height growth; Indian data are scanty, but diameter growth in sal and teak is known to continue after active height growth has finished for the season. Bamboos make no further diameter growth after the first season.[20]

Width of annual rings

The width of the annual rings is primarily dependent on growing conditions, being greater for large-crowned trees with ample growing space, and greater in favourable seasons. It has been possible to correlate average ring width with the sunspot cycle of climate fluctuations in some cases,[37] a discovery of interest and value in dating archaeological finds. Where extra breadth of ring is due mainly to increase of the softer spring wood, it is associated with a falling off in timber density, hardness and quality. This is general for coniferous timbers, and in extreme cases, such as have been recorded for *Cryptomeria* in low altitude plantations in Bengal, it may render the timber practically useless. In most broadleaved trees, however, increase in ring width (or rate of growth) is not associated with deterioration of timber quality, in fact for ring porous woods, moderately rapidly grown wood is on the average distinctly stronger than that which has grown more slowly.[38a] For teak 4-15 rings per inch is the optimum.

It is possible that special silvicultural operations may have to be undertaken in some of the super I quality teak plantations of Eastern Bengal in order to slow down the growth rate to produce a better strength.[52,53]

Heartwood

Heartwood formation

The functional life of the wood elements is usually limited to two or three decades, after which the moisture content falls off and the cells die ; their contents block the cavities and the walls become permeated with various materials which if coloured indicate fairly sharply the limit of the still functional *sapwood* from the central heartwood (cf. p. 65).

Time required for formation

The average number of years required for the transformation of a ring of sapwood into heartwood varies widely, from 10 to 80 years. The only Indian species for which detailed investigations have been made is deodar, in which a variation of 16 to 54 rings of sapwood were found, rather more in slow-growing than in quick-growing trees (the same holds for teak in Java), more in big trees than small ones, and rather more with increasing height above ground. Sal heartwood appears to take 20 to 30 years for its formation. The boundary of the heartwood does not follow the same ring all round the tree but may vary irregularly over several rings. Access of air seems to have some connexion with heartwood formation since injuries seem to hasten it, as also does closeness to dry branch stumps. A typical case is the valuable heartwood of sandalwood. In most heartwood, the spiral vessels become blocked by the formation of *tyloses*, short-lived sack-like outgrowths from the wood parenchyma cells growing through the bordered pits.

Durability

The difference in durability between heartwood and sapwood is often so marked that the latter may completely decay in 1 or 2 years under conditions in which the heartwood may remain sound for 10 years or more. This fact and the superior value of the heartwood for most purposes render the rate of transformation important in forest management, rotation and thinning procedure. It should be noted, however, that strength and other physical properties of sapwoods are only slightly, if at all, inferior to those of heartwood

Maturity and Longevity

Maturity is a term somewhat difficult to define for trees, and it requires qualification to indicate what meaning is to be understood by it. The commencement of flowering and fruiting has been seen to take place often from an early age, though usually full activity in this respect, at least in closed crops, is postponed till the period of active height growth is passed, a phase reached with representative trees such as sal, teak, chir pine and deodar, at about 60 to 90 years of age, depending on conditions. This reproductive maturity is obviously of the greatest importance for natural regeneration.

After the height growth has slowed down, a definite leading shoot is lost and a more or less umbrella-shaped crown is developed. Thereafter the height of the tree remains practically constant till death at a level determined by species and site factors. The tree will continue to grow in diameter and volume for a further period, the duration of which is primarily a specific character but is also dependent on locality and other factors such as liability to injury. The natural durability of the timber is also obviously influential, as is well exemplified by teak and deodar.

Overmaturity

Physical overmaturity would be reached when diameter increment in turn fell off or was offset by decay. In forest practice, however, the term maturity often refers to attainment of the size determined by the objects of management. This may be the size corresponding to attainment of the maximum mean annual volume increment, as retention for a further period then involves a loss in the annual average volume outturn of the forest, but is usually the size corresponding to the maximum average outturn of material of certain specified dimensions. This size is often largely determined by a particular market.

Development of bamboo

A scaly rhizome or underground stem is produced from the base of the seedling plant and, after growing vertically downwards a short distance, curves up again and appears as a small culm. Further rhizome sections develop in succession from the first and follow the same course, penetrating deeper into the soil till the optimum depth of about a foot is reached and sending up successively larger culms. Full-sized culms are produced after 4-12 years depending on species and conditions. The rhizomes often branch, two or more club-shaped lengths, each ending in a culm or culm bud, developing from buds on a single older length. It appears to be unusual for culms to be produced from rhizome sections more than 2 or 3 seasons old. Growth accordingly normally tends to be peripheral, but rhizomes sometimes grow towards the centre especially if conditions are unfavourable. Where the rhizome extends some distance before sending up a new culm, the culms themselves are well spaced out and individual plants often cannot be distinguished from their neighbours, e.g. in *Melocanna*, but in many of the more important species, notably *Dendrocalamus strictus*, the rhizome sections are short and the culms remain close together in a clump. Even from dense natural regeneration, a clumped form ultimately develops by the death of most of the plants, though the surviving clumps probably often originate from more than one seedling. The production of new culms is apparently mainly dependent on weather conditions and the reserve materials accumulated in the rhizomes in the previous season ; in unfavourable seasons no new culms may be produced. The size of clump, method of cutting, overhead cover, and various factors also affect the number of culms.[20,56] The individual culm in *Dendrocalamus strictus* lives about 6 or 7 years.

Longevity

Only for trees with definite annual rings can age at maturity and ultimate longevity be ascertained, and decay at the core often renders it difficult to obtain a direct count. Very few records have been published for Indian trees : they include the following, some interesting foreign figures being included for comparison :—

(*Sequoia sempervirens*)	California	Over 4,000 years
(*Sequoia gigantea*)	California	3,230
(*Taxus baccata*)	England	3,000
Ficus religiosa	Ceylon	2,200
Cedrus deodara (Section in F.R.I.)	Balcha, Tehri-Garhwal	704
Tectona grandis		
(Section in Coimbatore Forest College)	Perambakulam, Cochin	456
(Reported by Anamalais Timber Trust)	Ulandi, Anamalais	Over 500
(Section in Pyinmina Forest College, 16′ 3″ girth)	Burma	408
Dalbergia latifolia		
(Section in Coimbatore Forest College)	Cochin	About 500
(520 rings with a 12″ diameter hollow, 22′ 10″ girth)	Ulandi, Anamalais	About 600
Pinus longifolia	Chakrata	327
Pinus excelsa	Pandrabis, Bashahr	275
Platanus orientalis	Srinagar[5]	293 (Reputed historically.)
Shorea robusta (Undoubtedly reaches a far higher age.)	Saranda, Orissa	168

Crop growth

As a tree crop grows up from a sowing or plantation, it commences as a collection of more or less independent individuals, but before long they come into contact both in the soil and above ground, and commence to react on one another. The same occurs with natural regeneration especially after a good seedling year, but as a rule there is very much less uniformity both in spacing and growth conditions, and this affects subsequent developments in various ways, as will be seen.

Root competition

It is probable that competition sets in between the root systems of adjacent plants before the branches meet, particularly between those of the same species with similar requirements. It is a safe assumption that the bigger the crown, the bigger the root system required to feed it. Reduction of the number of competing crowns carries with it a reduction in the number of competing root systems, and it is difficult to differentiate the effects of the two factors. Experiments with sal at the Forest Research Institute however show that the growth of an overwood is significantly reduced by the root competition of an underwood of coppice shoots. It has also been amply demonstrated that the competition of the root system of an overwood has a markedly detrimental effect on the development of seedling regeneration, though this may be masked (as in experiments with deodar in the Punjab) by the greater effect on competing weed growth. The roots of adjoining woodland may similarly check the growth of a plantation along their line of junction.[39] Moisture supply is believed to be the usual limiting factor, and weak development commonly ascribed to inadequate light is often really due in the first place to excessive root competition for water : this competition of course generally only sets in during the normal dry season or an exceptional drought period, and is unlikely to come into play under the monsoon conditions which usually prevail during the first few months of a seedling's life in many parts of India. It is to be remembered that wide spacing of seedlings may be of little help if the vegetation between them competes as actively as other tree seedlings would. That supply of mineral salts and nitrogen is not primarily involved in this question of root competition is shown by the fact that the application of artificial manures will not compensate for the moisture shortage in untrenched teak plots adjoining older growth.[39] Competition is accordingly of the greatest importance in dry climates both in the tropics (dry deciduous forests and acid areas) and temperate climates (dry deodar forests).

Crown differentiation in crops

As the above ground part of the crop closes up and continues its growth, lateral competition becomes more and more intense as the individual trees all strive to develop the larger crowns they need for full development, and very soon a definite *crown differentiation* sets in, small differences in inherent vigour, in soil conditions, or in minor influences of the general environment, determining the relative position attained. In young regeneration a certain number of the seedlings, either older or with chance favourable conditions, get above the general level and form exceptionally branchy crowns, such plants being termed *wolf-trees*. In natural regeneration they often originate from *advance growth*, i.e. seedlings or saplings which are already on the ground at the commencement of regeneration operations ; in plantations, they are usually developed from seedlings growing on an exceptionally good patch of soil. It is important in the tending of crops to have a standard classification of crown classes and the one adopted for use in India is given on p. 289.

Natural pruning

A very important effect of the closing up of the crop is the hastening of the natural dying off of the lower branches, undoubtedly owing to the reduction of the light reaching them. The denser and more uniform the crop, the more effective is this process, but as already noted (p. 59) there is much difference between different species, some such as *Tsuga brunoniana* having to be kept very dense, whilst others such as *Michelia champaca* and even teak can safely be opened up a good deal without harm in this respect. See Plate 6. The thicker the branch before it dies, the longer it is likely to take in falling, and the less likely it is to break off leaving only a small scar which is readily occluded by the growing cambium all round it.

Reduction of stem number with age

The increasing space required by the growing trees in a crop can only be obtained by a reduction in their number per unit of area, though of course vertical differentiation permits of the development of some at the expense of others. If the numbers of stems in a regular crop are reduced from time to time to an extent which permits the development of healthy crowns on all trees left standing, the conditions to which our yield tables apply, the reduction in numbers with increasing age is very striking ; illustrations are given below. The relation between number of stems and average diameter is closely connected with this : for young crops, quality of site does not make much difference, but with increasing age a tree of given size requires more space on the poorer site—thus for sal, 15″ crop diameter, the numbers of stems per acre are 93, 85, 67 for quality Classes I, II and III respectively. The lighter the thinning, the more stems per acre for a given crop diameter, thus roughly 295, 240, 190, 150 for 15″ deodar, under B, C, D and E ordinary thinning respectively.

Species	Quality and thinning grade	Number of stems per acre at various decades														
		10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Deodar	II E	Many	1612	698	391	273	207	171	149	136	124	114	106	98	91	
	II C	Many	2994	1259	730	506	394	329	293	268	245	228	209	193	180	
Sal	I C	478	288	215	170	140	116	97	81	70	60	53	47	42	38	34
	II C	525	316	241	198	164	138	114	95	80	69	61	53	47	43	39
	III C	572	370	281	224	184	153	124	102	86	74	65	57	51	47	43
	IV C	704	460	326	259	203	163	131	106	90	78	68	61	56	51	47
Teak	I C	234	108	76	61	49	40	32	26							
	II E	268	132	90	72	58	47	39	32							
	III C	320	170	114	89	73	61	50	41							
	IV C	450	255	172	130	106	86	72	59							
	V C	772	472	304	233	194	168	146	125							

Crop diameter increment

The crop diameter increment curve for regular forest follows a very similar course to that for single trees, but flattens off more as maturity is reached, especially if the comparison is made with trees well above average size such as are often used in stump analysis. Reference to the yield table curves does not however indicate any marked falling off at the end of the age-range covered, so that if diameter were the only consideration, there would be no serious loss in retaining crops considerably longer. The irregular crop provides conditions in which the large trees are fairly free from crown competition and so can maintain a high diameter increment for a long period.

Crop volume increment

The following data illustrate the rate of growth of even-aged crops for species for which yield tables are available :—

Species	Site quality	Maximum current annual increment (timber)	Maximum mean annual increment (timber)	Age of maximum mean annual increment (timber)
		cu. ft.	*cu. ft.*	*years*
Deodar	I	250	159	100
	II	199	113	120-130
Sal	I	142	99	115-135
	II	106	70	125-145
Teak	I	180	126	65-75
Chir pine	I	211	131	100
	II	153	86	110
	III	109	54	110-120
Blue pine	I	330	193	90
	II	250	178	90-100
	III	187	106	110

For completely stocked forest, rates of growth per tree are faster. Formulæ have been put forward for estimating growth with open stands.[45]

Rapid volume growth

As examples of rapid growth in other species, the following figures for standing crops before thinning will serve :—

Species	Age	Number of stems per acre	Total standing volume	Mean annual increment	Locality
	years		*cu. ft.*	*cu. ft.*	
Eucalyptus globulus	30	628	15822	541	Mutinad, Nilgiris.
Albizzia moluccana	6	177	3000	500	Andamans.
Cryptomeria japonica	37	201	17487	473	Darjeeling Dn., S.P. 6
Duabanga sonneratiodes	20	147	7538	377	Darjeeling Dn., S P
Betula cylindrostachys	37	153	8912	241	Darjeeling Dn., S.P. 3.

VEGETATIVE REPRODUCTION

The reproduction of forest trees takes place almost entirely by seed. The formation and dispersal of the seed, its germination and the establishment of the seedlings, have already been considered and it only remains to refer to the vegetative reproductive powers.

Root suckers

Reproduction by *root suckers* occurs to some extent naturally (many *Bignoniaceae*, *Garuga*, *Butea frondosa*) but is usually induced by felling the parent tree or by injury to the roots ; in the former case the shoots are developed from adventitious buds formed on any part of the root system (*Flacourtia*, *Ehretia*, and *Stereospermum*), and in the latter mostly at or near the cut ends (*Dalbergia sissoo*, *Bombax malabaricum*), cf. p. 177.

Seedling coppice

The seedlings of many trees, of which sal is the best known are able to produce new shoots ('seedling coppice') from below ground (from the hypocotyl or roots) if the original shoot is injured or checked in growth, and may do this annually for many years ; chir pine also has this power, though it is unusual among conifers (*Podocarpus* has it, too). The development of a thickened more or less fleshy stock is a usual accompaniment to this habit, which is often associated with a habitat involving periodical ground fires.

COPPICE

Coppicing powers

The power of producing new coppice shoots from the stump after the tree is felled is also very prevalent, though sometimes entirely absent. Teak and sal provide examples of good coppicing powers, whilst coniferous trees do not usually coppice at all. The following table gives illustrations of species with different degrees of coppicing powers, but must only be read with the foregoing remarks on the influence of conditions :—

Coppice strongly	Coppice fairly	Coppice badly	Do not coppice
Tectona	*Pterocarpus marsupium*	*Acacia arabica*	*Pinus*
Shorea	*Terminalia tomentosa*	*Adina cordifolia*	*Cedrus*
Dalbergia spp.	*Terminalia belerica*	*Bassia latifolia*	*Picea*
Acacia catechu	*Quercus incana*	*Hardwickia binata*	*Abies*
Albizzia spp.		*Bombax malabaricum*	
Anogeissus latifolia			
Eucalyptus globulus			
Eugenia jambolana			
Salix spp.			

PLATE 6. Natural pruning. (*L*) Natural regeneration of *Hopea parviflora* showing clean stems, Coorg. (*R*) Plantation of *Tsuga brunoniana* in which the process is very slow, Darjeeling, Bengal.

Facing p. 104.

Effect of size of tree

The size of the tree is influential, coppicing power very generally falling off as the tree increases in size ; if shoots are produced from big trees, they tend to be weak and short-lived, even if vigorous young poles of the same species will coppice strongly. (*Terminalia tomentosa* is a good illustration of such behaviour.)

Influence of light

Access of light is a most important factor in coppicing, the new shoots appearing to have very high light requirements, but excessive exposure is liable to result in the drying up of the bark and failure. The shoots may depend entirely on the root system of the parent stock, but it is not unusual for them to develop their own roots and for the stock to rot away—the usual method of propagation of *Platanus orientalis* (Kashmir *chenar*) depends on this ability.

Rate of growth

Coppice shoots grow at first much more rapidly than seedlings of the same age, but as a rule the seedlings tend to catch up to the coppice and even to surpass it after some years. Teak seedlings sown in *rabs* have been noted to catch up to the coppice in about 7 years in clear-felled coupes (Kolaba, Bombay), whilst with sal in the Gorakhpur *taungyas*, the seedlings are said to equal the coppice in height in about 6 years[40] though this figure is almost certainly too low.[41]

Cuttings

Rhizome cuttings

Bamboos can usually reproduce the plant from a portion of the rhizome including a growing point.

Stem and branch cuttings

Some trees can reproduce a root system if small stem or branch cuttings are stuck in the ground, examples being many of the figs, *Dalbergia sissoo* and *Tamarix articulata*, but the faculty does not seem to be so well developed in tropical trees as in those of temperate climates (*Populus ciliata* and *P. euphratica* strike with difficulty in contrast to the European and American poplars). Examples of the use of cuttings are given on p. 240.

Examples of species that will strike from quite large branch cuttings (as large as fence posts) are some of the willows, *Poinciana elata* and *Commiphora* species. This is a particularly useful attribute in the afforestation of dry areas.[54,55]

Root sections

In a few species, the whole plant can be reproduced from a root section, *Bombax malabaricum* providing an example of this. Very interesting discoveries have been made of late concerning the physiology of growth, which has been shown to be initiated and regulated by the presence of definite growth substances in minute amount only demonstrable by their effects. The regeneration of roots on sections of stems and roots has also been studied but cannot be discussed here.

Stumps

Both root and shoot systems can be regenerated from a length cut from the main axis of a seedling to include a portion of stem and taproot. Such *stumps* (formerly known as root and shoot cuttings) are being used to an increasing extent in plantation work. (Cf. p. 238.)

INHERITANCE OF PARENTAL CHARACTERS

Racial strains

Conclusive proof is now available that many tree species are composed of a complex of different races which may differ in almost any character, including the important ones for forestry such as vigour, rate of growth, susceptibility to damage by climate, insect attack or disease, growth habit including branchiness and bole form, and even timber properties and appearance.

Racial inheritance

The characters of these races tend to be handed down to successive generations through the seed with the usual complications, now fairly well understood, due to the crosses which freely occur. Often the character inherited is a tendency or liability the results of which only become apparent under certain environmental conditions. In India, the only detailed studies we have are those demonstrating the inheritance of the tendency to spiral grain in strains of *Pinus longifolia*,[42,43] as illustrated in Plate 7, and of the leaf

PLATE 7. Inheritance of stem form in chir pine. (*Above*) 14-year old crop raised from seed from a straight-boled strain. (*Below*) Crop raised from seed of a strain with bad bole form attributable to spiral grain. Both photographs, Almora, U.P.

Facing p. 106.

and shoot form in races of teak from different parts of the country,[38b] but there is every reason to believe that such races exist for most of our species especially those with a wide geographical distribution (above all if this is discontinuous, as for teak), or a wide altitudinal range (as for *Pinus excelsa*).

Examples

The following conclusions have been drawn[30] from a survey of Indian information and related foreign experimental work in this field :—

(1) Individual bole shape, branchiness and spiral grain when due merely to position in the crop or to injuries incurred, have no hereditary value, but it is usually impossible to discern whether bad shape is of individual or racial origin.

(2) Marked bark variations occur within a species, e.g. *Acacia arabica* and *A. catechu*, and have been demonstrated in some cases to be inherited and associated with other characteristics of growth form, etc.

(3) Left-handed spiral grain in pines is or may be transmitted through the seed and developed in the individual without the action of adverse locality factors ; the latter do however tend to develop and intensify any existing tendency to twist.

(4) No information exists as to whether figured grain is an inherited character or not though the subject has been under study for a number of years. The production of solid culms in *Dendrocalamus strictus* is probably an inherited character.

(5) Strains with characteristic foliage and fruit forms, which may be associated with crown, bole and timber characters, exist within a given climatic race, and this is probably also the case for shape of bole.

(6) Parental seasonal history tends to be reproduced in the offspring of a tree, a feature which may have an important effect on survival and tree form under pronounced climatic conditions involving frosts or drought.

(7) It is very probable that strains of different disease-resisting powers exist in tree species as in short-lived plants, the ultimate reasons being phenological, anatomical or physiological. The position is the same with regard to insect attack.

(8) There are ample grounds, if no strict proof, for the belief that quick growing strains exist in most tree populations—similarly for high resin-yielding strains in *Pinus*.

(9) It has been amply established in other countries that the rate and form of growth of some species vary appreciably with

altitude, and that the differences may be inherited and apparent in sapling or small pole crops grown at different elevations.

(10) It appears that inferior growth due to poor soil conditions may sometimes become an inherited racial character.

Hybrids

Mention should finally be made of the phenomenon referred to as 'hybrid vigour', when a first hybrid generation shows greater vigour than either of the parents. Hybrids in the genera *Larix*, *Populus* and *Salix* are the best examples but no clear case has yet been reported from India.[30]

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III

TREE AND CROP PHYSIOLOGY

WATER RELATIONS

WATER ABSORPTION

Absorption from the soil

As described on pp. 66-9, the ultimate ramifications of the roots are set just behind their growing tips with unicellular thin walled root hairs, though sometimes these are replaced by a mycelial felt of mycorrhizæ. These root hairs and fungal coatings have been shown to be the only parts through which the soil solution is absorbed by the root system ; they come into extremely close contact with the soil particles, and by osmotic and adsorption forces are able to extract much of the moisture held on and between their surfaces. The solution appears to be stored at first in the loose tissues of the cortex, and then passes through the specialized endodermis layer to the conducting tissues which are free of air.

Root pressure and bleeding

If a tree be cut, particularly when the new foliage is expanding, there is sometimes considerable 'bleeding' of watery sap containing sugar and small amounts of other materials. The excretion of this sap is evidently due to pressure from the root system, which can be shown to vary from a low figure up to as much as 8 atmospheres ; but it is absent in many trees (e.g. some pines) and varies greatly with season in others, and so cannot be the chief factor concerned in passing on the solution to the above ground parts.

Wilting point

Plant roots can absorb moisture from ordinary soils till the residual amount has dropped to a limiting figure which varies from 20 per cent in fine clay soils to below 1 per cent for coarse sandy soils.[1] When this limit is reached, the plants wilt permanently, most species on the site indicating practically the same figure. The more *mesophytic* plants and communities which are structurally less adapted to minimize water losses tend to occupy soils with high water content at wilting point, and the better adapted *xerophytic* plants those with low water content at wilting point.

Crucial depth for seedling roots

Under the usual Indian conditions, which include a prolonged dry season, it is essential for new seedlings that their roots should penetrate during their first growing season to a depth greater than that to which the soil dries out to the wilting coefficient, especially as the air is very dry and hot dry winds are prevalent at the same time. Thus for sal, it appears that this depth may be about a foot in North India in an average season.

Effect of soil acidity and salinity

Water absorption is difficult in acid or saline soils, and the wilting point is reached with a higher percentage of water than in average soils : such soils are said to be physiologically dry, and though they may be visibly moist or even wet, the vegetation they carry may be decidedly xerophytic. The roots of mangrove vegetation maintain osmotic pressures as high as 40 (*Avicennia*) or 60 (*Sonneratia*) atmospheres during the monsoon as compared with 20 atm. for the soil solution, and in the dry season, when transpiration is more active, the figures may rise to 80 or 90 atm.[6]

Conduction

Passage through the stem

If a narrow ring of bark down to the cambium be removed from a tree, it is usually a long time before there is any visible effect on the health of the tree. If however it is girdled deeply through the outer layers of wood, death normally ensues after a few days or weeks, the portions above the girdle drying out. This and other experiments serve to demonstrate that the moisture absorbed by the roots travels up to the crown through the outer layers of wood, and not through the heartwood in species in which there is heartwood differentiation. There is direct longitudinal communication between the tissues of the outermost annual ring of wood and the absorbing root hairs and conduction is greatest in this layer, falling off gradually inwards to *nil* in the heartwood the vessels or tracheids of which are full of air and often blocked with tyloses and secretions. In *Robinia* only 1½ rings are functional in this way ; in birch 15 rings. Lateral conduction is relatively slow though provided for in tissue and cell structure.

Mechanism

A great deal of study has been devoted to determining the mechanism of the upward 'transpiration current', the outcome of which is the conclusion that it is the great cohesion of water, as expressed by the resistance to rupture of a thin column, which is the chief factor. The current will pass through dead tissues and so is evidently not directly a vital process. If a gas bubble forms in a trachied or vessel the bubble will immediately extend to fill the whole of it under the tension conditions prevailing in the bole of a tree. The structure of the conducting tissue elements is accordingly such as to restrict the rupture to a single element, and the familiar bordered pits on the walls are excellently adapted to fulfil this function whilst facilitating vertical and horizontal communication till such rupture occurs. Not only has a column of water up to 300 ft. long to be maintained (corresponding to pressures up to 10 atmospheres), but it has to be moved against the very considerable frictional resistances offered by the very fine tubes and their cross walls. This resistance varies directly with the rate of flow and inversely with the fourth power of the diameter of the tube[2]; it may exceed the weight of the water several times and amounts to about 0·1 atmosphere per foot length. The rate of flow varies from 6″ to 8″ an hour, and exceptionally to as high as 20 to 30 feet for *Eucalyptus* with vessels several yards long.[2] The necessary force is found to lie in the suction of the cells of the leaves, as will be described later.

Transpiration

Rate of loss of water

The leaves lose water continuously by evaporation. The rate of this transpiration varies greatly with conditions prevailing in the leaves and the physical conditions of air, humidity, temperature and light. Transpiration rate increases as humidity falls and it is increased by rise of temperature and by light.

Structural modifications for reduction of transpiration

Transpiration from the leaf may be reduced by structural details such as thickened cuticle, sunken stomata, hairy or waxy coat, etc., these xerophytic characters all being associated with physically or physiologically dry conditions at least at some season of the year.

Effect of deciduous habit

A summer deciduous habit is a most effective xerophytic adaptation commonly met with in regions with marked dry and wet hot seasons, reduction of leaf surface and protected leaves being more usual in permanently dry sites. It is accordingly the more remarkable that a number of the tree species of the deciduous forests come into new leaf in April and May at the hottest and driest season of the year when transpiration is at its highest and soil moisture at its lowest. Such trees are *Cassia fistula*, and *Lannea grandis* whilst *sissu*, sal, and others leaf out in March when it is already hot and dry. This phenomenon calls for quantitative studies of the water relations involved, but it appears that the rate of transpiration only increases up to a certain relatively low value, about one-fifth the rate of evaporation from an open water surface, and then remains almost constant.[7] The significance of the deciduous habit in tropical forests has been much discussed of late and is clearly a complicated matter.

Mechanism of water movements

The water evaporated from the cell wall of the leaf cell is replaced by imbibition from the cell contents, and the cell contents in turn absorb it osmotically from the water channels of the leaf veins. The osmotic forces available are found[8] to be up to 40 atmospheres for ordinary forest trees (*Rhododendron grande* 6 atm., deodar 20 atm., *Azadirachta indica* and *Grevillea* 18 atm., *Tamarix gallica* 50 atm.) and even up to 100 atmospheres in some mangroves[6] (200 atm. have been reported abroad). This is more than enough to lift the sap to the tops of the highest trees without the aid of root pressure or vital processes, but it may be limited by the smaller maximum osmotic power of the lax-walled parenchymatous cells of the leaf, the collapse of which would stop the process. The forces of cohesion ensure the transmission of the lifting forces to the roots, and the tissue structure ensures localization of any breakdown due to the formation of gas bubbles. The root hairs lose water to the conducting elements in the root and replace it by absorption from the soil.

Inorganic food in transpiration current

The maintenance of the transpiration current is essential for the supply of inorganic food carried with it even where transpiration is kept low by a moist atmosphere, and actually an appreciable amount of water is absorbed from the wood by the leaf parenchyma in dissolving the products of assimilation.[2]

Quantitative Data

Water consumption of forests

There are many difficulties in arriving at the annual water consumption of a forest, but European workers have arrived at figures varying from 11″ depth (or rainfall) for beech crops down to 2″ for pine[9]. Indirect methods involving the analysis of the total precipitation on the forest into evaporation, run-off and transpiration lead to fairly similar figures. It is of interest to compare this water consumption with that of agricultural crops, estimated at 5″-6″ for cereals and about 3″ for meadows.[10]

Unfortunately, practically no data are available for Indian forest trees[7] and deductions by analogy from European data are unwarranted and liable to be dangerously misleading.

It is interesting to compare the above figures with the 3′ to 5′ delta usually given annually to the irrigated plantations of the dry areas of north west India but it must be remembered that we do not know how much of the delta is actually consumed by the forest crop and how much is evaporated.

LIGHT RELATIONS

Sun and shade leaves

On many trees, leaves growing in the shade are thinner and tend to be larger than those growing fully exposed to light. It is evident that this is an adaptation to varying conditions and explains why plants raised in the shade (and so bearing predominantly shade leaves), may thrive better than plants raised in full light when both types are planted out in shade—and conversely—as the formed leaf is no longer capable of adaptation to the new conditions, and works less efficiently under conditions to which it is not suited.

Intensity of Light in the Forest

Variations in intensity

The intensity of direct radiation increases with increasing altitude more than the intensity of diffused light falls off—as it does rapidly. This results in changes in the apparent light requirements of a species at different altitudes, and accounts for the greater importance of aspect as one ascends hills. Passage directly through two or three leaf thicknesses is sufficient to absorb almost all measurable light, and the light below the tree canopy is that which has got through the gaps, having mostly been reflected repeatedly from the leaf and other surfaces. The extent to which the incident light is reduced depends on the minimum intensity with which the leaves of the canopy can function, for if conditions would not permit of this they would not be developed, or if present they would die. This varies greatly with species ; very few data are available for Indian trees but European data serve to illustrate various of our types, thus a *Buxus* canopy which is densely evergreen causes a reduction in the interior of the crown to less than one-hundredth that of the incident light, as contrasted with *Larix* or *Acer* causing a reduction to about one-fifth.[2] Under a high canopy, the reduction is less than this and depends on the locality and thinning intensity, more light getting through, the cooler, poorer and drier the locality ; in other words, the minimum light-demand of the shade leaves is higher in such places. The ordinary range of thinning intensity corresponds roughly to a 100 per cent range of light passing through the upper canopy.[2]

Measurement of light in the forest

There are difficulties in measuring effective light intensity in the forest owing to the different values to the tree of light of different wave lengths, and to the diurnal and seasonal variations in the position of the sun. To some extent these difficulties can be overcome, and instruments devised to give practicable results,[11,12,13] but considerable caution is advisable as indicated by the marked disagreement between data recently reported from Borneo and Malaya.

Ground vegetation as indication of light quality

It should be realized that the ground vegetation itself, if in its natural undisturbed condition, is the best practical indication of the light reaching it ; in fact the use of standard plants for measuring effective light intensity has been extensively developed by leading workers on the subject.[14]

Effect of light on regeneration

Regeneration generally is more tolerant of shade than are older trees. The technique of natural regeneration depends to a considerable extent on the regulation of the light reaching the forest floor and consequently the seedlings growing there. By manipulating the leaf canopy in a way most favourable to the regeneration, it is possible to enable the latter to establish itself and ultimately to replace the parent crop. This subject is discussed more fully in Chapter V.

Light-demanders and Shade-bearers

Description

It has been customary to make a rough classification of forest trees into *shade-bearers* and *light-demanders*, though it has long been recognized that the terms are relative and require much qualification as to conditions to be of much practical value. This becomes apparent directly an attempt is made to classify trees on this basis. Shade-bearers are those, mainly evergreen in this country, which are capable of regeneration and development under a more or less complete canopy of other species, whilst light-demanders require more light for regeneration and development.

Examples

For the three most important forest types the following examples will serve :—

Moist temperate forests

Light-demanders . .	*Pinus excelsa, Populus ciliata,*
Moderate shade-bearers .	*Picea morinda, Quercus dilatata, Cedrus deodara.*
Good shade-bearers . .	*Abies pindrow, Taxus baccata.*

Tropical moist deciduous forests

Light-demanders . .	*Bombax malabaricum, Shorea robusta, Tectona grandis, Adina cordifolia, Terminalia* spp.
Moderate shade-bearers .	*Cedrela toona, Dalbergia latifolia, Pterocarpus marsupium.*
Good shade-bearers . .	*Xylia, Schleichera, Mallotus philippinensis, Eugenia jambolana, Litsaea sebifera, Careya.*

Wet tropical evergreen forests

Light-demanders . .	*Dipterocarpus* spp., *Calophyllum*, *Sterculia alata*.
Moderate shade-bearers .	*Artocarpus* spp.
Good shade-bearers . ..	*Mesua ferrea*, *Palaquium*.

Similar lists have been published for particular provinces or districts.[15,16] It has been questioned whether any of our shade-bearers can be termed shade-demanders at any stage of their development.

Variation with age

Full exposure of seedlings to the sun is likely to imply drought as well as intense light and heat, and some of the species of the tropical evergreen forest do seem to benefit from a certain amount of shade during their first two or three years of growth, e.g. *Palaquium*, *Artocarpus*, *Swietenia* and *Eugenia* spp., but they too grow better with full light in all later stages. Again, many species will not regenerate naturally on soil fully exposed to the sun (deodar, silver fir, *Morus* and *Olea cuspidata*) though in their later stages they may be merely shade-bearers or even light-demanders.[17] The root competition investigations already referred to have shown that failure of regeneration to become established under shade is often in part due to factors other than inadequate illumination, but light intensity and its indirect consequences are probably the chief factors none the less.[18]

Side shade

The effect of side shade is often important, especially to small regeneration where the various strip systems aim at applying available knowledge on the subject ; deodar regeneration, for example, is greatly benefited by side shade. In a strip a chain wide running east and west cleared in forest on flat country in N. India, the sun will rise in the east round about midsummer and will pass more or less vertically overhead so that there will be no shade at all except directly below the crowns of the marginal trees. At the end of the monsoon, say in mid-October, the sun will be rising somewhat south of east and will never be overhead, so any seedling regeneration along the southern edge of the strip will be appreciably shaded and will be cooler and moister than the exposed northern edge, conditions between varying with the latitude, date and height of forest. The post-monsoon drought is a dangerous time for new recruitment and the difference may be important, though perhaps not so much so in India as in Europe.

It must be remembered that in South India at mid day, the sun is to the north in the summer months and to the south in the winter months and hence arrangement for shade for young regeneration is far more complicated than say in the Bengal regeneration areas where the sun is always to the south and an east/west shade line always gives shade on its northern side.[23]

Leaf mosaic, etc.

Leaf Arrangement and Light

In hot dry climates, full sunlight may be more intense than the optimum for the foliage, and adaptations are met with to reduce the incidence. Whereas in temperate climates the leaves tend to be disposed and shaped so as to intercept the maximum amount of light (*Acer* provides a pretty example of such a leaf *mosaic*), in dry climates the leaves tend to assume an edge-on position and their long axis may be more or less vertical instead of horizontal as in the adult leaves of *Eucalyptus*. As noted, many of our species are leafless when exposed to the strongest summer light and a dry atmosphere.

Coloured foliage

A marked feature of many evergreens is the red colour of the new foliage due to the presence of *anthocyanin* and lack of chlorophyll. The young leaves as they unfold may be white or pale pink, the colour deepening till it may be a brilliant red, and then darkening off to the normal green as chlorophyll is developed and the anthocyanin fades out or is at least masked. Mango shows these stages without the brilliant red phase which is seen in *Schleichera*, and still better in *Mesua* and the montane temperate forests of S. India. Experiments have shown that the red anthocyanin acts as a light screen, protecting the young leaves. When persisting in older leaves, as in red foliaged varieties of many trees, it only allows assimilation to begin above a certain intensity of light.

Other Effects of Light

Germination

It has already been mentioned (p. 84) that light affects germination to an extent varying with different species, at least for herbs, from completely inhibiting it to being essential.

Bud development

It has often been suggested that the development of epicormic shoots on suddenly isolated trees is due to light stimulus on dormant buds, but other factors appear to be more influential even though light does in fact promote the sprouting of buds.

Natural pruning

The death of the leaves of the lower branches of a tree or crop through the shade cast by the upper canopy results in the death of the branches carrying them and so to natural pruning. This gives the clean boles required in forestry. Further, the continued restriction of the crown to the upper part of the tree results in the development of a much more cylindrical stem form than would otherwise be formed, so that regulation of light conditions by thinning provides the forester with a powerful weapon for regulating the form and quality of timber raised.

Light increment

Free access of light results in the development of a relatively large crown to the tree, and consequently rapid growth. It is accordingly a common procedure under organized management to increase considerably the space available to trees towards the end of their life, after they have been raised in close crops until long branch-free boles have been formed. The light stimulus so given results in a rapid diameter growth of these good boles, which is known as *light increment*.

FOOD RELATIONS

Carbon Assimilation

Chlorophyll and other pigments

When light passes through a leaf it is in part absorbed, notably a band of rays in the red end of the spectrum and one in the violet. Though there are minor differences, this absorption is similar for all species and is known to be due to the green substance called *chlorophyll*. With the chlorophyll are usually present varying amounts of two yellow pigments of less importance, viz. *carotin* and *xanthophyll*.

Synthesis of sugar and starch

The chlorophyll occurs in plastids in the cell protoplasm, and when exposed to light is capable of bringing about the assimilation there of atmospheric carbon dioxide, with the formation of carbohydrates. The energy required to effect this is obtained from the solar rays absorbed. The first carbohydrates to appear are sugars such as *glucose*. The accumulation of these osmotically active sugars would react unfavourably on the cell activities, and they are rapidly further polymerized to starch. The formation of chlorophyll itself requires light (with rare exceptions, e.g. the cotyledons of conifers), but light of almost any wave length or of a very weak intensity suffices.

Liberation of oxygen

The assimilation of CO_2 is accompanied by the release of an equal volume of oxygen. The carbonic acid is present to the extent of 0.03 per cent of the air and reaches the interior of the leaf by diffusion through the stomata—a far more efficient process than might be imagined, owing to the physical properties of small apertures —and the rest of the process occurs in solution.

The size, arrangement, spacing and physical efficiency of the stomata of a number of the timber trees of Malabar have recently been studied.[24]

Respiration

Respiration in leaves and roots

There is another process going on in the tissues also involving oxygen and carbonic acid, viz. *respiration*, by which organic substances are oxidized to carbonic acid with the absorption of oxygen. In leaves exposed to light, respiration is completely masked by carbon assimilation, but under other conditions it results in the continuous using up of oxygen and liberation of carbonic acid. This same process in roots and soil organisms results in a much higher CO_2 percentage in the soil gases, even $\frac{1}{2}$ to $\frac{3}{4}$ per cent, which is constantly diffusing into the air in quantities almost enough to supply the whole requirements of the vegetation covering the soil. Assimilation is increased by moderate increases of CO_2 in the air, but 1 per cent already begins to have deleterious effects.

Effect of Temperature

Assimilation is increased like all other chemical reactions by rise of temperature, but complicating factors intervene and a maximum is reached at about 100°F. ; the process practically ceases at 112° F. (in Europe). *Respiration* increases much more rapidly with rising temperature than does assimilation, increasing twofold or more for a 10° rise of temperature. It has been found to use up about 30 per cent of the products of assimilation.

Nitrogen Assimilation

Protein synthesis

Even less precise information is available about the synthesis of organic nitrogen compounds, but the evidence favours the view that this process too takes place chiefly in the leaves, which are found to contain more protein by day than by night, nitrates accumulating in darkness. Light is not essential for protein formation but the presence of carbohydrates, potassium and calcium has been demonstrated to be necessary.

Other sources of nitrogen

It has already been mentioned in connexion with the soil (pp. 42-3) that certain plants are not entirely dependent for their nitrogen supplies on protein synthesized in the leaves from inorganic nitrogen reaching them with the transpiration current. Plants with mycorrhizae are able to utilize the more complex nitrogen compounds in the soil, and those with bacterial nodules obtain nitrogenous organic substances built up by the bacteria from atmospheric nitrogen and carbohydrates, etc., supplied by their hosts. The bacteria or fungi penetrate from the soil through the root hairs, and they or the products of their metabolism seem to be absorbed by the host, and good growth is possible on media devoid of or poor in nitrogen.

Inorganic Food Supplies

Phosphorus is an essential constituent of protoplasm especially for the nucleus. It is accordingly required wherever cell division is active, and conversely, growth, particularly root growth and the setting of seed, is checked by phosphorus deficiency.

Potassium is necessary for carbohydrate and protein synthesis and seems particularly important to the proper development leguminous plants. With potash deficiency, the leaves remain small and weak. Potash forms 15-40 per cent of the mineral ash of timber.

Calcium

Lime is also necessary for carbohydrate and protein synthesis, possibly in connexion with phosphorus metabolism. Deficiency causes stunting and discolouring of the roots. The role of lime in the soil however appears relatively much more important than its role in the plant. It is present to the extent of about 10-50 per cent in the mineral ash of timber.

Magnesium is an actual constituent of chlorophyll to the extent of 3 per cent and of some protein substances such as the *aleurone grains* of seeds, and it is always present in actively dividing tissues as well as in the sieve tubes. In wood ash it is present to about half or third the amount of lime.

Iron

Small quantities of iron are necessary for the formation of chlorophyll though there is actually none in it. There is usually about 1 per cent in wood ash but there may be considerably more or less.

Manganese is also always present in plants and may even form over 20 per cent of wood ash ; the salts have a stimulating effect on growth processes at least in some plants, but the function of this element is not understood.

Silicon

Silica occurs as a component of the cell wall and is sometimes deposited in the cell cavity ; there is very little in timber (chir pine 0.01 per cent), and it appears to be largely returned to the soil with the leaves ; it is present in greater quantity in bamboo stems, even up to 8 per cent having been found.

Other elements

It is unnecessary here to refer further to the other mineral nutrients such as sodium and chlorine, as even if they may be essential in small amounts they are always available to that extent.

Law of minimum

The theory has been propounded for plant nutrition that it is the factor which is present in minimum amount relative to requirements, which determines the total amount of production. Thus, if any one essential element is only available in quantity below requirements, productivity falls off even if all the other substances are available in quantity. Though not as generally applicable as it has been represented, this theory does appear to account for behaviour in many instances, and for forest trees, nitrogen supply sometimes seems to be the limiting factor and, less commonly, phosphorus.

Quantitative data

The actual amount of organic material elaborated by a forest in a year is of interest. Taking the maximum current increment of even-aged crops, sal annually forms about 5, 4 and 3 tons of dry wood per acre per annum on sites of Quality Class I, II and III respectively, and chir pine similarly 6, 4½ and 3 tons. Of these total weights, ½ per cent and ⅓ per cent is formed by inorganic substances to which lime contributes over one-half in sal and rather less in the pine, and silica only a twentieth in sal but half in pine. The available data indicate that there is not a great deal of difference between the total weight of material which can be built up by different species on a given site, nor between herbaceous and woody crops.

TRANSLOCATION AND STORAGE OF FOOD MATERIALS

Apart from nitrogen assimilation in the root nodules the food materials, primarily carbohydrates and proteins, are in the first place built up in the leaves, and from there have to be distributed throughout the living plant, particularly to the growing points of root and shoot systems.

Translocation in sieve tubes

It has long been known that this translocation occurs largely through the phloem tissues, particularly the *sieve tubes*, which like the conducting tissues of the wood provide continuous longitudinal lines of communication from leaf to root tip. Whereas the conducting wood elements are empty of protoplasm, the functional sieve tubes retain their plasma lining and so provide for the transport of sap without loss of the food materials it carries, the latter not being above to diffuse through the membrane. Only the youngest phloem is functional in this way, the sieve tubes becoming blocked after about a year. The sap in the sieve tubes may contain up to 20 per cent solutes and it circulates with a rapidity of the same order as the transpiration current, i.e. a foot or so an hour.

Mechanism of descending sap stream

The mechanism of the movement of the descending sap stream is that of a simple pressure filtration, the driving force being the osmotic energy of the newly formed assimilates in the leaf, and the pressure fall that due to the loss of osmotic force where the dissolved substances are used up in non-soluble forms such as cellulose, starch, etc., where growth or storage is in progress. Diffusion processes alone would be completely inadequate to account for the facts.

Translocation and storage in the wood

It requires to be mentioned that translocation of organic food materials is not however limited to the sieve tubes or to the phloem, for the sap in the wood frequently contains much sugar and other organic substances. Starch is stored in quantity in the wood parenchyma and medullary rays behind growing points, and is latter mobilized and delivered to the growing cells by the transpiration current. Similarly in trees producing large crops of starchy seed such as oaks, there is a preliminary big accumulation of starch in the outer rings of wood, which is presently carried out with the transpiration current as sugar to the fruiting twigs. In this connexion reference may be made to the fact that in winter the stored starch may be temporarily converted into sugars, which appear to increase resistance to damage by low temperatures. The sap exuded from cut stumps of some species has already been mentioned as containing much carbohydrate in solution, and some trees, like the Canadian sugar maple, are 'tapped' for sugar extraction.

Bamboos accumulate a store of starch in the culms and in the rhizomes and this reaches a maximum just before to the new culms begin to develop. In the early part of the rains this starch is converted into sugars and the new culms develop. By the winter when the development of the new culms is complete the bamboos are almost devoid of starch. This starch content is the main attraction for many insect borers and hence to avoid borer attack the culms should be cut in the cold weather when the starch content is lowest. During the war this was one of India's biggest forest problems in the supply of bamboo tent poles, chiefly to the Middle East.

Translocation in latex

In trees with laticiferous tubes, there is little doubt that these play a significant part in the conduction of carbohydrates and other food materials, and it has been found in some *Asclepiadaceae* at least, that a well developed laticiferous system is associated with poorly developed sieve tubes. Starch is conspicuous in the latex tubes of *Euphorbiaceae* often in the unusual form of dumb-bell shaped granules. The milky appearance is mainly due to minute globules of caoutchouc, resin, gum, etc., which coagulate and harden on exposure and so serve to occlude wounds, and, being unpalatable or poisonous, fill a protective function also.

Losses on leaf fall

It might be imagined that there is a considerable loss of material to the tree when the leaves are shed, but it has been found that in temperate forests at least, 25 to 70 per cent of their nitrogen content, 20 to 40 per cent of the phosphorus, and 10 to 50 per cent of the potassium, is removed beforehand. Lime does not appear to be removed and may even be found in greater quantity in falling than in green leaves, and similarly for the less important silica ; it is probable that the lime has fulfilled its function when it is separated out as crystals of oxalate. Particularly in view of the great value of lime in the humus and soil, this return of material is by no means a total loss to the vegetation.

Parasitism

The only important tree which is parasitic on other plants is sandal.[19] The seedling is at first independent but cannot live more than a few months without effecting haustorial connexions between its roots and those of other plants in its vicinity. Commonly, it first parasitizes herbs or shrubs as temporary hosts before finding the roots of suitable trees capable of serving as permanent hosts. It may form haustorial connexions with other sandalwood trees. The haustoria are not always easy to trace but are often formed in large numbers particularly with certain hosts. As sandal has a fairly normal crown of foliage, it is presumably able to assimilate its needs for carbohydrates and proteins, but depends to an undetermined extent on its hosts for moisture and inorganic food.[25]

Other parasitic plants are important as forest pests, among which the epiphytes *Loranthus* and *Viscum*, with normal green leaves, and the climber *Cuscuta* lacking leaves and chlorophyll, are the chief.

MOVEMENTS

Orientation and Movements

Tropisms[3]

The direction taken by the growing points of a tree and the orientation of organs resulting from the distribution of growth in still growing tissues, are determined by the variable response of the growing cells to a variety of stimuli, detailed study of which is not necessary to the forester though occasionally some knowledge of them is required.

The course of the roots is determined by positive *geotropism* (response to gravity), negative *heliotropism* (turning away from light) and *Chemotropism* (turning towards food substances or moisture, or away from toxic substances).

Stem orientation and movements

The development of a straight vertical stem is important and is determined mainly by negative geotropism and partly by positive heliotropism. The latter reaction is influential in causing growth of trees in the lower canopy of a forest towards gaps whether fortuitous or caused by thinning or felling operations. Broadleaved trees have been found to exhibit this response in a quite marked degree and some authorities consider that the curved base so commonly seen on trees growing on step hillsides owes its origin largely to the same cause, the young plant tending to grow away from the hill whilst its geotropic response makes it try to grow vertically at the same time. It must however be realized that better illumination on one side may result in greater development on that side, and in turn a curvature towards that side under the increased weight, perhaps augmented by atrophy or death of the parts on the shaded side.

Leaf orientation

The arrangement of the leaves on a shoot is often considerably altered from that which might be expected to result from the position of the insertions (the phyllotaxis) This is usually brought about by bends and twists in the petiole, and results in better distribution of the leaf surface with regard to the incident light. The two-ranked arrangement (*bifarious*) of the alternate leaves of *Holoptelea* provides a good example, as also does that found in *Abies pindrow*.

Trembling leaves

The trembling of the leaves of poplars has been shown[1] to result in a marked (even 50 per cent) increase in transpiration and hence in soil solution absorbed, and it is possible that this movement may benefit trees such as *Ficus religiosa* whose leaves similarly vibrate.

Leaf movements

The leaf movements of *Desmodium gyrans* may perhaps promote transpiration, and those of *Mimosa pudica* under stimulus may give the plant some degree of protection from grazing animals. The folding of the leaflets of *Leguminosae* at night is a very common phenomenon well seen in *Albizzia* spp. It is brought about by changes of turgidity in the swollen pulvini of the base of the leaves and leaflets acting in a way not yet understood.[3]

Floral movements

Various movements are involved in flowering, fruiting and seed dispersal, some of them growth movements and some mechanical (such as the vibratory movement of the dry fruiting bracts of *Hymenodictyon* caused by wind and resulting in gradual shedding of the seed).

Climber movements

The growing tip of climbers follows a spiral course, and contact with a support results in the stem growing round it in the same direction. Some climbers constantly follow the sun (or hands of a watch), examples being the left-handed spirals of *Spatholobus*, whilst others go the opposite way with right-handed spirals as in *Millettia*.

EXCRETIONS

Resins

The appearance of the resin ducts found in the bark and wood of many trees is described on Ch. II, p. 66. It appears likely that the secretion of the resin under pressure causes the formation of the actual duct by pressing back the secreting cells till they appear as a thin lining layer. How the resin passes through the cell membrane and wall is not understood. When a duct is cut, the epithelial cells absorb water from the wood and develop osmotic pressures as high as 100 atm. The resin is thus squeezed out till the pressure is relieved and the hardening of the resin on exposure prevents further movement.[1] The tapping procedure depends partly on reopening the ducts at appropriate intervals, and partly on the formation of numerous additional ducts as a wound response. Unfortunately, very little is yet known of the details for chir pine and our *dammar* and oil-yielding Dipterocarps, of which sal and the *gurjans* are representative. The quantity of resin which may be obtained from a tree without appreciably affecting its vigour is high, amounting in chir pine to 6½ lb. in one season from a single channel 4″ wide, large trees taking two channels without much reduction in the average yield. The tapping causes increased diameter increment at the level of the blazes as would be expected from response to the wound stimulus, but this is compensated by a reduced increment higher up the bole.[20] The oleoresin tapped from *Melanorrhoea usitata* and used in Burmese lacquer work provides another example of this class of secretion.[21]

Essential oils

Pine resin yields the important essential oil turpentine on distillation, as do other oleo-resins. Essential oils are also secreted by many other plants including conifers, *Rutaceae*, *Myrtaceae* (notably *Eucalyptus*) and a few grasses (lemon grass). Sandalwood oil is also in this class. These secretions apparently fulfil a protective function to the plants producing them, but very little information is available.[2]

Latex

With the dropping out of *Ficus elastica* as an important source of supply of commercial rubber, latex has lost much of its interest to forestry though it is still a minor product of some value locally, gamboge from *Garcinia* spp. (*Guttiferae*) providing an example.[21] The physiological problems involved[2] are much as for resin, with the additional complication that the composition of latex is more complex and variable. The contents of the latex tubes and vessels (cf. p. 123) include food materials under translocation and temporary storage, sticky, acrid, and even poisonous materials serving to protect the plant from injury. The latex probably also contains waste products of no special function. Latex is usually collected from the bark, and its presence in leaves and young shoots is of course commonly used as an aid to recognition of the species containing it. The latex content of many Indian species was intensively studied during the recent war.[26]

Gums

Very many trees excrete gums, some of which e.g. *gum arabic* from *Acacias*, *katira gum* from *Sterculia urens* and the gum of *Bauhinia retusa*, are collected on a commercial scale. These materials are produced by internal glands, usually in the bark, and may collect in reservoirs or ducts either resembling resin ducts or laticiferous vessels. Wounding increases the flow.[2]

Lac

Lac is a resinous crust secreted by small insects (*Tacchardia lacca, Homoptera*) which suck the juices from young shoots of a variety of trees among which *Schleichera*, *Butea*, *Acacia*, *Zizyphus* and *Shorea* may be mentioned as illustrating the wide range of families included. Very little appears to be known of the biochemical processes involved in the production of this important substance from the cell-sap, but it has been put forward that gum is probably the chief food of the insect, so that active gum secretion, a diseased condition of the host, is favourable to it.[22]

General

It is thus seen that our knowledge of the physiology of Indian forest trees is very meagre. For general details the reader is referred to standard text-books on plant physiology, a selection of which is given below.

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IV

FOREST COMPOSITION AND DISTRIBUTION

PURE AND MIXED CROPS

GREGARIOUS HABIT

Gregarious tree species

The top canopy of many of our natural forests is composed very largely, sometimes entirely, of a single tree species. Examples might be quoted from any part of the country except the most luxuriant moist tropical tracts, and the most extensive is undoubtedly chir pine which is found in practically 100 per cent pure crop over hundreds of square miles in the Himalayas from the North West Frontier to E. Nepal. Several other conifers, notably blue pine, deodar and spruce, similarly form pure crops, but are more commonly mixed with a varying proportion of other species. Sal is a good example of gregarious habit among broadleaved trees (Plate 9), though it also usually has some admixture of other species. *Quercus incana* and *Q. semecarpifolia* provide excellent examples from the temperate hills, as do *sissu* and *babul* on the plains. Even in the wet tropical forests, some species often exhibit a definite tendency to occur in more or less pure groups, e.g. *garjans*, perhaps with some mutual benefit and at least to no mutual harm.

Gregarious underwood species

Gregarious habit is also often well developed in the underwood as with most bamboos, or among the ground shrubs as with *Strobilanthes* spp., *Clerodendron* and *Adhatoda*.

Biotic influences

Human activities tend to increase the predominance of gregarious species as will be seen in a later section. This may be done intentionally as in the case of many sal forests under technical management, or unintentionally as by fire protection in untended sal, oak, and chir pine forests.

Mixture of Species in the Top Canopy

Simple mixtures

The most usual condition is a mixture in the top canopy of a varying number of species. Simple mixtures are presented by the conifers, e.g., deodar and spruce with silver fir, or deodar with blue pine or *Pinus gerardiana*, and by sal with *Terminalia tomentosa*, or *sissu* with *khair*, but more commonly in tropical forests there are several to very many species all contributing to the top canopy.

Tropical evergreen forest

The more luxuriant the growth, the more complex the mixture, till in wet tropical forest no single species contributes even 10 per cent, and but few over 1 per cent, as exemplified by a Tavoy area[6] in which the highest percentage even for a genus was only 6½ per cent of the total number of trees over 12″ diameter, and the twenty most important genera together only contributed 37½ per cent. Another example is given by the following list for trees over 6¾ ft. in girth in a fairly typical area in Coorg,[7] the following species being present in the proportions shown, considering timber trees only.

Vateria indica .	26·4%	*Mesua ferrea* . .	2·0%
Hardwickia pinnata	23·2%	*Mangifera* sp. .	1·4%
Dipterocarpus indicus	14·5%	*Eugenia* spp. . .	1·4%
Palaquium . .	6·7%	*Artocarpus hirsuta* .	1·4%
Hopea parviflora .	6·4%	*Diospyros* sp. .	0·9%
Calophyllum sp. .	5·8%	*Dysoxylum binectariferum*	0·9%
Bombax . .	2·9%	*Artocarpus integrifolia*	0·9%
Cedrela sp. . .	2·9%	*Tetrameles nudiflora*	0·9%
Acrocarpus fraxinifolius	2·3%		

In all, there were 345 of these trees on 100 acres.

Tropical deciduous forest

In the tropical deciduous forests which cover so large a part of India, the greater part of the top canopy is formed by 6 to 10 species ; thus in one example *Terminalia tomentosa*, *T. belerica*, *Lagerstroemia parviflora*, *Sterculia villosa*, *Adina cordifolia*, *Bombax malabaricum*, *Lannea grandis* and *Cedrela toona* ; and in another, *Tectona grandis*, *Terminalia paniculata*, *T. crenulata*, *Lagerstroemia lanceolata*, *Adina cordifolia*, *Dillenia pentagyna*, *Stereospermum chelonoides*, and *Grewia tiliaefolia*.

Exploitable species

In forest working, it is commonly the position that even of the top canopy species only one (e.g. teak) or few are workable at a profit, and management aims at increasing the proportion of such exploitable species as far as silvicultural considerations indicate to be desirable—the limit has probably sometimes been overstepped, as locally with teak and sandal. Many forests are workable for teak only, where this species may form 10 per cent or less of the crop.

Vertical mixture of species

In addition to these top storey mixtures, we frequently have to deal with vertical mixtures in which one species or set of species occupies the top storey, and others form an underwood ; chir pine forests commonly have no underwood, but this is exceptional. Fir forests often have a complete underwood of oak or *Rhododendron*, and oak forests one of mountain bamboos (*Arundinaria*).

Sal forests have more or less underwood when it has not been cut out or kept out by fire, but it tends to be of low branchy trees such as *Mallotus*. In moister unburnt sal forest, a dense largely evergreen underwood is developed, including species which may grow into quite large trees wherever they have space and light even if they rarely reach into the top canopy. This leads on to the wet tropical forest where below the mixed top canopy is a complete underwood of trees of all heights, with a tendency to a tiered arrangement when young growth of the dominant species does not predominate ; this underwood is usually as complex in composition as the overwood.

The beneficial effect of species mixture in the humification processes in the soil has been mentioned on p. 40 and the question of species in plantations is considered on p. 183, where the relative merits of pure and mixed crops in forestry are discussed.

COMPETITION BETWEEN SPECIES

Struggle for existence

Where a number of species grow together, there is severe competition between them for the limited and fixed amount of space, light and moisture available on the site. As the trees get larger there is room for fewer and fewer, and the weaker either drop out altogether or at least lose their place in the top canopy.

DIFFERENCES IN GROWTH

Rate of height growth

The first requirement for success is rapid height growth, as the trees which reach highest shade the slower growing ones, and thereby reduce the amount of light the latter receive and also their rate of transpiration (and so their supply of inorganic food). It is possible to pass the optimum in this direction, as insolation and water loss may become excessive with full exposure. Rapid height growth also reduces the risk of animal damage to young saplings and the risk of serious climber damage.

Growth habit

If the species has also a vigorous branching habit, it can make fuller use of the advantage given by its height ; it can develop a leafy crown sufficient to ensure good diameter growth also and tending still more to suppress its competitors. A limit commonly interposes, perhaps owing to a necessity for simultaneous development of the root system, and trees of very rapid height growth are not usually very branchy in their earlier stages, teak exemplifying this point.

Shade tolerance

As in natural forest all trees have to develop from seed on the forest floor, ability to endure shade is a very imporant factor in seedling competition. The ideal combination is a large seed with ample food supplies to give the seedling a good start during the typically very unfavourable conditions prevailing on the forest floor, fairly rapid height growth to enable it to get above often dense ground cover to better light conditions, and then pronounced powers of shade endurance without losing the power to respond to improved light with renewed rapid height growth, thus keeping the sapling in a condition to make immediate use of a chance gap in the canopy. *Artocarpus* spp. and *Dipterocarpus* spp. provide good examples of species occurring in the tropical evergreen forest which are well endowed in these respects. It has already been seen that most species are markedly more shade tolerant in their earlier stages than later, and we have here a good reason for it.

Shade tolerance is usually associated with a more or less evergreen habit so that evergreens are often found as an understory to deciduous forest. Regeneration of deciduous species is very difficult in forest with an evergreen underwood or a high proportion of evergreens in the upper canopy, so it is usually restricted to chance openings and to species of rapid height growth, e. g., *Acrocarpus* in tropical evergreen forest. Similar is the inability of chir pine to regenerate where a broadleaved underwood is developed as a result of fire protection. Even deciduous species in their younger stages may cast so dense a shade that nothing can grow under them. Gregarious habit seems to assist in the establishment of regeneration, especially where fire is an active locality factor and only a dense growth can thin out the inflammable grass.

Change in relative growth rates

Where a slower growing shade-bearer is competing with a quicker light-demander, it sometimes happens that after the early stages the height growth of the latter falls off, whilst that of the former is maintained or increased, so that it catches up and may even surpass and suppress the light-demander. This is sometimes found in mixed plantations. A typical example is that of rosewood (*Dalbergia latifolia*) in a teak plantation.

Variation in Hardiness

Recovery from injuries

The young tree struggling for a place in the sun is exposed to many risks from climatic factors, animals, parasitic plants, and man, and its powers of resistance to these are important to a degree depending on the severity of their incidence, in many instances deciding the very existence of the species. The most valuable character is a well developed power of coppicing, so that the damage done does not kill the plant but is quickly repaired. The seedlings and saplings of almost all species are able to replace a broken shoot, but only some can send up a new one from the collar or root if burnt or broken back to ground level, as not in frequently happens : teak and sal can both do this. Under the difficult conditions below a dense canopy with weak light and low growth activity, damage is more likely to be fatal than in open forest.

Resistance to *fire* is most important over the very large areas exposed to fires. Many sal forests owe their existence to the remarkable power of this species to withstand repeated burning and to establish itself on burnt grassland. The purity of such sal forests is largely attributable to the fact that its associates are less resistant, and none of them appears able to establish high forest in periodically burnt grassland, as the hardy and gregarious sal can. Exceptional fire-resistance also largely accounts for the purity of chir pine forests and their occurrence in areas where, with protection, oak, blue pine and deodar rapidly establish themselves.

Tropical wet evergreen forest is exceptionally sensitive to fire, which has driven it out of large tracts in S. India in favour of the more resistant species of the deciduous forest, many of them also associates of sal. The abrupt edge of the evergreen forest often reveals this history. Similar too is the driving back of the temperate evergreen forest in favour of grassland in the hills of S. India, though lack of frost-hardiness in the trees is also believed to be an important factor.

Grazing :

After fire, grazing is probably the most influential factor controlling the composition of the forest over most of the country, though not usually in the wet tropical forests. Commonly associated with grazing damage is lopping for fodder and fuel, and the many other injuries inflicted by the graziers. The relation of grazing to burning depends on its intensity and on the locality factors. Grazing usually leads to the replacement of woody undergrowth by more inflammable grass and a generally drier type of vegetation, and it considerably increases the chances that fire will be set intentionally or carelessly. In an already grassy area, however, it reduces the damage by thinning out the grass and trampling it down. Resistance to destruction by grazing is effected by non-palatability due to tannins as in teak, to acrid juices as in *Rhus*, *Aegle* and *Apocynaceae*, to thorns as in *Randia* and Acacias (no protection against camels), or to sour smell as in *Holarrhena* and *Holoptelea*. Many trees escape damage except at certain times of the year, being usually only browsed when the shoots are new and tender, and tannins may even attract instead of repel (as in sal), or when herbaceous feed is scarce. These repellants are of course of primary importance to the seedling and sapling stages, for it is ultimately on these stages that successful competition depends. In long and heavily grazed areas it will be found that practically every tree is characterized by unpalatability, thorniness, or marked coppicing power, and most by more than one of these properties, all other species having been eliminated. Heavy grazing also results in a compacted surface soil in which germination and establishment are difficult, so that seedling hardiness and a suitable seasonal history are further important aids in competition. Moderate grazing on the other hand helps some species which benefit from their seed being trodden into the soil and from a thinning out of the ground vegetation.

Wild animals

The properties which influence species competition in grazed areas will have much the same effects where *browsing* by wild animals is concentrated. In certain instances palatability is a great handicap, as with *Artocarpus* where elephants are numerous, and locally for sal with sambhar. As a rule the damage is, however, not intensive enough to be an important factor, but sometimes it effectively prevents the establishment of regeneration, as with sal in parts of the United Provinces.[8]

Adaptation to Climate and Soil Factors

Variations in adaptability

The degree of adaptation to the locality factors varies widely, and within limits, the closer this adaptation is, the more favoured the species in its competition with others. Some species, however, especially those found in extreme types of habitat such as the mangrove swamp, appear to have lost the power of adjusting themselves to changed conditions and soon drop out if such a change occurs, whilst other species appear able to adapt themselves to a wide range of conditions. Thus *Acacia catechu* and *A. arabica* may predominate both on alluvial deposits liable to inundation and arid hillsides, whilst *Eugenia jambolana* is found in swamps, and relatively dry forests. Chir pine flourishes on a very wide range of altitude, rock and soil, only requiring good drainage. Such adaptability is a great asset in competition and so is naturally enough frequently met with in widely distributed species. The opposite condition is well illustrated by *sissu*, which is admirably adapted to its characteristic habitat of new gravelly or sandy alluvial deposits, but is entirely confined to such sites : this may be mainly due to the failure of the seedlings under competition as the species grows well when planted, and from seed, on cleared ground.

Poor soils

It should be noted that many species which are found mainly on poor soils are there, not because they grow best on them, but because they fail in competition with other species on richer soils and can only hold their own on the poorer.

Frost

Another locally important locality factor is the occurrence of frost. [9, 10, 11, 23.] Here again general hardiness and case of production of new shoots is the chief adaptation required, as very few of our trees outside the Himalayas are fully frost-hardy. Hardening off of the twigs and shedding the leaves is the best protection, and occurs in *sissu* and mulberry : there seem to be no fully frost-hardy evergreens in the plains, though mango is fairly so. Frost as a factor in competition is probably mainly effective in the seedling stages when it may be lethal, but relatively tender species usually become dominated by the hardier ones which are not killed back so far in a severe frost year.

In the hills where frost is a regular feature, all species seem well adapted to it. The deciduous species are well protected from winter frost but may be caught by late frosts. The conifers and broadleaved evergreens are generally hardy but may suffer from exceptional winter frost at high elevations. It has been found that in many trees most of the starch in the cells is converted into sugar, which has a protective action against freezing.

Longevity in competition

The normal length of life of a tree may also be an influential factor in species competition, a long-lived species being at a considerable advantage as it is able to hold a place once gained, and to continue seed production for a long period. It is probably no coincidence that notoriously long-lived species also tend to be common ones, though there are exceptions such as *Taxus baccata*, and it is evident that other advantages such as rapid growth and profuse regeneration may be equally effective.

Reproductive Powers

Seed crops

The abundant production of fertile seed with a good dispersal mechanism greatly increases the chances of gaining ground against competitors. This is true whether very large numbers of minute seed (and consequently weak seedlings) are produced as with *Adina cordifolia*, or relatively fewer large seed and so well provided seedlings, as with sal. Many species cannot regenerate under their own shade, either from lack of light (*Mesua*) or an unsuitable seed bed

PLATE 8. Colonization and succession on N. Indian alluvium. (*Above*) Colonization by grass and *sissu*, Siwaliks, U.P. (*Below*) *Holoptelea* regeneration under *sissu*, Haldwani, U.P.

Facing p. 137.

(sal and spruce), and so are unlikely to reoccupy a gap caused by the death of a large tree of their own kind if competition of other species is at all severe. This must be an influential factor in play when we find under selective logging a steady diminution of the stock of the species removed.

Value of dispersal mechanisms

An effective seed dispersal mechanism and seedling adaptation to the special rather unfavourable conditions, provide the means of occupying newly exposed soils such as new alluvial deposits, landslips, coastal accretions, or inland blown sand and volcanic deposits. Not many species have the necessary characters, so that the composition of the new colonizing growth is usually very simple, often only of one or two gregarious species, as will be seen later when dealing with succession (p. 138).

COLONIZATION AND SUCCESSION

New Sites

Types of new sites

In India, new sites become available for colonization by vegetation on—

(1) New alluvial deposits—sands, gravels and silts.
(2) New estuarine deposits—clays and silts.
(3) Sand dunes.
(4) Landslips.
(5) Screes.

Of these, the first have no soil strictly speaking and may be almost completely devoid of humus ; the sand dunes present the special difficulties of their non-retentiveness of moisture and their instability as well as poverty in humus ; the estuarine deposits may be rich in humus and mineral food, but are often very heavy and badly drained ; landslips may provide good growth sites, with good drainage, original soil mixed with rock and the water seepage which caused the slip is often in reach below ; screes are found chiefly in dry or cold mountainous places and rarely form good sites. The silting up of lakes provides a further variety of new site for forest, but is rarely encountered in India (Kashmir lakes and depressions in old river beds).

Colonization

Riverain sites

The colonization of these new sites by tree growth is fairly rapid under Indian climatic conditions. The water bringing the materials out of which the deposits are built up, brings also the seed of species growing along the stream further up its course, this applying both to the upper reaches (e.g. *sissu*, shown in Plate 8, and *Trewia nudiflora*) and the estuary (most mangrove species). Airborne seeds also figure fairly largely in colonizing riverain deposits (*khair*, *Tamarix*, *Populus*).

Dunes and landslips

The arrival of seed is mainly dependent on wind dispersal and the most successful colonists produce quantities of small or light winged wind-borne seed (e.g. *Alnus*, *Populus*, *Tamarix*, and *Casuarina*).

Regeneration of first colonists

The original colonists of new sites are rarely found to regenerate *in situ*, and even when they do the second generation no longer monopolizes the ground, but has to compete with later arrivals. Many of the new sites are unstable and may be carried away before the colonists have attained maturity, but the redeposition of the material reproduces the conditions under which they can start again. Relatively few of the *sissu* woods on the islands and banks of the Ganges river system ever attain maturity. Early seeding of colonizing species is common (*sissu* and *khair*) and is probably connected with this uncertainty.

Frequent occurrence of root nodules

Another characteristic feature of colonizing species is the presence of root nodules with nitrogen-fixing bacteria, particularly important in sterile sand. These nodules occur in the leguminous *Dalbergia* and *Acacia*, in *Alnus* and *Casuarina*.

PRIMARY SUCCESSION

The vegetation first established on a new site does not usually remain in possession longer than a tree generation or so, but is gradually replaced by new forms which in turn give way to others, until finally a stage is reached at which the vegetation seems to be in equilibrium with the climatic and soil site factors and further change ceases to be apparent. This progression in time is known as the *primary* succession, and the final stage as the *climax* vegetation.

Soil formation

The early colonists at once commence the building up of a true soil, adding humus by their leaf fall and roots, and nitrogen from their root nodules ; they also shade the soil and make conditions favourable for the establishment of an undergrowth. The changed conditions make it possible for a number of more exacting species to establish themselves, and it is usual to find an understorey of shrubs and seedlings under the canopy of the original colonists as soon as the latter has lifted and opened up somewhat. These second arrivals (e.g. *Holoptelea* shown in Plate 8, *Bombax*, *Cedrela*, *Adina* and *Albizzia* spp. under *khair* and *sissu*) also mainly have wind-borne seed, but as the original wood provides shelter and food for birds, bird-carried seeds (e.g. mulberry) are also brought in.

Rate of succession

With the soil still relatively poor, the number of species at first remains small, but gradually increases, the quicker the more favourable the conditions : thus this primary succession takes place much more rapidly in Bengal with better distributed rainfall and milder winter than in the United Provinces with a dry season six months long and usually frosty winter.

Divergence in the later stages of succession

Whereas the early stages of succession are easily recognized and relatively uniform, much variation sets in later, and recognition and correlation become difficult. This divergence is mostly due to differences in moisture conditions themselves connected with the depth of the water table, the soil texture and the climate. There will naturally also be differences due to the nature of the adjoining older forests and the seed arriving from them.

Climax Forest

Attainment of the climax

Each succeeding generation of trees—and of course the generations overlap and merge—results in changes in composition and appearance, a chain of causes and effects, until the processes of building up and breaking down of the soil reach an equilibrium and the forest likewise attains a stable composition in which the dominants can maintain themselves indefinitely. With this final stage completing the primary succession, the climax forest type is reached. This climax type may not be identical over a whole tract of country experiencing the same general climate, but may vary with micro-climate and soil (cf. p. 46).

Stability of the climax

It has been questioned whether our conception of a stable climax vegetation is altogether correct, mainly owing to the difficulties experienced in obtaining natural regeneration of the dominant species. It has been suggested that perhaps the natural process is for a rotation of crops to occur. The available information is inadequate for a final decision on the point, but Indian evidence is on the whole in favour of the conception of stable climax types. It is possible however that on a given spot within a type, a rotation of constituent species may take place, and the soil conditions may fluctuate, especially as regards humus accumulation in temperate climates.

Effect of aspect

In the hills a change of aspect is often associated with a marked change in forest type, but this is generally to be considered as resulting from an actual difference of climate, and so the types naturally belong to different climaxes ; thus chir pine may grow on a southerly aspect and *banj* oak on the opposite northerly slope.

Typical Successions

Riverain successions

The stages leading up to the climax sal forest of the Gangetic alluvium in the United Provinces are fairly well known, and provide a typical example. They are illustrated in Plates 8 and 9 and are roughly as follows :—

(1) *Khair—sissu.*
(2) *Khair—Holoptelea—Adina—Albizzia procera.*
(3) *Holoptelea—Adina—Lagerstroemia parviflora—Bombax—Terminalia belerica.*
(4) *Adina—Lagerstroemia parviflora*—Terminalias—*Shorea.*
(5) *Shorea—Lagerstroemia*—Terminalias—*Adina.*

If the soil is rather damper, *Trewia nudiflora* and *Cedrela toona* appear in stage (3) and *Terminalia tomentosa* in stages (4) and (5), with *Eugenia jambolana* mainly below the top canopy.

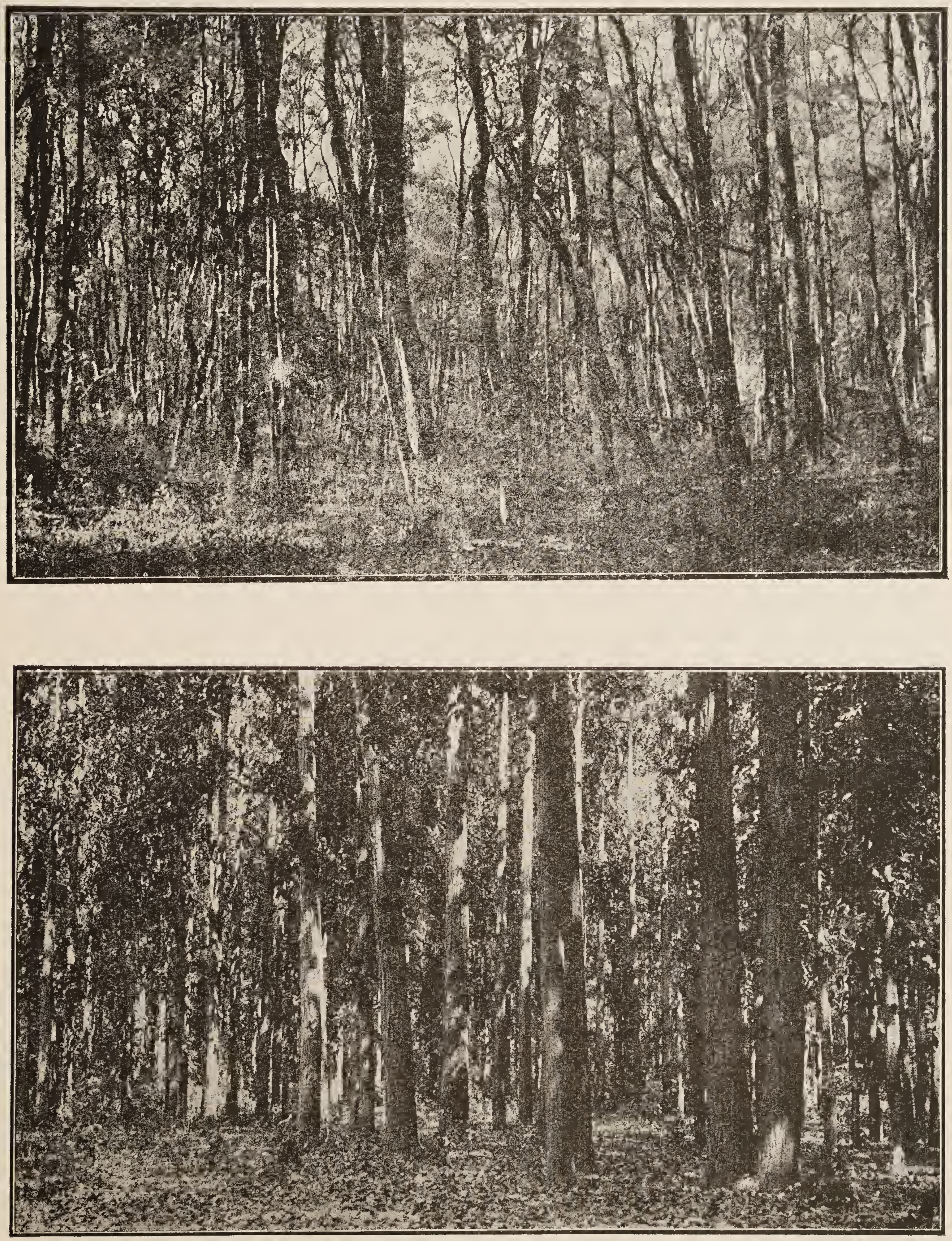
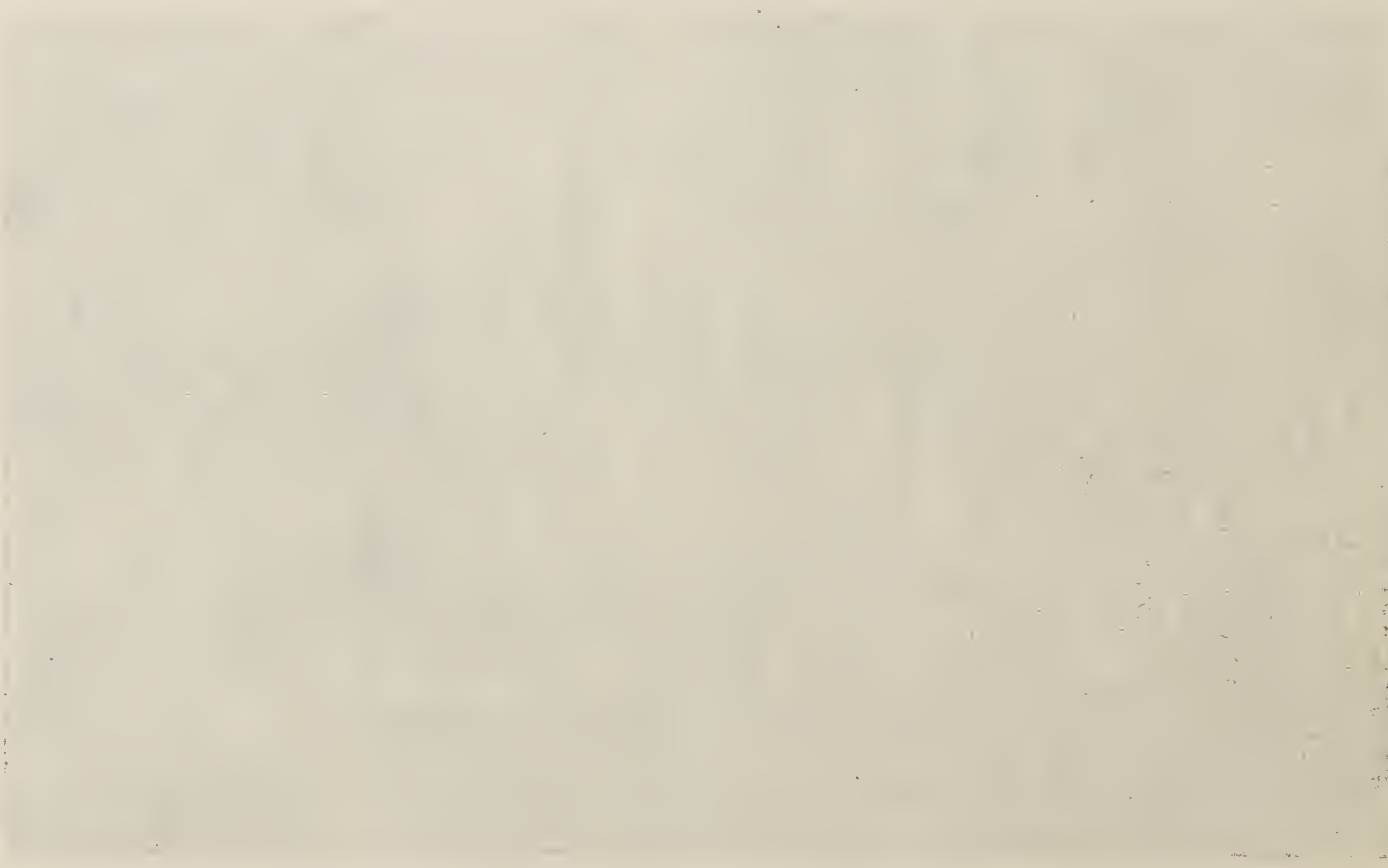


PLATE 9. (*Above*) Mixed deciduous forest of *Lagerstroemia, Bombax*, etc., Goalpara, Assam. (*Below*) Sal forest, the apparent climax, Haldwani, U.P.

Facing p. 140.



Estuarine succession

The successional stages on the mud flats and tidal estuaries are also well known. In the simplest case, the succession begins with (1) mangrove scrub, and passes through (2) tree mangrove, (3) slow growing salt water *Heritiera*, (4) finer fresh water *Heritiera* forest, (5) fresh water swamp forest without *Heritiera*, to (6) the local climax of evergreen or semi-evergreen forest.[24]

Coniferous succession

In the temperate mixed coniferous forests, a typical succession at about 8,000 ft. is (1) shrub associations, (2) blue pine, (3) mixed coniferous forest of deodar, spruce and blue pine, (4) mixed coniferous forest of spruce, fir and deodar. A good example of succession occurs on landslips in the forests at 8,000-9,000 ft., as at the head of the Parbatti valley in Kulu. Here the first tree colonist is *Pinus excelsa*, which forms pure woods. Gradually an understorey of silver fir comes in and ultimately after a period of 100-200 years the climax forest of silver fir drives out the pine, which dies from suppression. All stages of this succession can easily be observed, and the present object of forest management is to put back this succession and to regenerate these forests to a mixture rich in the more valuable pine.

Forms of Climax

Edaphic climax, Preclimax and Postclimax

The climax forest is not completely uniform as residual differences persist in site factors due to variation in soil texture, drainage and extraneous supplies of moisture. The general climax is known as the *climatic climax*, and a climax dependent on soil peculiarities as an *edaphic climax*. Thus in the sal climatic climax on the Gangetic alluvium, patches of heavy clay carry edaphic climax forest in which *Aegle marmelos* or *Terminalia tomentosa* predominates.

Exceptionally unfavourable sites, particularly those with low available moisture supplies, often carry a type which is more xerophytic than corresponds to the general climate and which is termed a *preclimax*, e.g. chir pine on ridges in subtropical broadleaved forest. Under the opposite conditions of locally cooler or moister sites, a more mesophytic type is found and is known as a *postclimax* ; thus sheltered damp sites in sal forest will carry semi-evergreen or evergreen forest, and similar sites in chir pine forest will carry oak forest. Such *preclimaxes* and *postclimaxes*, though often indistinguishable from the related climatic climax, not rarely have characteristic features of their own. A pre-climax type can be distinguished from the subclimax next to be described by its greater stability due to its dependence on soil conditions.

In the hills, chir pine forest is in many places a stable pre-climax with burning to an oak (*Q. incana*) climatic climax, and the S. India moist deciduous forest with *Terminalia paniculata*, *T. crenulata*, *Lagerstroemia lanceolata*, etc., often stands in a similar relationship to wet tropical evergreen forest.

Subclimaxes

Subclimax types

The primary succession in a thickly populated country like India very rarely proceeds undisturbed to the climax type. Outside the wet tropical evergreen, there appears to be extremely little forest in the country which has escaped the results of human settlement in the past and the conditions under which succession takes place now are fundamentally altered by burning, grazing, selective fellings and many other forms of interference. As noted when considering the competition between species, burning is the most influential factor of all.

A type which is prevented from progressing to the climax in this way, but which is more or less stable under the conditions prevailing, is termed a *subclimax*. The succession may be continued if the inhibiting factor is removed, but will not be the same as the undisturbed primary succession.

Intensive use as grazing grounds without burning may also greatly check or reduce the rate of succession, and influence its course and the composition of the crop. Closure to grazing may have very striking results in such cases.

Grassy riverain subclimax forest

After an initial period, the early stages of the succession of new riverain deposits include a good deal of grass which becomes very inflammable and usually gets burnt more or less annually. Any form of damage reducing the tree canopy increases the grass growth, and the establishment of the second stage species becomes increasingly difficult. The original colonists gradually die out and only a scattered growth of the hardiest species such as *Bombax*, *Dillenia pentagyna*, *Lagerstroemia parviflora*, etc. gets up, forming a savannah type which may persist for a long period. The miscellaneous forests of N. Kheri division in the United Provinces provide a good illustration, the *Acacia catechu* having been largely worked out and nothing having replaced it.

Retrogression

Causes

When adverse influences such as grazing, burning or felling are introduced into an existing forest at any stage in the primary succession or into the actual climax forest, the progression which has hitherto predominated is altered to a more or less marked retrogression to forms resembling those prevalent at an earlier stage. Deterioration of climate may produce the same results, as appears to be happening in some of the sal forests of the United Provinces.[8b] It is impossible to revert exactly to the earlier stage for there always remain the after-effects of the former forest and soil, but in some features there is a marked parallelism. Retrogression stages are more often lower and more xerophytic than the original. Where the new factor is fire, the type may be completely altered in composition by the destruction of fire-tender species as seen in the substitution of deciduous forest for moist evergreen forest in many places, and of scrub or bamboo brakes for evergreen hill forest in the higher Himalayas. Where grazing, lopping and felling are combined with burning, as on the edges of the forest wherever it adjoins human settlements, the climax forest may be opened into an open irregular wood in which the most useless trees with unpalatable foliage and wood useless for timber or fuel predominate.

Status of grassland

It is doubtful if grassland forms the climatic climax vegetation in any part of India except perhaps in some of the alpine pastures. Where it appears to be a local edaphic climax on wet soils and in frost holes in the sal belt and in the hills elsewhere, its climax status is still rather doubtful. The hill grassland of S. India appears to have largely replaced temperate or subtropical evergreen forest with clearing, burning and grazing ; frost and excessive moisture may result in a grassy climax in the hollows. The most extensive grasslands occur on the lower alluvial deposits and are a stage in the primary succession at least on the wetter sites, too wet for the trees which might colonize them ; most of them however seem to be the result of a modification of the primary succession at an early stage due to burning, felling and grazing. *Saccharum spontaneum* is a good example of a grass which may dominate at the beginning of the primary succession on sandy river deposits. (Cf. Plate 8.) The grasslands of the higher alluvium are usually traceable to destruction of pre-existing forest by human settlement and prevention of re-colonization by fire, grazing and deteriorated soil conditions.

SECONDARY SUCCESSION

Description

When the adverse influences which have brought about retrogression are removed, or when an area on which the forest has been destroyed and replaced by grassland or arable cultivation is left to itself, progress at once reasserts itself and a *secondary succession* takes place. It is naturally not always easy to distinguish between corresponding stages of the primary and secondary succession and retrogression stages, but some instances are clear enough.

Secondary sal forests

In many parts of the sal tract, the climax forest has been destroyed and grassland taken its place.[8] Sal seedlings gradually colonize the burnt grassland, and if a seeded-up area is fire-protected, the seedlings may shoot up, and if strong or numerous enough, they will thin out the grass sufficiently to enable them to withstand further fires. Sal forests which originate in this way tend to be purer than those which have orginated under conditions more like the primary succession. If the grassy savannahs in the Bengal and Assam submontane tract are fire-protected, a wood of *Macaranga* may spring up, shading out the grass and initiating a woodland succession quite different from the primary which lacks the pure *Macaranga* stage. In these moister forests of the sal tract, most if not all the sal forest we now have is itself only a stage in the secondary succession ; it is only a stable preclimax with burning, and continued fire-protection results in further progression to the largely evergreen *wet mixed forest*. This again probably only has a similar status, but so little climax forest is traceable that we cannot at present recognize it with certainty although it is probably a form of the wet tropical evergreen type.

Species also found in primary succession

It is not unusual for the colonizing species characteristic of the beginning of the primary succession to be dominant or at least conspicuous in the secondary also ; thus *Pinus excelsa* regularly colonizes landslips and new gravels and it also invades abandoned cultivation. *Trema* spp. and *Anthocephalus cadamba* behave similarly. *Macaranga* spp. are more typical of the secondary succession in moist forests.

Secondary shrub stages

The frequent occurrence of a shrub stage in secondary succession is noteworthy, particularly in the hills. Clearings (or burns) in the montane temperate areas nearly always develop a shrub cover before tree growth becomes re-established, the species varying with aspect, moisture and elevation, e.g. *Woodfordia floribunda*, *Indigofera pulchella* and *Berberis lycium* successively higher. The shrubs presumably provide a measure of shelter and protection to the tree seedlings, being shortlived but developing more quickly.

Secondary succession after fellings

Similar secondary succession occurs after heavy fellings in any climax type. In the tropical evergreen forest, for example, such fellings greatly alter light and moisture conditions and cause a reversion to a semi-evergreen or moist deciduous type through the arrival of quick-growing often deciduous species such as *Acrocarpus fraxinifolius*, *Callicarpa*, *Trema* and *Macaranga*. Under these, an evergreen underwood develops, and in time the evergreen forest closes in once more ; if climbers are heavy the process is greatly delayed. There are good grounds for believing that it will take even hundreds of years before another crop like the original can re-establish itself after fellings in tropical evergreen not followed by intensive tending operations favouring the climax species.

CLASSIFICATION OF FOREST TYPES

Definition

The better defined and more stable of the developmental stages in the history of our forests are usually referred to as *forest types*, though no adequate definition can be given, particularly for the non-climax types ; the degree of subdivision to which we must go for practical purposes in differentiating types depends largely on the intensity of management. Thus at present we continue to deal with our wet tropical evergreen as a single type despite its obvious complexity and variation, whilst for forest with sal as the predominating species, it has been found advisable to distinguish at least 13 and preferably 21 subtypes differing to such an extent that a treatment applied in one might produce different results in another.[8] For practical forestry purposes, a single classification and standard nomenclature are required to cover the great variety of forests found in the country ranging from the dense moist evergreen occurring on the west coast, in Upper Assam and other parts, to the open thorny scrub hardly worthy of the name of forest on the edges of the deserts ; to scrub again on the mountain tops at ' timber limit ' ; to dense low evergreen in the tidal estuaries ; and to open park or grassland in both hills and plains.

Forest Types in Relation to Climate

Factors of climate affecting forest types

The close relationship between climate and the form of climax forest is so marked that most students of climate find the vegetation itself the best indication and measure of the summation of the climatic factors.[1] The chief of these factors are *temperature* and *moisture*, the others such as *wind* being relatively much less influential.

Temperature

Given adequate moisture, the effect of temperature shows itself in the luxuriance of the forest in that height, density, variety of species and rate of growth all fall off with falling temperature. The conifers reacts somewhat differently from broadleaved trees, reaching their best development in temperature climates, where they surpass their broadleaved associates. Ascending in the hills with increasing cold, winter-deciduous species become more prevalent, and the forest gradually degenerates to scrub form at timber limit, where, however, hard-leaved evergreens predominate (*Rhododendron*).

Moisture

As moisture conditions become less favourable with tropical temperatures, the forest falls off in density and in richness in species, and an increasing proportion of species become summer-deciduous, first in the top storey, and then lower down also. In still drier climates, the height also falls off and the leafless period lengthens, thorny trees become more abundant, and xerophytic adaptations become more and more prevalent till an open thorn scrub stage is the last that can be considered as forest.

Temperature zones

Four temperature zones require to be recognized in India as follows :—

(1) *Tropical.*—Mean annual temperature over 75°F. ; mean January temperature over 65°F. Cold season short or absent. Frost and snow unknown. This occupies the whole country within the tropics except for the higher hills.

(2) *Subtropical.*—M.A.T. 62°—75°F. ; mean January temperature 50°—65°F. Cold season definite but not severe. Frost rare. This occupies the northern part of the country below about 5,500 ft. and the southern hills between 3,500 ft. and 6,000 ft.

(3) *Temperate.*—M.A.T. 45°—62°F. ; mean January temperature 30°—50°F. Winter pronounced with frost and some snow. Hills above 6,000 ft. in the south and between 5,500 ft. and 10,000 ft. in the north.

(4) *Alpine.*—M.A.T. below 45°F. ; mean January temperature below 30°F. Winter long and severe.

There is one respect however in which this climate classification is not altogether suitable for application to forest types, for many of the latter in the plains are almost identical in tropical and subtropical climatic zones, the effects of the hot dry early summer, followed by the hot wet monsoon period common to both, outweighing the differences due to the minor difference in the dry cold weather when in any case there is little vegetative activity.

Moisture effects

The relative prevalence of mesophytic or xerophytic evergreens and of deciduous or thorny species, indicate well the varying moisture conditions within the climatic zones, and lead to the classification given on p. 150 in which some of the better characterized edaphic and seral types are included in brackets, the remainder being viewed as climatic climaxes.

Forest Types in Relation to Soil

Soil factors

The undisturbed type of vegetation which clothes a given tract of country is thus found to reflect very clearly the prevailing climate ; variations within the climate are clearly connected with soil differences and the soil itself may, as we have seen, also be ultimately determined to a large degree by climate. Thus a pronouncedly lateritic soil is developed from a variety of rocks under the appropriate climatic conditions and often carries a similar type of vegetation. Physical differences in soil may however cause considerable differences in the climate of the soil itself : thus a cold wet clay may closely adjoin a warm light sandy soil, and the vegetation on the two soils may present marked differences. The change from (predominantly) sal forest to (predominantly) teak forest in the Central Provinces is ascribable in this way to change of soil, not change of climate,[12a] and many similar examples are on record.

Predominant effect of physical properties

As a rule, even when there are marked chemical differences in the parent rock, as between limestone, quartzite and granite, the difference in vegetation is less determined by the chemical than by the physical differences in the soil. Some trees appear remarkably indifferent to soil, as is well illustrated by chir pine, which is found on an extremely wide range of rocks ; but here the hilly topography results in adequate drainage, which is the chief essential for the growth of this tree.

Some mechanical analyses[13] carried out on soils associated with different types of forest bring out well the influence of the clay per cent in sal tracts :—

Type	Good sal Quality II			Fairly good sal Quality III			Rather poor sal with miscellaneous spp.			Pure *Aegle* crop		
Depth . .	1′	3′	7′	1′	3′	7′	1′	3′	7′	1′	3′	7′
Percentage of clay . .	14	13	17	12	20	12	17	21	20	16	25	27

It should be noted that because a given species predominates on an inferior soil, it does not follow that this soil is the most favourable to it. More usually, the implication is greater hardiness or adaptability than that of its competitors which can crowd it out on better soils—thus *Terminalia tomentosa* often predominates on stiff clay but grows infinitely better on a deep rich loam.

Soil indicators

Bearing these considerations in mind, it can still be said that in India certain soils with pronounced characteristics are commonly associated with certain forest species or types.[12, 14, 15] As examples may be cited the following :—

New river gravel : *Khair-Sissu* association.

Black cotton soil : *Acacia arabica.*

Markedly saline soil : *Prosopis spicigera, Tamarix articulata, Acacia arabica.*

Coastal sand : *Calophyllum inophyllum, Casuarina equisetifolia, Hibiscus tiliaceus.*

The various forms of tidal forest are also closely related to soil conditions, mainly moisture and salinity.

In Burma, it has been shown that as a rule the superficial horizons determine species (through their influence on regeneration) whilst variations in the profile limit height growth.[16] Dominant teak is associated with the finer soil of the older alluvium and overlying black soil deposits, and other soils like them.[17]

Lime content and vegetation

Forest and botanical literature are full of references to ' calcifugous ' and ' calcicolous ' species, respectively avoiding and preferring soils rich in lime, but it is now realized that the chief effect of lime in the soil is not as a plant nutrient or poison, but as a modifier of soil conditions both physical and chemical. A species may differ markedly in its relation to lime soils in different parts of its climatic range, being for example calcicolous in colder northern and higher localities, and more or less calcifugous in warmer regions (beech in Europe). This is related to the lower soil humidity and hence greater salt concentration in the warmer sites.[18]

Forest Types in Relation to Biotic Factors

The far-reaching effects of human activities in clearing forest, in burning, and in grazing flocks, have already been described when considering succession on p. 142, and there is little more to add. Under natural conditions, it is unlikely that wild animals such as elephant, deer and pig, ever do enough damage to influence the dominant forest types, though their undue multiplication and local concentration through human interference now renders them important in regeneration operations. Similar is the matter of insect attack, each species and type of forest being adapted to cope with the amount of injury to which it is exposed under natural conditions.

Savannah types

In India, the most easily distinguished form of forest owing its existence to biotic factors is grassy savannah forest. The climate is such as to support tree vegetation wherever closed vegetation is possible, and not grassland, but extensive areas are met with in which the tree cover has been kept or rendered very open, and grass has taken possession of the soil. Owing to its inflammability, and its being frequently fired in connexion with grazing, the savannah types perpetuate themselves and are, in fact, very stable subclimaxes.

The boundary lines between adjoining forest types tend to be shifted in favour of the more xerophytic wherever human influences are at all pronounced.[19]

Chief Forest Types and their Characteristics

The following list is taken in abridged form from a recently compiled survey for India and Burma.[1] Brackets imply edaphic climaxes or seral stages.

I. Moist Tropical Forests

1. *Tropical wet evergreen* .	Tall dense forest with mesophytic evergreens predominating in all Canopy layers.
1*a*. *Evergeeen Dipterocarp* .	Evergreen Dipterocarps conspicuous ; the finest forests in India.
(Freshwater swamp) .	Less dense and with fewer species.
(Tidal forests) . . .	A complex of successional types, all evergreen but rarely tall or dense.
(Secondary Dipterocarp) .	*Hopea* spp. in almost pure crops of medium to poor quality.
(Wet mixed forest) . .	An evergreen type succeeding sal forest on wet ground.
(Cane brakes) . . .	Occupy wet hollows in the main type.
2. *Tropical semi-evergreen* .	Deciduous species occur mixed with the evergreens in the top canopy, the lower canopy being mainly evergreen. Leafless period short.
(*Garjan* forest) . .	*Dipterocarpus* spp. of rather poor quality predominates.
3. *Tropical moist deciduous* .	Deciduous species predominate in the top canopy with more or less evergreen in the lower canopy.
3*a*. *Moist* (*mixed*) *deciduous* .	Several species, including teak, contribute equally to the top canopy.
3*b*. *Moist sal* . . .	Sal largely predominates in the top canopy.
(Moist savannah) . .	Open deciduous forest with heavy grass soil cover.
(Bamboo brakes) . .	Usually due to destruction of the overwood.

II. Dry Tropical Forests

4. *Tropical dry deciduous* .	Low forest almost entirely deciduous in all canopies.
4*a*. *Dry* (*mixed*) *deciduous* .	Several species contributing equally to the top canopy, including teak.
4*b*. *Dry sal* . . .	Sal predominates in the top canopy.
(*Khair-Sissu*) . . .	A nearly pure forest of these two species in varying proportions, occurring on new sandy or gravelly Indo-Gangetic alluvium.
(Tamarisk-Poplar) . .	A nearly pure forest of these two species on new alluvial deposits along the Indus.
(Dry savannah) . .	Open deciduous forest over grass.
(Indaing) . . .	Deciduous Dipterocarp forest on sandy soil and hills in Burma.
5. *Tropical thorn* . .	A low open pronouncedly xerophytic forest in which thorny leguminous species predominate (*Acacia*, *Prosopis*, etc.).
6. *Tropical dry evergreen* .	A low but often dense dry evergreen forest developed on the Carnatic coast with no summer rain. Small-leaved and thorny species predominate.
(Beach forest) . . .	A thin evergreen forest developed on coastal sands with *Casuarina* as the characteristic species.

III. (Montane) Subtropical Forests

7. *Subtropical wet hill forest* .	Tall luxuriant forest with evergreen species predominating.
8. *Subtropical pine* . .	Open inflammable pine forests with or without an evergreen underwood.
9. *Subtropical dry evergreen* .	A xerophytic type including thorny species and small-leaved evergreen such as olive.
(*Subtropical savannah*) .	Trees scattered singly or in groups on grassland.

IV. (Montane) Temperate Forests

10. *Wet temperate forests* .	Evergreen or semi-evergreen mixed forests with dense undergrowth.
10*a*. *S. wet temperate* . .	Dense low evergreen forests of mixed species.
10*b*. *N. wet temperate* . .	Tall forests of mixed evergreen (*Castanopsis*, *Quercus*, etc.) and deciduous species (*Betula*) and evergreen undergrowth.
11. *Moist temperate forest* .	Evergreen forests of conifers or oaks, etc. or a mixture of both. Undergrowth rarely dense and partly deciduous.
11*a*. *Lower oak-coniferous* .	Deodar with some blue pine in the west, *Tsuga* in the east. *Quercus incana* in the west and *Q. lineata* and *Q. lamellosa* in the east.
11*b*. *Middle oak-coniferous* .	Spruce, deodar and some fir in the west ; *Tsuga* and spruce in the east. *Quercus dilatata* in the west and *Q. pachyphylla* in the east.
11*c*. *Upper oak-coniferous* .	*Abies* with *Quercus semecarpifolia* in the west and *Q. pachyphylla* in the east.
12. *Dry temperate forest* .	Open evergreen forest with open scrub undergrowth. Deodar, pine and juniper with xerophytic broadleaved trees including *Quercus ilex*.
(Temperate deciduous forest)	Mixed deciduous forest very similar to European deciduous forest. Apparently an edaphic climax or seral stage.
(Alder woods) . . .	More or less pure crop of *Alnus* on riverain sites.
(Temperate bamboo brakes)	Due to destruction of the overwood.

V. Alpine Forest and Scrub

13. *Alpine forest* . . .	Evergreen conifers, and mainly evergreen low broadleaved trees.

Plate 10. Forest types. (*L*) Tropical wet evergreen forest, Kanara, Bombay. (*R*) Tropical moist deciduous forest with teak, Mount Stuart, Madras.

Facing p. 152.

PLATE 11. Forest types. (*Above*) Tropical dry deciduous forest of almost pure *Boswellia ersrata, Nimar,* C.P. (*Below*) Tropical thorn forest which has degenerated to a *Euphorbia-Salvadora-Capparis* desert type, Dabeji, Sind.

Facing p. 153.

13*a*. *Birch-Fir* . . .	A fairly dense mixed forest of high-level fir and deciduous birch with evergreen (*Rhododendron*) and deciduous undergrowth.
13*b*. *Birch-Rhododendron* .	Low tangled forest, often dense, of evergreen rhododendrons with or without a deciduous birch overwood.
14. *Moist alpine scrub* . .	Often dense, mainly evergreen, scrub of dwarf *Rhododendron*, juniper, etc.
15. *Dry alpine scrub* . .	Open xerophytic scrub of *Artemisia*, *Eurotia*, *Potentilla*, etc.

GEOGRAPHICAL DISTRIBUTION OF TREES AND FOREST TYPES

Distribution of Species, etc.

Local floras

The forest flora of most parts of India is now fairly well known, though there are still discoveries to be made in the richer areas in the east, and one or two large gaps such as that represented by Nepal. These local studies permit of the compilation of maps showing the geographical distribution of species, genera, and families over the country and these maps bring out many interesting features.

Differences in geographical range

A complete range is found between such species as *Azadirachta indica*, *Eugenia jambolana*, *Bombax malabaricum*, *Lannea grandis*, *Careya arborea*, *Adina cordifolia* and *Acacia catechu*, which are found in suitable sites over practically the whole of India from the foot of the Himalayas southward to Travancore (and even into Ceylon), and in Burma ; and others such as *Balanocarpus utilis*, *Tectona hamiltoniana* and *Pterocarpus santalinus*, which, although without any very special demand on the locality factors, are limited to very restricted ranges in Tinnevelly, U. Burma, and Coromandel respectively.

Variation associated with wide range

Species with a very wide range tend to show differences to a varying degree in vegetative characters, growth form, etc., in different parts of the range, though intermediate forms generally occur. The systematic status of these racial forms is not easy to determine, and must usually remain a matter of opinion. *Acacia catechu* has thus been subdivided into three varieties which could probably be still further differentiated into racial forms, each with its own inherited characteristics, whilst the aggregate covered by the old name *Terminalia tomentosa* exhibits a still wider range very difficult to analyse. Chir pine on the other hand is remarkably uniform.

Discontinuous distribution

There are many other species and genera in which a wide distribution is broken up into two or more unconnected areas, such as an eastern and western, or a northern and a southern, teak and *Rhododendron* respectively providing examples. The isolation is fairly evidently due to a former more continuous distribution, broken up by the present lack of suitable conditions for growth or reproduction in the intervening tract. With discontinuous distribution, the tendency to break up into local forms is generally still more marked, as is well illustrated by *Xylia*, the eastern and western forms being now considered as separate species, *X. dolabriformis* and *X. xylocarpa* respectively. *Teak* provides another good example of discontinuous distribution, and the eastern or Burma form is easily distinguishable from the western or Indian form, though fortunately this has not yet been recognized by botanical systematists ; moreover, there is also further marked differentiation within the western area. On the other hand, sal and *Bischofia* occurring in two separate areas do not appear to have differentiated appreciably.

Botanical Areas

Areas recognized

Comparison of the recorded floras of the various parts of the country has led to the recognition of a number of botanical areas each with characteristic features. Details are not required here, but the areas are the following[20] : (1) E. Himalayan, (2) W. Himalayan, (3) Indus plain, (4) Gangetic plain (divisible into dry, humid and tidal areas), (5) Malabar (West Coast generally), (6) Deccan (Peninsular India, divisible into northern or C. India, and southern or Deccan with Carnatic), and (7) Burma. If now the floras of these areas are compared with those of adjacent countries, affinities are brought out suggesting the probable origin of the differences. It is evident that there is no 'Indian flora' as a separate entity, but our vegetation is compounded of several elements which are present in very different proportions in the different areas. These elements are, in order of dominance for the country as a whole : (1) Malayan, (2) European and Oriental (meaning the Near East), (3) African (or better, Indo-African), (4) Tibetan and Siberian, practically confined to the Himalayas, and (5) Chinese and Japanese, mainly in Burma and the Himalayas.

History of forest flora

Present distributions and geological history[21] suggest that the oldest element in time is the Indo-African, including various *Combretaceae, Acacia arabica, A. catechu* and *Zizyphus jujuba*, which is common to tropical Africa, Madagascar and India, and that it extended to the W. Himalayas in later periods. In Burma and Assam, the Malayan element, exemplified by the Dipterocarps, *Myrtaceae, Garcinia, Tectona, Schleichera* and *Dillenia*, may be nearly as old, and it probably extended westwards in about Miocene times, with indications that there must then have been a much easier route for spread to S. India than now exists, such as a direct connexion from Malay to Ceylon and Malabar—it may be noted that Ceylon has a number of most interesting endemic Dipterocarps. The Tibetan element consists mainly of alpine herbs and shrubs (*Hippophae rhamnoides*) and must have existed along the northern limits of the country since the Himalayas reached a height of 12,000 ft., and has extended widely in later Tertiary times. The Sino-Japanese element includes many *Ternstroemiaceae* such as *Schima, Altingia, Rhododendron, Engelhardtia, Tsuga* and many oaks such as *Q. semecarpifolia, Q. serrata* and *Q. glauca*, and has similarly worked westwards and southwards.[22] The European element soon followed the Tibetan, extending rapidly from the west eastwards and down into Burma. It is well illustrated by some oaks, notably *Q. ilex, Juniperus* spp., *Crataegus*, and *Cedrus*.

It is of interest to note the presence of a few typically Australian genera in India, such as the coastal *Casuarina*, the commonly planted ornamental tree, *Melaleuca* (though this only reaches Mergui in the wild state), and the genus *Helicia* (*Proteaceae*) represented by various species in all the moist parts of the country.

Geographical Distribution of the Chief Forest Types

The geographical distribution of the types listed on pp. 150-3 is shown on the map at the end of the book. This map, owing to its small scale and the incompleteness of the recorded data, is inevitably somewhat diagrammatic, but brings out the main features, among which the following may be mentioned.

1. *Tropical wet evergreen forest.*—This type is found along the western face of the Western Ghats, in a strip extending south-west from Upper Assam through Cachar, and southwards through the Chittagong Hill tracts and along the Arakan coast, and in a strip from N. Burma down the Salween valley and the coast to Tenasserim, with a westwards extension across the Irrawaddy delta linking it with the Arakan coastal strip. This corresponds roughly with the regions with rainfall over 100″. In Tenasserim, with its Malayan affinities, the Dipterocarps become predominant, forming the evergreen Dipterocarp forest which is the most luxuriant type of forest we have ; more or less similar forest occurs locally elsewhere in the tropical wet evergreen, notably in the Andamans.

In the sub-Himalayan tract of Bengal and the adjoining part of Assam, the typical wet evergreen type is not, or is only very locally recognizable, despite the high rainfall. Sal forest has taken possession of much of the area, apparently as a subclimax with burning, and with fire-protection it has progressed to an evergreen type known as *wet mixed forest*, and would perhaps ultimately progress to typical wet evergreen. The secondary Dipterocarp type is only found on the Malabar coast.

2. *Tropical semi-evergreen forest.*—This type usually adjoins the tropical wet evergreen, forming a transition to the latter from the moist deciduous much influenced by human activities. It is well developed the southern part of the Pegu Yomas in Burma, and locally along the W. Ghats, whilst a northern form occupies considerable areas in Assam and the lower slopes of the E. Himalayas where it is characterized by *Schima* and Bauhinias. The *garjan* forests of Chittagong appear to owe their characteristic appearance to a secondary seral status leading to evergreen or semi-evergreen forest.

3. *The tropical moist deciduous forest.*—This type together with the following one is referred to as *monsoon forest*, which is perhaps the most characteristic type of India. It occurs as a strip along the foot of the Himalayas, another strip along the east side of the W. Ghats, a large block centring on Chhota Nagpur, a wide ring round the dry zone of U. Burma, and a tract to the lee of the Khasi hills. The typical rainfall is 60″-80″ with a dry season of 4-6 months. The moist sal forests form the greater part of the northern half of

the range, and moist teak is equally typical of the southern half. Throughout the area, more or less open *savannah* forest, ascribable to biotic factors, is found.

4. *Tropical dry deciduous forest* occurs in an irregular wide strip from north to south of the country, from the foot of the Himalayas to C. Comorin, bounded on the NW. by the Sind desert, on the SW. by the W. Ghats, and on the east by the wetter forests of Bengal. It is also found over a relatively small area in Burma where the typical rainfall of 40″ to 50″ with a dry season of about 6 months occurs.

Sal- and teak-bearing forests are again typical, but are of a much inferior type to the moist deciduous, and these important trees are wanting over much of the area.

5. *Tropical thorn forest* occupies a big strip in the Indus basin in S. Punjab, Rajputana, and Sind where the rainfall is about 10″ to 30″, and is also found over large areas in the Upper Gangetic plain and the Deccan plateau, as well as in the Dry Zone of U. Burma.

6. *Tropical dry evergreen forest* is restricted to a relatively small area on the Carnatic coast.

7. *Subtropical wet hill forest* is limited to the lower slopes of the Himalayas in Bengal and Assam, and local occurrences on other hill ranges, such as the Khasi, Nilgiri, Mahabaleshwar hills, and the Shan plateau in Burma.

8. *Subtropical pine forest* is constituted by the chir pine forests found between 3,000 ft. and 6,000 ft. throughout the C. and W. Himalayas, and local occurrences of other pines in the Khasi hills and Burma at corresponding elevations.

9. *Subtropical dry evergreen forest* is only found in the NW. corner of the country.

10. *Wet temperate forests* are characteristic of the E. Himalayas between 6,000 ft. and 9,500 ft. and also occur on the tops of the hills of S. India and N. Burma.

11. *Moist temperate forests* are found between 5,000 ft. and 10,000 ft. in the C. and W. Himalayas except where the rainfall falls below about 40″ in the inner ranges, especially in the NW. The occurrence of oak or coniferous forests depends on minor local variations of conditions.

12. *Dry temperate forests* occur on the inner ranges of the Himalayas throughout their length, and are best represented in the N.W.

13. *Alpine forest* occurs throughout the Himalayas above about 10,000 ft. up to timber limit.

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V

NATURAL REGENERATION

NATURAL REGENERATION BY SEED

COLONIZATION OF NEW SITES

New alluvial soils

In the last chapter, the natural phenomena of colonization and succession have been described. In forestry practice these two processes frequently bring about the establishment of a young crop, and sometimes, as with *sissu*, *khair*, poplar and tamarisk on new gravelly or sandy alluvium, and the mangrove species in the deltas, they are sufficient to do all that is required, giving a full crop on suitable sites ; sometimes they will give a crop over a part of the suitable area, artificial supplementing, perhaps only by broadcasting more seed, being required over the rest, as with *Acacia arabica* in Sind.

Recolonization of old clearings

The recolonization of old fields is often a matter of importance and interest as most reserved forests include more or less land of this type, either long abandoned by the cultivators, or acquired in the interests of proper management and simplification of boundaries. Sometimes the process is quite a rapid one, the fields being seeded up from the adjoining forest and soon reclothed with tree growth, examples being provided by blue pine in the Himalayas especially where the slopes are not or are only roughly terraced. More usually, the process is very slow and is severely checked by the concentration of grazing common in such places, acting both through the compacting of the soil and direct injury ; this effect is enhanced on heavier soil types and by terracing (though the terrace banks often provide suitable growth sites for trees, as seen with deodar and chir pine in the hills) ; and burning may exert a similar delaying influence. The result is that in many of our forests which have been reserved and protected for 50 years or more, old fields are found still blank or only with a few semi-cultivated trees such as mango and figs, and the attainment of the local climax forest type seems as remote as ever. The difficulties encountered in attempting to restock these blanks artificially indicate that far-reaching changes in soil conditions and drainage are probably primarily responsible.

Natural Regeneration from Seed on Clear-felled Areas

Clear-felled blocks

In certain types of forest in other countries, notably with *Pinus maritima* in SW. France and other pines in North America, satisfactory natural regeneration is obtained over large areas after clear-felling, by the germination and establishment of seed lying dormant in the soil together with that from the felled trees. The necessary conditions for this rarely appear to be present in India.

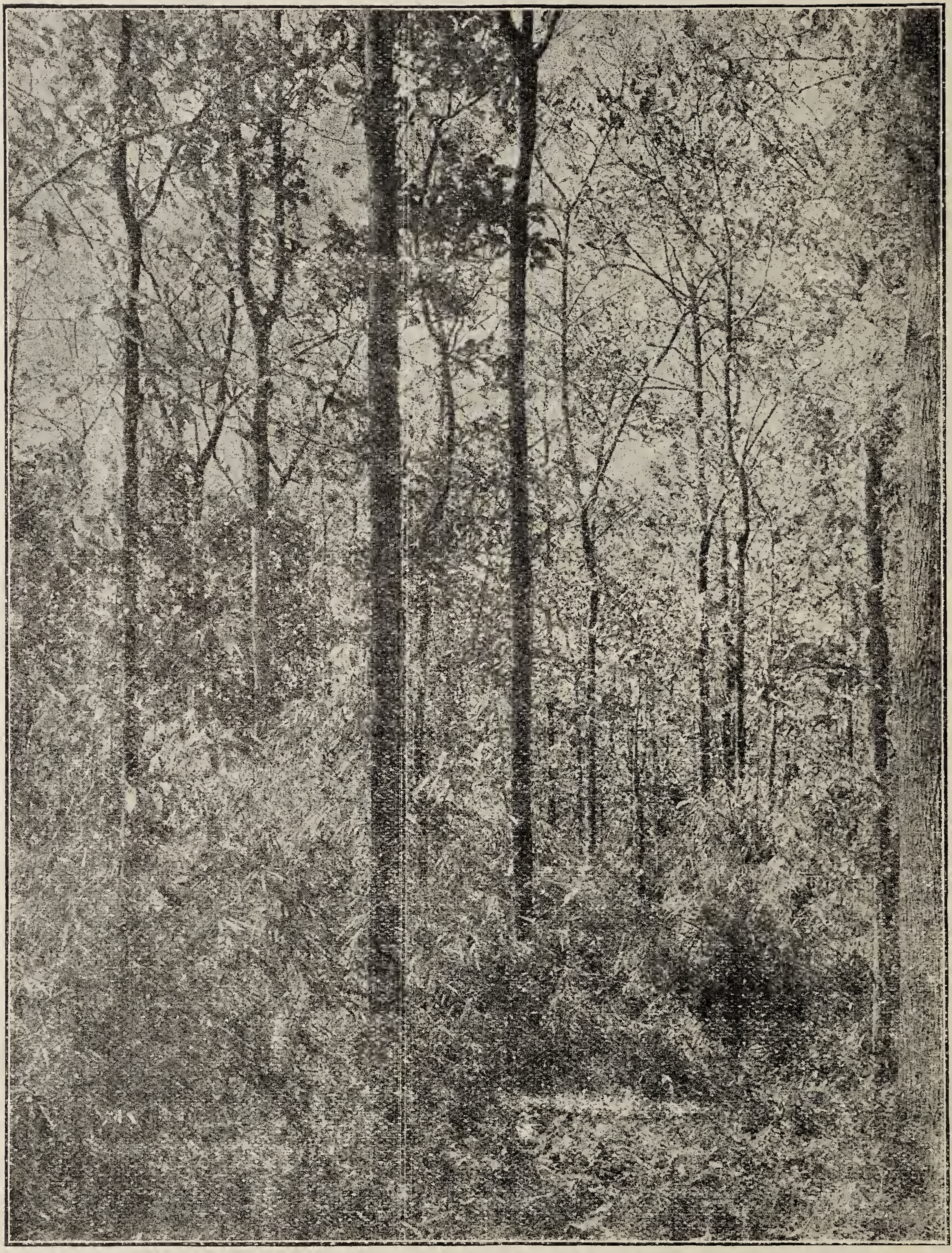
The only recorded case is that of some of the Singbhum sal (Bihar) and even there it is only comparatively recently that it has been realized that the old practice of leaving two or three seed bearers per acre was unnecessary.

Clear-felled strips

If the clearing takes the form of a relatively narrow strip, it is possible for it to be seeded up from the adjoining forest. Where the shade from the latter is a significant factor in germination and seedling establishment, conditions closely approximate to the shelterwood regeneration described on p. 161, but in our tropical and subtropical climates, this shade can hardly be very effective except with very narrow strips. The clear-felled strips system for *Pinus khasya* provides an example of natural regeneration in this way (with some artificial supplementing of the seed supply) ; it has also been tried with sal on an experimental scale in the United Provinces, where it failed for lack of the weeding, etc., essential to the development of the seedlings, and on a large scale in Sambalpur division, Orissa, where it was abandoned as offering no advantages over the much more convenient clear-felling dependent on stock and seedling coppice regeneration. Plate 12 shows conditions approximating to clear-felling.

PLATE 12. (*Above*) Natural regeneration of teak filled in by dense natural regeneration of *Adina*, S. Coimbatore, Madras. (*Below*) Dense growth of *Lantana* completely preventing regeneration, in mixed deciduous forest which has been opened up too heavily, Coorg.

Facing p. 160.



LATE 13. Teak P p'antation 32 years old, underplanted with bamboo (*Cephalostachyum pergracile*), Nilambur, Madras.

Facing p. 161.

Influence of soil differences

The important difference must be noted between regeneration on newly deposited soils or abandoned cultivation, and regeneration on the forest soils of clear-felled areas. The latter are far more suitable for seedling growth in many ways, especially in their relatively high humus content and porosity, implying a good soil micro-flora and fauna. Even if the area is burned after felling, this superiority persists or may even be temporarily heightened (cf. p. 51), and the only disadvantage of the forest soil is the likewise favoured growth of herbaceous and woody weeds.[10]

Natural regrowth on felled areas

It has already been seen that clear-felled areas left to themselves are recolonized by a limited selection of species, usually quick-growing soft-wooded deciduous species with wind-borne or bird-carried seed, and that a secondary succession sets in, slowly leading back towards the local climax. Owing to the fact that a large proportion of Indian broadleaved trees produce coppice shoots unless the stocks are killed by fire, many of the original species persist and the soil cover is fairly rapidly renewed, though with a crop very different in composition from the original. Fires, heavy grazing, or repeated cutting result in inferior retrogression stages from which progression to the climax is usually extremely slow.

Concentrated Natural Regeneration with an Overwood

Regeneration under a shelterwood

In Indian forestry, practically all natural regeneration work from seed is effected under a canopy, though the latter may vary between wide limits of density and composition. The influence of the varying factors of canopy density and composition, of undergrowth and soil conditions, and of extraneous factors such as grazing and burning will be considered in the following paragraphs. The application of the conclusions reached to forest practice is dealt with in a separate publication on silvicultural systems.

The Overwood

Seed trees

One of the first conditions for successful natural regeneration is an ample supply of good seed. This calls for well developed crowns on good seed trees distributed over the area in numbers and position varying with the species and the site conditions. Even as few as three good chir pine on an acre would suffice to seed it up if all other factors were favourable, and 6 to 8 is usually found enough to guard against casualties, etc. Sal requires considerably more trees, say 10 to 15, but a single *Adina cordifolia* per acre is probably enough to seed up all suitable sites (cf. Plate 12). As most of the existing forests are incompletely and unevenly stocked, large-crowned seed trees are usually available, though, owing to their uneven distribution, quality (both as regards size and maturity) may have to be made up by quantity in some places. In regenerating crops which have grown up in close canopy, whether from plantations or natural growth, it is sometimes advisable to free the crowns of the trees to be relied on for seed in impending regeneration operations. This opening up is termed a *preparatory* felling, but the term is now almost obsolete, as under Indian conditions it is rarely needed to ensure seed supplies, though it may be necessary to lighten the canopy for other reasons.

Initial light conditions

In addition to supplying the seed, the overwood determines through its density the amount of light reaching the forest floor, and this in turn greatly influences the soil and ground cover, germination, and seedling development. Light is probably the chief single factor concerned in regeneration ; fortunately, at the same time it is the most easily manipulated factor. Owing to the natural irregularities in the canopy, considerable variation occurs in the conditions existing at any time over any given patch of the forest floor, and critical examination of the connexion between the amount of spontaneous regeneration and these conditions will provide valuable suggestions as to promising methods for trial. This spontaneous regeneration found before special regeneration operations are commenced is known as *advance growth*, and in many successful regeneration areas, *ad hoc* operations have only consisted in removing an overwood over ample advance growth.

Manipulation of canopy

Despite the demonstrations that the root competition of the overwood plays an important part in regeneration, the amount of light penetrating the canopy provides the most practical measure of the summed effect of the main factors in play. The extension over the regeneration area as a whole of the light conditions appearing most favourable to regeneration is accordingly the correct first step, always bearing in mind the possibility of different requirements for *recruitment*, i.e. new seedlings, and *establishment*, i.e. the further development of seedlings already present. In practice, prescriptions take the form of giving either the average spacing for the top canopy trees, or the number of trees per acre to be retained ; also species, and crown and canopy class when necessary ; or conversely, they indicate the size of the gaps to be created. Corresponding instructions for the lower canopy layers when present are also necessary.

Uniform shelterwood regeneration

In the simplest case, that of uniform shelterwood regenertion applied to chir pine, it suffices to prescribe the retention of a specified number of seed-bearers and the felling of everything else on the area except the groups of immature poles to be kept to form part of the new crop. In good quality sal in the United Provinces, the seed will germinate and the seedlings persist for a few years even under a practically complete canopy, but to get up the seedling crop, it now appears that the overwood must be opened up in time, first to give about half a crown's space between adjoining trees, and further only as the seedlings respond ; undue haste results in the development of weeds or grass and stagnation of the seedlings. Protection against browsing and a variable amount of weeding, particularly during the rains, may also be necessary.[1, 1a] It has already been seen that many species only regenerate naturally in the shade of an existing crop—thus *Morus alba* and *Holoptelea integrifolia* under *Dalbergia sissoo*—whilst others such as *Adina* appear to require full exposure.

Lightening the canopy from below

The best treatment to ensure the regeneration of the more complex types such as the wet tropical evergreen has still to be determined but the indications of recent work have been that the most satisfactory method of admitting the additional light necessary for the establishment of regeneration is to remove or thin out the lower and middle canopy first, wherever it is standing under a fairly complete top canopy. Any preliminary opening up of the top canopy mainly benefits the middle canopy, which is usually of inferior species, and further opening encourages weeds more than regeneration.

Group regeneration

Instead of regularizing the canopy to cover a whole unit of area at once, it is sometimes advisable to reproduce the canopy conditions favourable to regeneration over small patches distributed over the regeneration area, and to widen these patches as seedlings become established in their centres till the groups of regeneration merge and finally extend over the intervening spaces (with some artificial help if needed). This *group regeneration* method has occurred naturally in the establishment of advance growth in most areas taken up for uniform shelterwood regeneration, and has been successful in deodar and *banj* oak forest. Apart from the utilization of such groups of advance growth, the method has failed with chir pine owing to failure of fire-protection, and with sal on account of weed growth ; it is under trial again for sal in Assam, where promising results are being obtained provided help is given by rains weedings when required.

Shelterwood strip regeneration

Instead of groups, a strip may first be opened out, and as regeneration is obtained on it, further fellings made to increase the light reaching the seedlings, whilst an adjoining strip receives the first operation. This is the *shelterwood strip* method which has not yet been applied in India. As already noted, it is little removed from clear-felled strip regeneration with narrow strips.

Effect of species on shade, etc.

The species retained to complete the desired canopy density after the requisite number of seed trees has been selected may influence the success of regeneration, and it may be desirable to prefer trees of species other than the chief dominant. In sal forest, the observation has often been recorded[2] that advance regeneration is better under trees other than sal, so that it may be better to retain the other species such as *Terminalia tomentosa*, *Lagerstroemia parviflora*, *Pterocarpus marsupium*, etc., and fell sal trees not needed for seed ; experimental evidence is still lacking on this point.

The Undergrowth

Variation in undergrowth conditions

The amount and importance of undergrowth varies very greatly with forest type and conditions. It is perhaps least in chir pine forests and is greatest in the wet tropical evergreen types. The natural undergrowth in most of our types is undoubtedly woody, but the annual or periodic burning to which all but the damper types are exposed has very generally brought about its replacement by grass. Conversely, successful fire-protection in hitherto burnt forest almost always results in the development of more woody growth, which often shades out the grass and may in time even render the forest difficult to burn—as in most of the damper sal forests.

Effect of heavy low shade

In a general way, heavy low shade appears more detrimental to regeneration than high shade, and the removal of dense low branchy underwood trees tends to be a routine measure in regeneration operations. As already noted, the taller underwood trees may be useful in providing moderate shade where the top canopy is too thin, but, as a rule, they too require to be thinned out at an early stage. Regeneration of moist deciduous forests of the Andamans, which have been worked over by timber fellings previously, has been successfully accomplished in the last few years by clear-felling all undergrowth up to a height of 60 ft. and burning the refuse broadcast (only a light fire occurs). Profuse recruitment occurs in June and is established by weedings and further lightening of the canopy from below as necessary, the final step being the felling or girdling of the remaining overwood. It is desirable to do this work as soon as possible after the timber felling, but most of it has been done in coupes felled several years previously which urgently called for attention. In the evergreen forests with Dipterocarps, etc., success has recently been obtained by similar methods, except that the first clearing of the undergrowth is rather lighter, only to 30 ft., and no burning is done.

Girdling, etc.

In evergreen forest of thin-barked trees, ring girdling and application of sodium arsenite is a very effective way of removing unwanted underwood (cf. p. 318) : it is less effective with deciduous species, which must be felled, girdled or pollarded.

Bamboo undergrowth

Bamboo often forms a dense undergrowth calling for special measures. The dense thickets known as *karka* in the C. P. and *wathon* in Burma are particularly difficult to deal with, and no really satisfactory method has yet been found which can be carried out at a reasonable cost. At the same time, teak seedlings are often found more frequently under and among bamboo than elsewhere.

Gregarious shrubs

Low shrubs, especially the gregarious species of *Strobilanthes*, often form a dense undergrowth in which regeneration is difficult, and similarly *Clerodendron* in sal forests, *Parrotia* or *Indigofera* in deodar forests, and *Lantana* in tropical deciduous forests (see Plate 12). Repeated cutting appears to be the only practicable method of keeping them in check, and burning is also often necessary. The season of cutting has a marked influence on results depending on the shrub and tree species concerned—cutting towards the end of a period of rapid growth and so exhausting reserve food materials is liekly to be most effective, but the season at which the seedlings are liable to suffer most from suppression or exposure must also be considered. Rains shrub-cutting has been found to be very important in getting up sal regeneration in damp forests.[1,1a] Uprooting is very generally more effective than cutting, and is not much more laborious or expensive for shallow-rooted shrubs when the ground is soft.

Lantana has been successfully dealt with in Madras by means of a sodium chlorate spray which, if of the correct strength, is selective in its effect and does not kill the seedlings under the *Lantana*. It is also often cleared by uprooting by departmental elephants.[11]

Grass undergrowth

A light grassy undergrowth generally appears favourable to tree regeneration, but it must be light. Such a grass cover permits sufficient light to reach seedlings in it, and does not react so unfavourably on the soil as dense grass does. Sal undoubtedly regenerates in the light grass growth which is associated with a fairly complete but not dense canopy and burning, better than it does under the double leafy canopy which is associated with long continued fire-protection in damp forests. Chir pine similarly regenerates better in burnt grass than in shrub growth. Dense grass however is very inimical to regeneration : very few species can establish themselves in dense *Imperata*, and sal fails in areas with dense *Pollinia ciliata* (*sau*).

Weeding natural regeneration

It has been repeatedly demonstrated that keeping tree seedlings weeded benefits them very greatly and may result in their becoming established where otherwise this could not take place. This has been found to be the case for sal in different forest types in Bengal, Assam and the United Provinces, and for teak and other species elsewhere. As a rule, it is rains weeding that is required, cold-weather weeding making relatively little difference and being liable to encourage *Eupatorium* which seeds in February ; some experiments in S. India seem to indicate that removal of the above ground portions of the competing weeds (' scraping ') may occasionally be as effective as digging them up by the roots. [12]

In all these natural regeneration operations, their cumulative cost must always be kept in mind for it not infrequently happens that it is considerably cheaper, quicker, and more effective to clear-fell a crop and regenerate it artificially (particularly if a *taungya* method can be used) than to regenerate it naturally by means of long continued expensive cultural operations.

SOIL CONDITIONS

Root penetration in soil

For successful regeneration, soil conditions must be such that with the light available the germinating seedling can become sufficiently well rooted to be safe during the dry season which is usually experienced when it is 6 to 8 months old, and to obtain moisture and inorganic food in quantity enough to permit of its active growth and successful competition with the surrounding vegetation.

Effect of acid humus

A thick layer of acid humus such as tends to form in the denser fir forests is liable to inhibit regeneration completely,[3] and a layer of sal leaves over the soil results in toxic conditions very harmful to sal seedlings.[2a] In the latter case a fire before seedfall provides the remedy, and in the former, the excess humus must be removed or its decomposition hastened by exposure or mixture with the mineral soil.

Soil working

Relative abundance of regeneration along dragging paths, roadways, etc., where the soil has been disturbed, is a very widespread phenomenon, and has led to soil working being tried as an aid to natural regeneration with various species many times and under many conditions ; it has not, however, often given results commensurate with the labour and costs, so that it is at present nowhere a routine operation. It is probable, however, that this has been largely due to unsuitable conditions of other controllable factors such as canopy density, game damage, etc., and soil working is quite likely to be adopted as a routine measure under certain conditions with sal and other species, as our regeneration technique improves with increased knowledge and experience. A compact soil hardened by trampling is difficult to regenerate, particularly when the drainage is inadequate, and provides the reason for the slowness in regeneration of many of the blanks in our forests. Soil working and improved drainage are the obvious remedies.

Dry soils

Light soils which support quite good forest may be so dry as to regenerate with difficulty especially when exposed : regeneration fellings have to be made very cautiously in such places.

Soil drainage

Bad drainage is a common cause of failure. In natural forest, badly drained sites are usually indicated by a change of species or type, and attempts to regenerate them with the climax type will probably fail. Thus sal gives way to *Terminalia tomentosa* in the less well-drained parts of sal forest, and this in turn is replaced by *Eugenia jambolana* on still wetter and stiffer soil. It is not usually practicable to drain such places, and the correct procedure is to aim at regeneration with the better adapted species.

Burning

Relation of natural regeneration to burning

Much natural regeneration owes its existence to the burning of the forests, though vast amounts of regeneration are destroyed in forest fires. In general terms, a fire is often a good preparation for regeneration but is inimical to existing regeneration.[10] In the upper coniferous forests, fires are very destructive as the important species are fire-tender, but the burning of the layer of undecomposed needles may provide a good seedbed if seed reaches the area ; blue pine is favoured over the other species as it seeds more freely and the seedlings stand more exposure. In the chir pine forests, a fire does no harm to the larger trees unless resin blazes catch fire or slash is present. It consumes the needle layer which may be excessive, as also the grass which may be too dense and tall.[13] On the other hand, it certainly increases soil erosion. An excellent seedbed is provided and, it is accordingly the practice to burn the forest in the spring before seedfall in areas due for regeneration, with the result that often in a good or even average seed year, a full seedling crop is obtained. A fire in the following year however will practically annihilate this regeneration. A proportion of 2 to 5-year-old advance growth will survive hot-weather fires and shoot again from the thickened collar, but regeneration 2 ft. to 8 or 10 ft. high is likely to be killed outright, whilst still taller saplings will escape or not, depending on the density of the crop and the intensity of the fire.

An up-hill fire is naturally far more destructive than a down-hill one, the damage done being particularly severe where the configuration of the ground is such as to give an increased draught.

Controlled burning in regeneration of pine forests

As the risk of destructive fires is great, it has become customary to put a fire through young chir pine regeneration during the cold weather at as early an age as possible, as a fire-protection measure—the so-called *controlled burning*.[4, 5, 10] It should be clearly understood that the adoption of this procedure does not imply that it has been established that such controlled burning improves the site factors of the forest, but only that the damage is much less than would result from an accidental fire later in the season and that the risk is rated high. Where possible, the saplings should be well spaced out when about 3 ft. to 6 ft. high, those removed being burnt in heaps in places where no harm will result ; this is not at present done in the United Provinces on the score of cost. Fire is set for about 2-3 chains along the top of a ridge or the lower side of a contour path, and allowed to burn down-hill , the width being kept roughly constant by firing from the edges as the fire progresses downwards. If the burning is unduly slow or irregular, it may be expedited by successively firing upwards from contours roughly parallel to the first and 30 ft. or so lower down (depending on the size of the regeneration) and letting the fire run up the short distance to the already burnt portion. One or two men must be stationed below the fire to extinguish rolling cones. Areas where the regeneration is not advanced enough to withstand the fire are always excluded from the burning by firing outwards from their periphery when the controlled burning nears them. This burning is done as far as possible in November and December before the winter rains unless there is much inflammable material, when it is postponed till after the first fall : in any case it should be finished by the end of February, or a little later on cool sites. The work requires careful organization and supervision ; without it, the term *controlled* burning becomes a misnomer, more up-hill burning takes place, and much damage is done to the regeneration.

Opening to grazing before burning helps to reduce the damage done. The details of the method of burning are still under experiment to reduce the damage done to a minimum and at the same time keep down the costs and the demand on the time of the range staff.

Controlled burning in sal regeneration

In sal forests, the position is very different. Much of the existing crop has originated as regeneration which was able to establish itself in hitherto burnt and open grassy forest. Many of the failures —complete in the damper types—of attempts at regeneration are due to the continuance of protection. Burning is then essential to thin out the underwood and replace it with light grass, to remove the toxic covering of dead sal leaves, and so to sweeten the soil. It is probably a necessary preliminary to natural regeneration where-ever grass is not already present. How long it might or should be continued, we cannot yet say, but continued burning inevitably lengthens the regeneration period owing to high mortality among the weaker seedlings and killing back of the stronger, and even if this has been the normal process in the past, other measures appear desirable once the seedling crop has been obtained. Burning of dry grassy sal forests is very harmful and only justifiable where the risk of hot-weather fires is exceptionally high. Conditions are generally similar for *Dipterocarpus tuberculatus* and the other more xerophytic Dipterocarps.

Teak regeneration and burning

It has frequently been recorded that natural regneration of teak is more abundant in burnt forests than in fire-protected areas, with the suggestion that the increased exposure, and even the actual burning, stimulate germination and facilitate establishment. Only weak seedlings are killed outright by fire, so a gradual accumulation of seedling stocks is possible even with annual fires, and ultimately the exceptionally fire-hardy saplings become established. Most naturally-regenerated teak bearing forests are not fire-protected, though the indirect harm done by increased soil erosion and destruction of fire-tender soil-improving associated species is now realized.

Fires in mixed deciduous forests

Very little is known about the influence of burning on regeneration in the other mixed deciduous forests, in which in fact regeneration is almost universally deficient.

Fire in moist evergreen forest

The wet tropical forest does not burn easily, but the constituent species are almost all very fire-tender, and burning along the edges results in a gradual reduction of area, and replacement by deciduous forest with grass undergrowth : leaf fires may however be a factor in the natural regeneration of some *garjan* forests (*Dipterocarpus costatus* and *D. turbinatus*).

Slash disposal

In inflammable types of forest under regeneration, notably in the coniferous types, success very usually depends ultimately on successful fire-protection or a reduction of the damage done by fire. Effective disposal of unwanted combustible material becomes an important routine operation, consisting in removing it from the base of the seed trees after the seeding felling, to open places or hollows where it can be burnt in heaps or left without danger after the final felling. The work is done as soon as possible after felling, and the burning wherever it is safe.[5, 6, 7] Apart from the reduction of fire risk, slash disposal may be necessary to permit the access of seed to the soil (deodar) ; it also tends to reduce later trouble from climbers which are liable to obtain a strong footing on the unconverted tops (tropical evergreen). The sites of burnt slash heaps form good places for sowing or planting when this is done to supplement natural regeneration.

Grazing and Browsing

Domestic animals

There has been the same reasoned veering round of opinion with regard to the effect of grazing on regeneration as for burning. Heavy grazing is almost invariably detrimental, but total stoppage has also not infrequently been found to react in the same way, and it is now clear that, as with fire, regulated grazing is to be considered a useful aid to natural regeneration. Grazing regulated to suit conditions may be helpful in reducing the amount of undergrowth, in exposing the mineral soil and mixing it with the humus, in trampling the seed into the soil, and sometimes in reducing the fire risk or fire damage. There is evidence for sal, chir pine and deodar that grazing in regeneration areas, provided it is well distributed and not excessive, can be helpful. In other types there is less informaton, but teak is rarely browsed and so may be helped against its competitors. Such grazing as an aid to regeneration should, with rare exceptions, only be by cows, oxen and sheep, since camels, buffaloes and goats all browse freely on tree growth.

Deer, etc.

It is only of recent years that it has been realized that browsing by wild animals, particularly *cheetal* and *sambhar*, may be so intense as effectively to prevent regeneration even when other conditions are favourable. It is now certain that this is true for sal, so that, where game is abundant, regeneration areas must be effectively fenced for success.[1, 1a] The burning and shrub-cutting which are also necessary to get up the seedlings only serve to make the latter more conspicuous, and even when the sapling stage is reached, the tops may be so systematically broken off that establishment is effectively prevented. The complete disappearance of regeneration of *Adina* in unfenced areas is probably due to this same cause. Exceptionally palatable species such as *Gmelina* and *Morus* rarely escape damage or destruction in the sapling stage, in which also much damage is done by stags rubbing off the bark with their antlers. *Artocarpus* is very liable to be destroyed by wild elephants, of which it is a favourite food. Further notes on fencing will be found on p. 210.

Control of Species Mixture in Natural Regeneration

It is important in natural regeneration operations to ensure that the specific composition of the new crop is the most suitable for fulfilling the objects of management, and the technical details of the work must be adapted to each set of conditions.

Different light requirements

In consequence of the fact that the more shade-tolerant species can regenerate under a full canopy of less tolerant species, whilst the latter cannot regenerate, advance growth is usually mainly of the tolerant species. This may be useful if the latter are fairly slow growing and an opening of the canopy results in adequate regeneration of the less tolerant species, a suitable mixture being thus obtained.

Coniferous mixtures

A mixture can be obtained in this way in the mixed coniferous belt with silver fir, spruce, deodar and blue pine, which are shade-bearing in the order given. The silver fir requires far less light for regeneration than the others and its timber is the least valuable, but the advance growth it gives does not develop so quickly as to prevent the development of the other species. The cultural tending operations required to produce this result are sometimes expensive.

Sal

In the damper sal forest, sal regeneration is completely inhibited by shade-bearing evergreens unless the latter are effectively checked, first by repeated burning with or without cutting to replace them by grass, and then by repeated cutting during the establishment period of the sal.

Tropical evergreen

In the complex wet tropical forests, most species are adapted to regeneration under heavy shade, the seedlings persisting for a varying length of time till chance openings in the canopy let them up, failing which they succumb to suppression. It is accordingly often possible to control to an appreciable extent the composition of the crop by freeing operations to favour the desired species, and much has been done in this way, as with *Hopea* and *Balanocarpus* in Madras, and several species in Coorg.

Present position

Considerably more silvicultural knowledge than is at present generally available and its systematic application, are necessary for effective species control. Thus mixed regeneration of deodar and blue pine appears very satisfactory in its early stages, but soon the blue pine outgrows the deodar, and being less valuable has to be cut out or restricted to groups usually where the deodar is inferior. As a rule, regeneration work in India concentrates on getting adequate regeneration of the chief species, only slight attention being given to associated trees, but the mixture is controlled to an appreciable extent during cleaning operation, when desirable subsidiary species are favoured, locally even against the chief species.

Natural Regeneration in Irregular Forest

General description

Regeneration should be a continuous process in irregular or selection forest so that all age-classes are adequately represented on each unit of area. In that the younger age-classes stand more or less under the older, an economy of space is claimed as compared with regular forest, but this is rarely attained in Indian forests owing to their complex composition, the younger age-classes of the important species being largely replaced by an underwood of more or less useless subsidiary species. Theoretically, when a mature tree or group of trees is felled, there should be younger age-classes ready to take its place, or at least the gap should be readily seeded up. In practice, the felling gaps under the Indian selection system—mainly selective logging—are rarely reoccupied by the desired exploitable species, but are invaded by masses of climber and weeds, and so far only intensive work after-fellings far too heavy to be considered selection fellings have given satisfactory results, as in Assam, in Coorg, and in the Andamans. As however the operations include not only heavy selection fellings of major species but also replacement of the predominating non-commercial species of the overwood by regeneration of the commercial species, the work done is usually more in the nature of a conversion operation to a more regular type of forest.

Coorg tropical evergreen forest

Thus in Coorg, in wet tropical evergreen forest, the procedure which has proved most satisfactory so far has been to extract all saleable trees over the exploitable girth except a few (3-10) per acre retained for seed ; as soon as possible after extraction, all valueless species interfering or likely to interfere with regeneration are felled, and this operation involves removal of much of the middle canopy and some opening in the top canopy. With the existing amount of natural regeneration and poles, the result is an increase in the proportion of the more valuable species more than compensating the original timber felling, but it is not anticipated that another main felling will be done for 50 or 60 years.[8, 8a]

Andamans forests

In the Andamans, exploitation fellings in moist deciduous and evergreen forests have not been followed by satisfactory regeneration, and latterly concentrated regeneration work has been successfully carried out as described above on p. 165.

Assam evergreen forests

Again, in Assam, a marked degree of success has been attained by timely weeding of the copious regeneration, mainly of *Terminalia myriocarpa* (*hollock*) which springs up along drag paths, etc., where the soil has been exposed in logging and extraction operations.[9] The weeding is done in June-July in the first year just before the weeds begin to suppress the regeneration, and is followed by a second year cleaning. In the third year the regeneration is 20 ft. high and only climber cutting and thinning are required. 40 per cent stocking is obtained in this way at low cost (Rs. 4 per acre for the first weeding).

NATURAL REGENERATION BY COPPICE

Seedling Coppice

Sal seedling coppice

This term has come into general use of recent years to describe a method which has been found to give good results with sal. Sal regenerates freely in good seedling years but is very slow to get established, and requires a rather special combination of circumstances to grow up and form a new sapling and pole crop. Established seedlings and advance growth are generally capable of persisting for a long time, probably even 40-50 years, without attaining a basal diameter exceeding about 3 inches. If now this established advance growth is cut back and freed from overhead shade, it usually shoots up strongly, and after a few years cannot be distinguished from a true seedling crop. This young growth is termed ‘ seedling coppice ’ and forms the bulk of the regeneration in several important sal divisions in the United Provinces, notably Gorakhpur and Dehra Dun, as also in parts of Bihar, Orissa and the Central Provinces.

Teak seedling coppice

Similarly with teak, the seedlings are often cut or burnt back for some time before they finally grow up. After a few years, the coppice origin cannot be traced and the new growth develops to high forest if allowed.

Stool Coppice

Coppicing power

The coppicing powers of different trees have been described on p. 104.

High stumps

The effect of the height of the stump varies with species, some with poor coppicing powers such as *Hardwickia binata* shooting better with a high stump or even when pollarded ; the converse case may also occur.

Low stumps

When possible, a low stump offers several advantages : thus the shoots are much less liable to get broken away by wind or animals, and shoots from ground level tend to develop their own root system and to be less affected by subsequent rot of the old stool. It was the custom in teak coupes in Khandesh to cut and trim the stump practically at ground level, but very low cutting is not generally done as it is difficult and expensive to carry out. It is not uncommon for the bark of the stool to dry out and split away from the wood for some inches down from the cut. The cambium is of course killed at the same time, and the new buds must be developed still lower down, which in some species at least they are slow to do. For this reason, it has often been recommended that stumps should not be cut too low, or death may extend below the level at which shoots are readily developed.

Trimming coppice stumps

It is also usually recommended to trim the stools carefully so that the cut surface slopes down from the highest point in the centre or near one edge, and the bark and cambium present a clean cut all round. The intention is that water shall at once drain off and the risk of rot be minimized, but it is doubtful whether there is adequate compensation for the extra labour and costs involved, and tests with sal indicated that there are no discernible differences in stool mortality or shoot vigour, so that the practice is now less common than formerly. Trimming has also been found to be harmful in the dry forests of Madras. In any case, the axe must be really sharp or more harm than good is likely to result from the operation.

Season for coppicing

The best season for coppicing appears to be in the latter part of the resting season shortly before the normal shoot extension is due to begin. Felling stimulates early development of shoots, so that in temperate forests with risk of late frost, frost damage may result from early fellings. Delayed fellings on the other hand, e.g. hot-weather fellings with sal, result in the loss of a part of the growing season. Where the coupe is burnt over, delayed work may also result in the killing back of the first-formed shoots, loss of growth and weakening of shoots.

Stimulation of coppicing

In tea planting practice, the application of washing soda to old stools will often cause sprouting where it would not otherwise take place : this has apparently not been tried in forestry ; it may be advisable in plantations of fodder species.

Stool mortality by coppicing

In all coppicing operations a stool mortality occurs, i.e. some stools do not send up coppice shoots. The extent of this mortality varies greatly with species, age, and local conditions generally. Sometimes it is made up by natural regeneration but more often not. In recent years this subject has received great attention in the drier forests and in the fuel forests of Madras it was found that at each coppicing, the stool mortality was of the order of 10 to 15 per cent and this loss was not being made up by natural regeneration. Hence the vital necessity of artificial regeneration operations in these dry fuel forests.[14,15]

Pollarding

True pollarding consists in topping a pole tree at some height above the ground so that it produces a crown of new shoots from buds below the cut, and in felling these new shoots periodically exactly like stool coppice. This is a common method with willows in Europe, Kashmir and Lahaul, but is nowhere else practised in India.

Lac culture

The somewhat similar process of severely pruning back the leader and main branches to bring about the development of strong new shoots is commonly adopted where lac is cultivated, being applied to the chief lac hosts such as *Schleichera trijuga*, *Butea*, etc.

Fodder and green manure

Where loppings are an important source of fodder or green manure, or are used systematically for feeding silk worms (*Morus* spp., *Terminalia tomentosa*), the same treatment is applied, and is often seen in village and private forests. *Quercus dilatata* in parts of the W. Himalayas is lopped every second year for fodder under a recognized system.

NATURAL REGENERATION BY ROOT SUCKERS

Root suckers

The chief species in which regeneration from root suckers is deliberately aimed at is *sissu*, which sends them up copiously when the roots are severed or mutilated ; regeneration in the plantations along the irrigation canal banks in the United Provinces is largely effected in this way. Formation of root suckers (cf. p. 104) is stimulated by trenching round standing trees or green stumps to a distance of about 20 ft. or sometimes by running trenches through an area with scattered trees. *Dalbergia latifolia* and *Azadirachta indica* can be similarly treated, and apparently *Bombax* also. Some unimportant species such as *Stereospermum* send up root suckers far from the parent tree without the stimulus of root wounding or severance.

WEEDING AND CLEANING NATURAL REGENERATION

Weeding and cleaning

With rare exceptions, notably chir pine under certain conditions, natural regeneration of the desired species is always accompanied by regeneration, both seedling and coppice, of unwanted or harmful species of trees, shrubs, herbs and climbers which it is necessary to eliminate or reduce in quantity, or to keep below the main species. The removal or cutting back of this competing growth in seedling crops is known as *weeding*, whilst the term *cleaning* is used to imply the removal or topping of inferior individuals or species from sapling crops (i.e. regeneration over 3 ft. high). Both operations are included under tending and so will be discussed in Chapter VIII.

CULTURAL OPERATIONS

Cultural operations

After regeneration fellings, it is very often necessary to work over the area to minimize the after-effects of the inevitable felling damage, and generally to improve the growth conditions for the regeneration. This work is usually referred to as ‘ cultural operations ’ and includes : (1) removal of marked but unfelled trees unless their removal is now found to be unnecessary or undesirable, (2) cutting back of damaged saplings where this can result in the growth of a good coppice shoot, (3) thinning out groups of advance growth or small poles under saleable size, (4) climber cutting, and (5) removal of inferior or weed species where these are harming or likely to harm better growth. The weeding and cleaning described in the last section are obviously included under this wider term, cultural operations, and further details are given in Chapter VIII.

REFERENCES TO LITERATURE

[1] *Ind. For.*, 1936, p. 186, [1a] *Loc. cit.*, p. 260. [2] *Ind. For. Rec.*, XIX(III), 1933, p. 62, etc. [2a] *Loc. cit.*, p. 18. [3] *Proc. Punjab For. Conf.*, 1933, p. 67. [4] *Punjab Forest Leaflet* 8, 1932, p. 8. [5] *Working Plan, W. Almora dn.*, 1935. [6] *Punjab Forest Leaflet* 6, 1932. [7] *Ind. For. Rec.*, XIII (VII), 1928. [8] *Proc. Silv. Conf.*, 1929, p. 98, etc. [8a] *Loc. cit.*, 1934, p. 142. [9] *Ind. For.*, 1934, p. 421. [10] *Ind. For. Bull* 130, 1946. [11] *Ind. For. Bull.*, 106, 1942. [12] *Ind. For. Rec. Silv.*, 5(2), 1942. [13] *Ind. For. Bull.*, 131, 1947. [14] *Ind. For. Rec. Silv.*, 3(8), 1940. [15] *Ind. For. Rec. Silv.*, 4(4), 1941.

VI

ARTIFICIAL REGENERATION

GENERAL CONSIDERATIONS

OBJECTS OF ARTIFICIAL REGENERATION

Artificial regeneration by sowing or the various forms of planting is done under a variety of conditions for reasons which also vary considerably from case to case.

Supplementing natural regeneration

Where reliance is mainly placed on natural regeneration, experience has taught that it is rarely possible to obtain adequate stocking over the whole of the regeneration area within a reasonable period of time, a varying proportion of it proving difficult, slow, or even impossible to regenerate naturally. It is accordingly common, especially in the more intensively managed forests, to complete the natural regeneration by stocking the failed or backward patches by artificial methods. There are also in most regeneration areas special sites where regeneration originally present has been destroyed or prevented by the felling, conversion or extraction operations, and artificial stocking is advisable—thus charcoal kiln sites in broadleaved forests, places where slash has been burnt in deodar and pine forests, timber depot sites, and so on. Often these places offer favourable conditions of growth which it is obviously desirable to utilize for regeneration rather than to leave for weeds to take possession. At the same time, it is usually not worth the cost and trouble of planting up petty blanks, and their presence should not be permitted to hold up early completion of regeneration operations.

This class of work may be done mainly under a shelterwood, e.g. with deodar ; in more or less natural blanks of varying extent, as in the sal coppice coupes of Gorakhpur, and in the *rabs* (cf. p. 213), in teak coppice coupes in Bombay and the dry evergreen of Madras ; in felling gaps, as in teak-bearing mixed deciduous forests and in moist tropical evergreen ; or in places where bamboo clumps have flowered and died.

A particular case of artificial regeneration to supplement natural regeneration is the extensive work being done in the dry fuel forests of Madras where coppicing results in a heavy stool mortality and natural regeneration is negligible.[47]

Replacing natural regeneration

Artificial regeneration is also being done on a large scale in many types of forest instead of natural regeneration, where the latter is too scanty, slow, or uncertain to be relied on, at least with present knowledge. It is also done in places where conditions especially as regards labour supply are such that artificial regeneration is quicker, more certain and cheaper than natural regeneration and so is economically the sounder method.

Sal forest

The outstanding example is sal in Bengal and parts of the

United Provinces and Assam, where artificial regeneration had to be adopted to permit of the continuation of fellings in the absence of adequate natural regeneration. With improved knowledge of natural regeneration technique, it is likely that there will be a reversion to it in suitable localities, but meanwhile artificial regeneration is being done on a large scale after clear-felling the existing sal forest.

Teak forest

To some extent a similar procedure is being followed in several provinces with teak, with the difference that whereas sal heavily predominates in the sal forests under regeneration, teak only forms about 10-30 per cent of the teak-bearing forests, and the proportion is greatly increased in the new crop.

Other tropical forest

The same considerations apply to the wet tropical evergreen forests and to the mixed deciduous forests of the Gangetic alluvium which contain a small proportion of valuable species.

Pine forest

A special case is illustrated by the chir pine forests of parts of Kumaon, where artificial regeneration with seed from straight-grained stock would be preferable to cheaper natural regeneration from the existing crop so badly twisted as to offer little prospect of ever producing timber fit for sawing. This has however not been applied in practice hitherto owing to financial considerations.

Artificial regeneration is perforce adopted where coniferous forest has been destroyed by fires, as has happened in deodar forests in the Punjab and chir pine in the United Provinces.

Increasing the more valuable species

Many forests, such as the wet evergreen and mixed deciduous types, and particularly the dry fuel forests contain only a small proportion of the more valuable species occurring in them, this position having been very commonly strongly accentuated by selective logging and continuation of conditions of grazing and burning which prevent natural regeneration. In such forests, artificial regeneration alone offers reasonable prospects of rendering them productive, and much work of this class is in progress.

Afforestation

Artificial regeneration is required in the reforestation of denuded areas, as in parts of the chir pine belt in the West Himalayas, in the grasslands of the S. Indian hills and the secondary savannahs and scrub forests of the Indo-Gangetic plain. The abandoned sites of former shifting cultivation are prevalent in several parts of the country, calling for similar treatment.

Artificial regeneration is also extensively practised in the dry thorn forests of the Punjab, and the N.W.F.P. where the advent of irrigation permits the establishment of a better and closer, more mesophytic type of forest. Afforestation without irrigation is also being carried out on a large scale in some of the very arid areas such as the N.W.F.P. plains. It should be a general rule in opening work of this kind to commence in what appear to be the easier sites, extending to the more difficult after experience has been gained. Chapter VII is devoted to afforestation problems.

Introducing valuable exotics

Wherever artificial regeneration is being done, the question arises of the introduction of valuable exotics, species not occurring naturally in the tract in question. The considerations involved in deciding whether to raise exotic species are dealt with in a later paragraph (pp. 185-7).

Choice of species

Control of the specific composition of our forests is far greater with artificial than with natural regeneration, and full consideration of silvicultural and economic requirements is needed, the latter being of course a management problem which working plans should provide for. The matter is further considered in the following pages.

Influence of Soil Conditions

Dearly bought experience has proved that, although in any area most of the local species may make a good start with the favourable conditions of worked soil and weeding, later failure is very likely to result with all except those which are properly adapted to the soil of the plantation site. It is therefore a matter of the greatest importance that each species be put only on the types of soil and site suited to it as indicated by good growth in natural forest or older plantations. There are few plantation areas of any extent which do not require the use of more than one species on this account. Examples are given on pp. 215-17.

The assessment of species to particular areas in a proposed plantation site on the basis of the species and growth of the natural forest already on it needs considerable care. This has been well exemplified in parts of Malabar where good forest containing excellent growth of scattered teak has not by any means always proved suitable for teak plantations.

Influence of Climate

The natural forest provides the required indications as to the species adapted to the local climate of a plantation area, but care must be taken to recognize variations within it. In areas subject to frost, only certain species are possible in the hollows or on the more exposed slopes. In the drier localities, aspect may make a considerable difference, change of species on different aspects being a very common phenomenon in natural vegetation. Examples are given on p. 140.

Pure v. Mixed Crops

Past practice

Almost all plantation work in the past has been done with single species, attempts at raising mixed crops having been relatively few and till recently rarely successful. Among the reasons for this are : (1) the much higher value of the species usually planted e.g. teak, deodar or sandalwood, compared with all possible alternatives, (2) the natural occurrence of pure crops, e.g. deodar, chir pine or *sissu*, and (3) the ease of raising, the geat hardiness, or the rapid growth of the selected species, illustrated respectively by *sissu*, teak, and blue gum.

The European objections to pure crops of light-demanders similar to teak, and of acid humus builders such as spruce, have long been appreciated, but there has been a tendency to accept them without critical study for the extremely different climates and soils of India.

Present tendencies

Attention has been repeatedly called to the fact that the majority of species in the tropical forests are not naturally gregarious but are only found singly or in relatively small groups in complex mixture ; it is argued that as this mixture is the natural conditon, attempts to raise pure crops are likely to fail. It would be more correct to deduce that they are likely to require more intensive management to keep them healthy and so to be rather more expensive but not necessarily superior from the economic point of view. The conservative and safer view would be to follow nature as far as possible and so retain the mixed type where possible. Of recent years the subject has been receiving more attention, and investigations have been initiated into the often difficult technique of raising mixed plantations.[11a] Experience has shown everywhere that the raising and tending of mixed plantations requires far more experience and knowledge of the relative rates of growth and varying light and space requirements of the constituent species under different conditions than is at present available, so that such work must still remain experimental for many years. Systematic experiments in teak plantations in Java[12] indicate that all mixtures result in a loss of increment in the teak much exceeding in value the increment of the subsidiary species, so that any benefit to be reaped from the mixture must be derived from the maintenance of the soil in good condition for future rotations. A similar drop in fertility was reported from Nilambur[11b,22] when second rotation teak was commenced there, and though it has since been shown that other factors were in play, there remains a body of opinion that, without an adequate soil cover, deterioration does take place.

Recent work has however shown that in teak plantations this adequate soil cover can be provided by a suitable undergrowth. As a result of this work many changes in teak plantation technique have taken place in the past few years.[48,49]

Risk of epidemics

Strong objection has also been raised to the (more or less) pure plantation on account of its greater exposure to damage by insects and other pests. This is particularly so with teak ; thus the bee-hole borer of teak timber in Burma is reported to show a far higher incidence in the plantations than in the natural forest with only a low concentration of teak, and repeated defoliation of teak plantations is quite spectacular at intervals of a few years.[11b,12] Much damage by insects has also been reported from plantations of *tun* and other *Meliaceae* from the shoot borer attacking them, from those of *Michelia champaca* from a sucking bug, and of walnut from a timber borer. *Loranthus* has ruined plantations in several provinces, e.g. *Gmelina* in S. Bengal. More statistical data are still needed in this connexion as such damage is always more conspicuous in plantations than when scattered in a mixed forest. The trees may also grow out of a vulnerable stage, as for *Phassus* in young teak, the borer in *tun*, and *Peridermium himalayense* in chir pine, and remedial measures may be practicable.[48,49,50]

Burning

Many other points have to be borne in mind, for instance fire-tender species such as *Michelia* must not be mixed with sal if it is intended to put controlled fires through the plantation later on.

Need of research

The general conclusion on this subject is that much further study of mixed crops is needed, and that in the meantime, where extensive operations are called for, it will be better to continue with more or less pure crops and the simplest mixtures, the technique of raising which is well known. Methods of mixing and the species used in mixtures are described on p. 241. A special need is for a good soil-improving underwood species to take the place of beech in European forestry ; mulberry appears to come nearest to filling this role in NW. India, *Pongamia* and *Xylia* being possibilities further south and east.

Indigenous v. Exotic Species

Introduction of exotics from neighbouring tracts

The meaning of the term ‘ exotic ’ in forestry lacks a generally accepted definition. It is here taken to imply any species grown outside its natural range of distribution since political boundaries are arbitrary and changeable, and the limits of natural botanical areas have not been agreed on. The exotic species under consideration may grow not far off under similar conditions of soil and climate, being only absent owing to inhibiting biotic factors, including fires, or chance barriers to natural extension, or it may even have been all cut out in the past ; in such cases there need be little hesitation in using it. Sometimes a small extension of the natural range, climatic or soil, may be involved, which is however enough to prevent natural spread. This may be due to failure of regeneration to establish itself though the species may flourish once it has been established with artificial aid, as with deodar both in the many temple groves in the E. Kumaon Himalayas and in the oak and scrub forests in the outer ranges where it is not indigenous, and also with chir pine on the floor of the Dehra Dun. This initial aid often permits a considerable extension of the range of a species into moister climates where it would be unable to compete unaided with the indigenous species—as with teak into the semi-evergreen and evergreen tracts, and deodar in the wet outer ranges—but growth may fall off again as the trees get older unless the more xerophytic conditions to which they are adapted can be maintained, as they sometimes can be by burning and other measures.

Teak

The species for which this question most often arises is teak, which is being planted extensively in several provinces outside its natural habitat. Other considerations tend to be outbalanced by the very high value of teak timber, often two or three times that of possible alternative species, and by the relative ease and certainty with which teak can be raised, an advantage due to its rapid early growth and its high degree of immunity to damage by grazing animals. The net result is that low quality teak is often a more paying crop than good quality growth of the other species. Under these circumstances, it seems justifiable to continue planting teak in preference to other species where it will grow reasonably well, until the demonstration that plantations of some other species are more desirable economically, silviculturally, or both. The exceptionally straight clean growth of teak gives it an additional advantage in rendering the disposal of the earlier thinnings at a profit more likely.[13]

Introduction of earlier or later stages of natural succession

It is also possible to introduce a species in advance of the natural succession which may be ultimately leading up to it—thus sal on to the younger alluvial soils—and this may be quite successful if conditions are ripe or nearly so for the advance ; serious setbacks are however possible in exceptional seasons, such as drought years. The converse procedure of reintroducing species belonging to an earlier stage of the succession, e.g. *sissu* into the mixed deciduous alluvial forest which naturally follows it, can usually be done successfully, but again when the change is great as in planting *sissu* on sal ground, good growth and health is improbable unless steps are taken amounting to forcing retrogression towards the earlier conditions. Species vary much in their adaptibility ; a promising start is often liable to be followed by disappointment at a later stage, as has often happened with teak grown in climates too wet for it, and with mesophytic species under conditions too dry for them (Etawah ravines).

Foreign exotics

When the introduction of foreign species is under consideration, a common condition for success is close similarity of climate (rainfall, rainfall distribution, mean temperature and temperature extremes), and soil, between the old and new habitats. This is the reason for the general failure with exotic conifers adapted to a winter rainfall when introduced to India with a dry winter and wet summer.[14] At the same time, species differ greatly in their adaptability to changed conditions, some flourishing over a surprisingly wide range, and doing even better as exotics than in their original habitat, e.g. *Cryptomeria japonica* in Bengal. Experience shows that it is inadvisable to rule out small-scale trials with valuable species even if indigenous in countries with rather different conditions, but that it is also unsafe to rely on any exotic till it has been well tested under the new conditions for some years.

Examples of foreign exotics

Examples of the profitable use of exotics are blue gum in the Nilgiris in place of the slow growing indigenous temperate evergreen forest, teak in S. Bengal and *Cryptomeria* in N. Bengal. Various species of *Eucalyptus* have been planted out in all parts of the country such as *E. rostrata*, *E. tereticornis*, etc. in the Punjab, *E. robusta* in Coorg, etc. and *E. rostrata* round Maymyo in Burma, and extensive trials are in progress in the Niligris with species producing good timber, among which *E. pilularis*, *E. paniculata* and *E. eugenioides* appear the most promising. Some of the Australian acacias have been freely planted in the hill areas, notably *A. melanoxylon*, *A. decurrens* and *A. mollisima* whilst *Grevillea robusta*, also from Australia, is to be seen in most parts of the country. As noted, exotic pines have rarely done well, but good plantations of *P. insignis* have been raised in the Palni hills of Madras and *P. caribea* is very satisfactory at Dehra Dun.

Hardwoods v. Softwoods

Market tendencies

A matter to which increasing attention is being drawn is the danger of overproduction of the hardwood timbers mainly used for heavy constructional work and railway sleepers, markets which are most threatened by substitutes such as metal and concrete.[11c,16] It is a fact that the better conservation and management of the existing natural hardwood forests will result in a very considerable increase in their outturn in the future, quite apart from increases in the area under hardwoods and in the proportion of hardwoods in them.

Future markets for sal

Thus the Bengal sal forests are at present yielding not more than one-tenth of the sustained outturn which can confidently be predicted for them in the next rotation if they are regenerated primarily to sal as at present, and it may well be questioned whether it is sound policy to bring about this increase in the supplies of a timber so threatened.

Future markets for teak

The position is less clear for teak, which is a first-class general utility timber, as likely as any to retain a good market ; as it is relatively cheap to raise, is fairly quick-growing , and yields good poles in its thinning, there appears every justification for continuing to raise it in suitable localities in India, despite the huge natural reserves in the more remote parts of Burma.

Quick v. Slower-Growing Species

Relative advantages

The hardwood species are mostly rather slow-growing and are required in rather large dimensions, so that long rotations of about 80 years upwards are required to grow them to maturity. This involves a greater investment of capital and dependence on very distant future markets, so that plantations of the quicker-growing softwoods such as *Gmelina*, *Cedrela*, *Duabanga*, etc. may appear a more attractive and safer proposition. Each case must be settled on its merits, a species producing a general utility timber being preferred to one of more restricted use unless there is a quite definite market in view, as with *Bombax* for matchwood.

Plantations of softwoods for plywood and paper pulp form part of the post war plans of most provinces and it is likely that big advances will take place in the immediate future. It is probable that some of these plantations will have rotations as short as 8 to 15 years.

Combination

It is important not to mix up the two types as this is liable to complicate management unnecessarily, and except where a combination of the two rotations has been expressly worked out, each type should be kept to its own working circle. Such a combination is illustrated by the combination of alder or birch in the E. Himalayas with *Bucklandia* or *Michelia*, the former two trees growing extremely rapidly and giving an early return, leaving the latter to form the final crop. Another example is *Gmelina* with *gurjan* and *Palaquium*.

Spacing

Present practice

There is undoubtedly an optimum initial spacing for each tree species put out in plantations, though this might vary appreciably with conditions. Actually, though very varied spacings have been applied, particularly with teak,[11d] until recently there was little really precise information to go on.[49] The commonest spacing used in Indian forest practice is 6′ by 6′ square spacing. It is noteworthy how generally teak spacing returns to this figure from closer and wider spacing and from rectangular, triangular or quincunx variations ; at the same time there are still adherents of rather opener spacing such as 8′ by 8′ or even 12′ by 12′ (Chanda, Central Provinces) and of such spacings as 9′ by 3′ or 4′ (Burma).

Modern tendency is to use the wider spacing of 9′ by 9′ in good quality areas (QI and QII) as modern developments in teak plantation technique have greatly increased the rate of early growth.[49]

Close spacing

Species which are particularly prone to low branching so that they require to be drawn up in the earlier stages should be put out with closer spacing—thus 4′ by 4′ is the standard for *Lagerstroemia flos-reginae* in Bengal—and the same applies to species which require to be grown close to ensure satisfactory natural pruning, or even to check diameter growth and so to prevent the formation of undesirably wide annual rings (*Cryptomeria* at low elevations in Bengal). Close spacing may again be advisable where it is important to get a closed canopy very quickly on account of the danger of weed growth or grass—as with *Lagerstroemia* on damp alluvial soils, and locally with teak.

On the other hand, closer spacing greatly increases the number of plants per acre (2,722 per acre for 4′ by 4′, as against 1,210 for 6′ by 6′), and therefore the cost. Moreover the additional number of stems may have to be cut out as unremunerative thinning at a later stage, and may make extra thinnings necessary, increasing the work to be done by a possibly limited supply of labour.

Wide spacing

Wide spacings mean slower closing, greater weeding expenses, greater persistance of low side branches, less stems to choose from in the thinnings, and sometimes a core of excessively wide rings in the timber. Wide spacing is however applicable to a few species such as *Bombax*, which has been successfully planted at 26′ by 26′ and 20′ by 20′ and *Casuarina*, for which 8½′ by 8½′ (Puri) or 12′ by 12′ (Karwar) appears best.

Spacing in Strip Sowing

Full plantations

A spacing problem also arises with the strip sowings in general use for sal,[1, 16, 17] and in mixed sowings in several provinces and forest types. The tendency has been to advance from wide spacings between strips such as 22′, 18′ or 15′, to closer spacings such as 10′, 8′, or often 6′, and the reason for this has usually been excessive weed growth between the sown strips, checking the growth of the latter, or involving greater costs in cleanings than are incurred with the closer initial spacing. Where growth is rapid as in the *hollock* (*Terminalia myriocarpa*) sowings of Upper Assam, the lines close over rapidly and the interspaces left of 12′ to 20′ are covered in 3 or 4 years, but with sal at Gorakhpur, the 18′ centre to centre lines still appear like hedges after 12 years. The density of the plants in the strips at first does not seem to matter greatly, exclusion of competing weed growth being apparently more important than competition between the tree seedlings. Wide spacing may be justified in plantations primarily for fuel and fodder, especially where weeds are kept down by cultivation.

Cleared strips

Occasionally, single or multiple lines of trees have been put out in cleared strips through a forest, e.g. lines of teak ½ chain apart in secondary forest on alluvium in Puri division, the method having the apparent advantages of economy in labour and plants and ample growing space for the planted trees as the growth on the interspaces is thinned out in their favour: Great care is however required to keep back the jungle growth in the earlier as well as the later stages, and it is doubtful whether any real economy is effected, whilst considerable risks of failure are undoubtedly run. The great advantage in this case is the propagating of a valuable exotic (teak) over a wide area at a small cost in a locality subject to severe cyclones. In Arakan, where teak is planted in hilly *Melocanna* bamboo forest, the planting is done at 6′ by 6′ in contour bands five rows wide separated by bands 30 ft. wide left unplanted.[11c] The special objects are to retain the bamboo as an understorey, and to permit fewer and heavier thinnings.

Artificial v. Natural Regeneration

Relative merits

A great deal has been said and written on this controversial topic, and many allusions to it have already been made in the foregoing chapters. The chief claims made for natural regeneration are : (1) minimizing of the exposure of the soil, (2) economy of labour, (3) flexibility, permitting of greatly extending the regeneration area in good seedling years and of obtaining regeneration in advance of fellings, (4) the survival of only the most vigorous seedlings out of large numbers, (5) reduced risk of damage from natural causes including pests and diseases, (6) maintenance of the natural mixed type, and (7) lower costs. The opposing claims in favour of artificial regeneration are : (1) quicker results, (2) full and even stocking, (3) facility with which species composition can be regulated, (4) concentration of all phases of forest work reducing costs and facilitating supervision, (5) more rapid early growth and so less risk from weeds, browsing and other dangers, and (6) in the long run, a better return for the financial outlay even when the actual operation is not cheaper.

Risk of soil loss

Much stress has been laid on the losses to the soil consequent on the clear-felling, burning and exposure usually associated with plantation work, especially with *taungya* in which the surface soil is kept loosened and agricultural crops are removed. In hilly country, not only may the surface soil be lost, but landslips may be started. There is indubitably a good case for careful management to minimize these losses, but it may be doubted whether they are or need be as serious as they have been made out, and whether much lasting harm is done by the operation properly carried out only once in a tree rotation. The risk is clearly greatest in tropical climates with high intensity rainfall where the loss of surface soil from sloping ground such as carries many of our forests is very real, and natural regeneration if we could get it under acceptable conditions of quantity, time and cost, would be preferable pending fuller knowledge of unavoidable losses consequent on clear-felling and planting. With lower intensity rainfall and easier slopes, it is unlikely that much lasting harm is done during the brief period of exposure, though here also, treatment should be such as to restore a protective cover to the soil as soon as possible and to include soil-improving species.

Time required

The value of the relative quickness of artificial regeneration is considerable as effecting economies in protection whether in the form of fencing against cattle and game, or in weedings, cleanings and climber cutting, or in general supervision. A good deal of plantation work is also done under conditions involving no more exposure than natural regeneration, as in the deodar work in parts of the Himalayas. Natural regeneration is very liable to delays, especially with species with a long seed year cycle or long and uncertain establishment period. Failure to complete natural regeneration within a reasonable time is likely to lead to a direct loss of increment and a further indirect loss through the lengthening of the rotation.

Relative cost

With regard to the question of the relative cost of the two procedures, the claims made for greater cheapness for natural regeneration have often lacked substantiation—the individual operations may appear cheap but they often have to be repeated at intervals over a long period of years, and a good deal of hidden and indirect expenditure has often been involved. It may be accounted among the merits of plantation work that success or failure cannot be hidden, and that the accounts are simple and mostly indisputable.

Concentration of work

Plantation work in mixed forests generally results in greater concentration of future supplies both in actual area occupied, and in accessibility, lack of which is a great hindrance to the utilization of existing scattered supplies. This concentration should result in making marketable intrinsically useful timbers which cannot at present be profitably worked. Though teak is the species most usually grown in this way, it differs from the others in that its high value renders it saleable even in low concentration and remote tracts. *Gmelina*, *Chukrasia*, *Bombax*, *Michelia*, etc. tend to be on a different footing, increased supplies and concentration being greatly needed.

Conclusions

In general terms, it may be said that natural regeneration should be preferred to artificial wherever it can be accomplished with reasonable expedition, certainty and cost. If the operations are liable to be drawn out, to include a considerable proportion of failure, and to be costly, then artificial regeneration is to be preferred, and it is almost always sound policy to finish off natural regeneration by artificial work after giving the former a reasonable time to accomplish what it can.

ORGANIZATION OF PLANTATION WORK

Necessity for Adherence to Time-table

At the very outset it is necessary to emphasize that in all plantation work it is essential to have a time-table for *all* the items of work and strictly to adhere to it. Artificial regeneration necessitates preparation of site, collection of seed and the sowing or planting of the area. The arrangements must therefore start often as long as 2 or 3 years before the actual planting takes place. If any one of the operations concerned is delayed the success of the plantation is jeopardized. Hence one must make arrangements in sufficient time, prepare a time-table and adhere to it. The plantation time-table is dealt with later (cf. p. 208).

SEED—GENERAL

The general subject of seed supplies and storage have recently been intensively studied and to this work the reader is referred for details.[51]

SEED SUPPLIES

General considerations

With few exceptions, among which teak and chir pine might be mentioned, conditions are not favourable to the development of an oragnized central seed supply establishment on the lines of those developed mainly for coniferous seed in Europe and North America. Arrangements have to be made locally in each division for the estimated seed requirements of the season, and it is most important that they should be adequate and reliable. Maximum use should be made of good seed years, as it is one of the advantages of artificial regeneration that the benefit can often be extended over 2 or 3 years even with seed that cannot be stored.

SEED COLLECTION

Agency

Seed is very generally collected by or through the agency of Forest Guards, though not rarely where *taungya* cultivation is practised, the cultivators are made responsible for it.

Great improvements are necessary in Indian forest tree seed collection. Its general low standard at present is largely due to lack of appreciation of its importance and the poorness and lack of responsibility of the agency used for collection.

Ripeness

In both cases the collectors have to be trained to distinguish ripe and good seed, especially in the case of species such as *Adina*, *Altingia*, and the small fruited Terminalias, with which mistakes are easily made but not always easily detected till too late. Ripeness of seed is most important, a safe rule in the absence of clear proof that earlier collection is permissible being not to collect till the seed is ready to fall naturally. Both the earliest and the latest seed to ripen and fall is often suspect, and best avoided. In the case of chir pine, cones may safely be collected at any time from December onwards even though still green.[18] Reference lists are available in most provinces giving the month in which the seed of different species ripen.[10]

Quantity required

The quantities required must be carefully worked out well in advance and a liberal margin collected not only against possible needs for resowing failed areas, but also in case a shortage of supplies of some species necessitates an extended use of others. Once again, published data provide the basis of the calculation, but these may require modification to suit local conditions in each centre.

Method of collection

The seed should as far as possible be collected of the trees immediately natural seed-fall commences, as if collected off the ground it tends to include much immature and insect-attacked seed. This can of course be remedied by sweeping the ground clean at the commencement and only collecting what falls or is shaken down later, this being the usual procedure with Dipterocarp seed. The cheapest and most convenient method of collection is from trees in the coupes of the year, special steps being taken if necessary to concentrate the felling when the seed is ripe.

Extraction, etc.

Extraction

Most of our seed, whether technically seed or fruit, is collected in the form in which it is sown. Extraction from dry fruits is however necessary in some such cases as chir pine, *Lagerstroemia* and many legumes, the usual method being to spread the ripe fruits in the sun till they open up, and then to shake or beat out the seed. Pulpy fruits with small seed such as mulberry, figs, *Anthocephalus*, *Broussonetia*, etc., require special treatment, whilst it is a safe general rule that the flesh should always be removed from fleshy fruits such as most *Lauraceae*, *Gmelina*, *Michelia*, etc., as there is liable to be considerable loss of germinative capacity if they are dried off with the pulp ; this step is of course in conformity with what usually occurs in nature, where the pulp is normally eaten or rotted off.

Drying

After collection, seed should be spread in the shade till it is well dried. Many species can be spread in the full sun, but this is known to be harmful to some species and so is better avoided in the absence of knowledge on the point : a good rule for doubtful cases is to expose it under the conditions prevailing in nature, so that species of open deciduous forest may be given full exposure, and those of damp or shady forests only limited exposure.

Cleaning

The dried seed has next to be cleaned of all foreign materials such as fragments of fruits and cones, husks, and empty or unsound seed, a step especially necessary when it has been swept up off the ground. Methods will vary with species. Water separation followed by redrying is a simple and useful method with many species, the vegetable debris and bad seed floating on the water, and the sound seed sinking to the bottom with mineral impurities. Winnowing deals with many medium-sized seeds but must be completed by hand picking of the heavier impurities. Sieving is sometimes helpful. Special cleaning is unnecessary in the case of seeds such as sal, which are sown individually after collection.

Grading

The significance of seed size has been discussed on p. 88 and shown to vary with species. With single seeds or single seeded fruits, large seed is always good ; seed under a certain size will tend to have low germination and to give small seedlings, but even so, under Indian conditions, it is not often that it is worth removing the smallest size grade. With multiseeded fruit, on the other hand, size is practically no criterion of quality : thus the single seed in a small teak fruit may give a better seedling than any of the several seed in a large fruit.

Imported Seed

Geographical races

Whenever seed is obtained from outside sources, even if from other parts of the same division, it is important to make sure that it is, or is likely to be, of good race, suitable to the locality where it is to be sown.[19] In teak and chir pine we have good examples of species for which clear proof is available that seed origin makes a big difference in the growth and quality of the crops raised from it, and it is evident that further research would demonstrate the matter to be just as significant for many other trees. Seed should accordingly only be collected from approved sites, which will be those in which the growth is relatively good and in which the stock is believed to be free from heritable defects such as bad growth form, liability to disease, timber defects, etc. This is elaborately organized for the coniferous species in Europe now, and India will doubtless have to follow suit in time. Available information indicates that local seed is generally preferable to that from any outside source, but sometimes seed from a better type in a rather more favourable locality may carry something of its superior quality to an inferior locality. Seed collected at high levels should not be used at low levels and *vice versa*. Seed of *sissu* for the irrigated plantations of the Punjab should certainly only be collected from trees of good form, as several growth forms are recognizable and their characters may well be inherited.

Individual trees

It is not usually possible to restrict collection to individual trees of approved type, and this is fortunately not usually necessary, as bad shape, etc. of individual trees in a good crop are not heritable characters. On general principles however collection should never be allowed from the low-branched isolated trees surviving on village lands, as these are particularly liable to pass on undesirable features.

Seed Testing

Seed testing has not hitherto been organized in India, but should be a routine procedure wherever seed is collected in quantity for distribution or storage.[20,51]

Appliances

Many appliances have been devised for carrying out the tests, but for most purposes nothing elaborate is needed. For medium-sized dry seed such as conifers and many leguminous species, the porous fire-clay plate made to stand in a dish of water and provided with a glass cover to maintain a moist atmosphere is convenient, especially where the plate has 50 or 100 depressions, obviating counting out the seed. For larger seed, a shallow wooden box such as is used for raising flower seedlings, or an ordinary earthenware flower pot, filled with clean sand, sawdust or light soil according to species and conditions, is quite suitable and easily procured. Plate 14 shows a selection of apparatus used for testing. Where nurseries are available the test can conveniently be carried out in the beds, though this method tends to give plant per cent rather than germinative capacity—actually the former is often of greater interest and practical value.

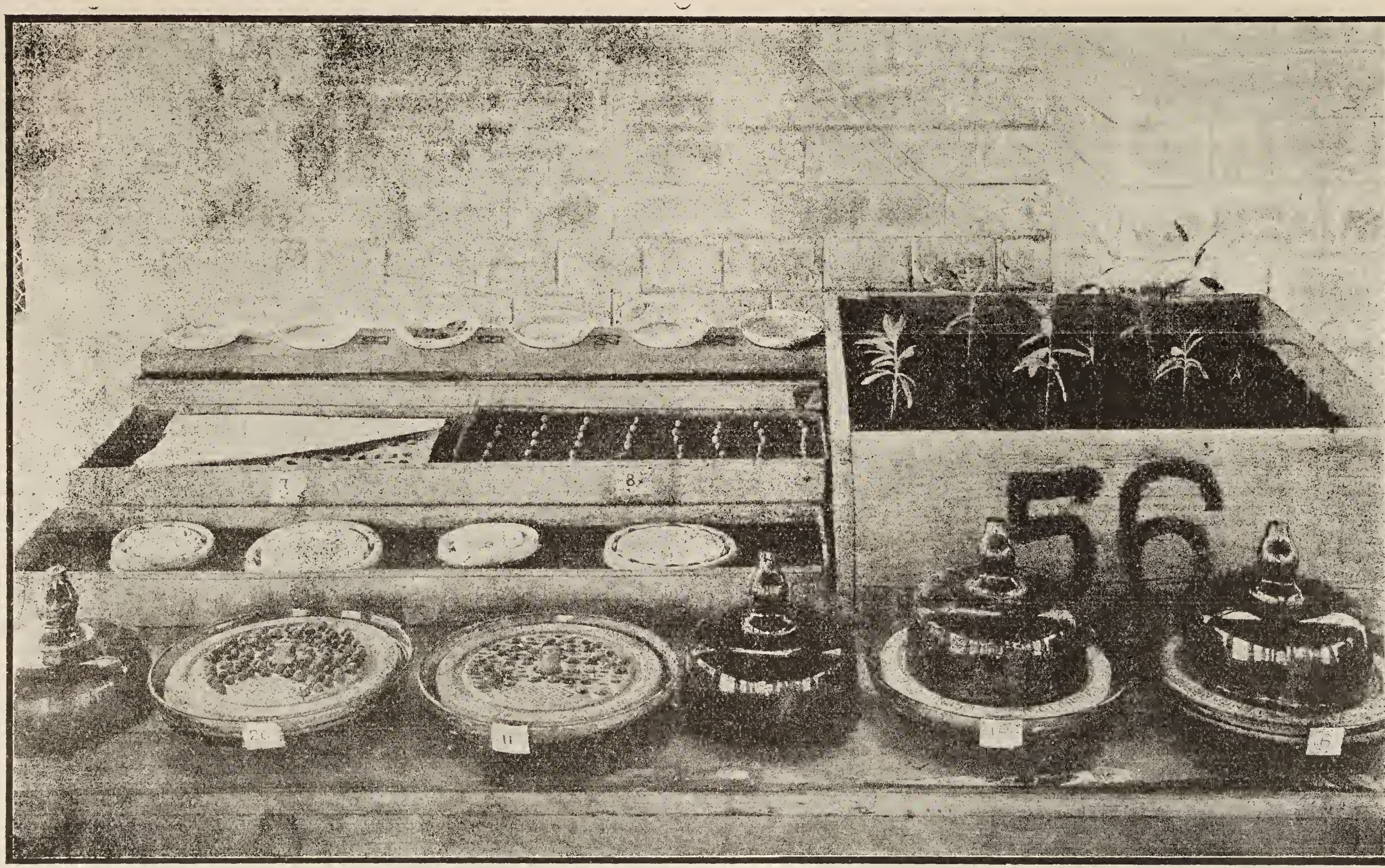
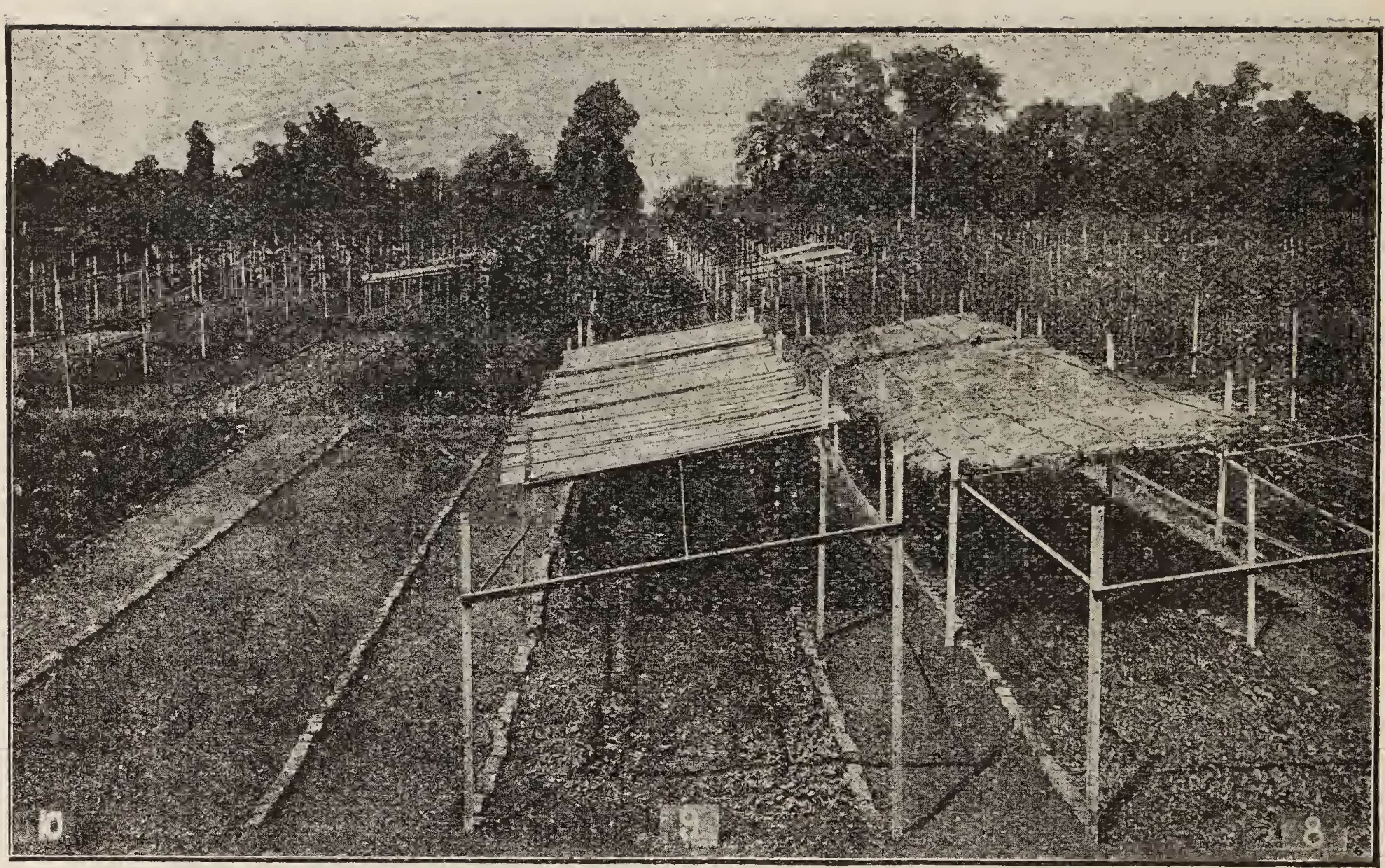


PLATE 14. Apparatus used for seed testing, New Forest, Dehra Dun.

Facing p. 196.



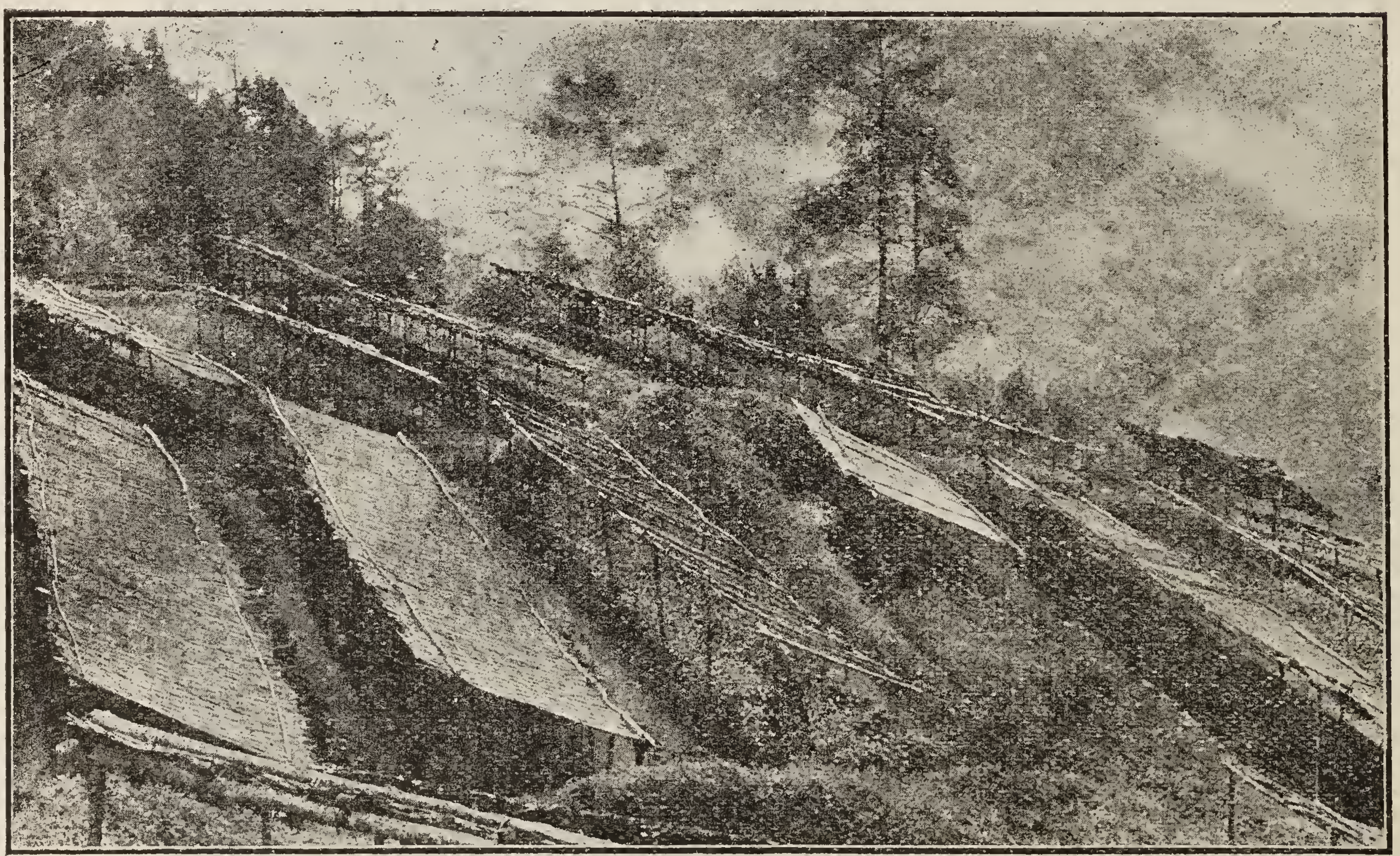


PLATE 15. Nurseries. (*Above*) Permanent irrigated nursery in the plains, New Forest, Dehra Dun. (*Below*) Temporary terraced nursery in the hills, Darjeeling, Bengal.

Facing p. 197.

Methods

If any comparison is contemplated either between different lots of seed or the same lot at different times, it is important that the tests should be carried out under identical conditions.

In carrying out germination tests, special care is required that mould and rotting are avoided as far as possible, as conditions favourable to germination tend to favour these dangers also : over-watering must be avoided and appliances such as the porous plates mentioned should be sterilized with boiling water after each usage. It is for this reason that sand and sawdust are better media than richer soils or leaf mould. Charcoal is useful in checking mould and rot.

It should be a rule not to send out seed without giving particulars as to source and germinative quality.

In India there is a standard forest department form (F.R.I. Form 199) for recording essential information regarding tree seed collection in government forests. This form is now in fairly general use for inter-province seed supplies but it is advocated that it should be used even for inter-district indents, for the mere fact of having to fill in the form conveys some sense of responsibility to the collecting officer and hence is likely to improve the quality of the supply.[51]

Seed Storage and Transport

Rapidly germinating seed

The seed of many species normally germinates as soon as it is ripe, without a rest period ; such are most Dipterocarps, and many oaks and mangroves. Such seed is usually collected off the trees or swept from the ground beneath them, and sown immediately in the previously prepared seed beds. It is usually dangerous to keep such seed in big heaps or with poor ventilation even for a short time, and if collected in sacks for transport to the sowing site, it should be at once spread out in the shade and only taken basketful by basketful as required. Many experiments have been made with sal seed which falls into this class to find methods by which the seed may be stored for a week or two, as there is often this interval between seedfall and the rainfall necessary to successful germination. As germination cannot be prevented without killing the seed, the methods depend on slowing down development as far as safely possible, so that a minimum of damage results from subsequent handling. It has been found that if the seed is spread in a thin layer on a hard floor and watered just enough to keep it alive, it can be stored for two weeks or more ; as sowing is more difficult and a lower plant per cent is obtained, the seed should obviously only be stored in this way when unavoidable, and actually, the occasion has rarely arisen. As a rule, the chief thing to see to in storing seed between ripening and sowing time, is that it is kept dry and well-ventilated, and the best method is usually to pack it loosely in sacks and hang the sacks from the roof or spread them on open shelves in an airy building.

The seed store

It is usually worth while to build a well-ventilated wooden shed as a seed store in any centre where plantation work is to be continued for any length of time, with shelves about three feet wide, movable trays being very convenient for handling, drying and airing.[1] Additional dangers to guard against are rats, squirrels and insect attack. The store should be protected if necessary by fine wire netting ; all insect-infected seed must be burnt, not left lying about, and old stock must be carefully watched that it does not breed vermin to infect the new. Treatment with carbon bisulphide for 12-48 hours is effective in killing insects before storage but this is a dangerous chemical in inexperienced hands.

Control of moisture conditions

Some kinds of seed lose their vitality if they dry out too far. These are usually species occurring in fairly moist climates, and with large seed not specially protected against desiccation—proof is clearest for some species of *Quercus* which have a resting period during the cold weather, and it may be true of a number of trees of temperate habitats. In Europe it is the practice to store such seed buried in pits or in cellar-like stores. Experiments with seed buried in the ground with and without charcoal at Dehra Dun have not given very encouraging results, but it is found in Bengal that all heavy seeds such as *Quercus*, *Machilus*, *Juglans*, etc., are best stored by burying them, provided that both seeds and soil are quite dry.[1]

Retention of germination power

Although it should be a general rule to use the most recent crop of seed in sowings, there are many species which only seed freely at intervals of several years, and it becomes necessary or at least desirable to store seed from a good seed crop for the following year or two, when a shortage or no supplies at all are likely to be available. The following are a few representative examples. Teak seed retains most of its germinating power for at least three years. Tests on chir pine seed have shown a germinative capacity after 1, 2, 3, and 4 years' storage in sealed tins, of 95, 90, 83, and 65, showing that storage is quite a feasible proposition. The corresponding figures for *Dendrocalamus strictus* and *Terminalia tomentosa* are 57, 54, 43, 5, 0 and 36, 38, 25, 6, 19, 4, respectively. It is important that the seed is very well dried before being sealed up, and the tins should not be opened at all during the damp monsoon period.[51]

Cold storage

Deodar loses its vitality very quickly and cannot be stored this way, but it has recently been demonstrated that cold storage is far more effective for other coniferous seed, and it is quite likely that it will be found that deodar could be kept a year or more in this way. Dry cold storage of tree seeds is very general in America ; and moist cold storage is also possible and effective, and would perhaps succeed with sal.

Other methods

Packing in charcoal or slaked lime has been found to be fairly effective in checking germination and permitting longer storage of seed such as sal, for transport of small quantities of seed for experimental purposes ; the thermos flask has also been found very useful in the same way.

Treatment of Seed

Water treatments

Most medium-sized dry seed germinates more readily and quickly if soaked 24 hours in water before sowing, and this is a routine procedure with many species such as chir pine and many *Leguminosae*. Hot water is sometimes even more effective, the seed being usually dropped into boiling water and allowed to cool in it, and this can be recommended for most hard-coated *Leguminosae* ; tests are easily made with other species likely to respond. A large volume of boiling water should never be used to a small quantity of seed, but only about enough to cover it. This boiling water treatment applied only for 20-30 seconds has been favourably reported on for oaks and chestnuts, with the considerable added advantage that it kills the insects with which these seeds are so commonly infested.

Passage through animals

It has been reported that quicker and better germination is obtained with certain species such as *Acacia arabica* and *Santalum album* if the seed is first passed through animals or poultry, the digestive juices softening the impermeable seed coat or pericarp and perhaps directly stimulating the embryo. *Zizyphus* fruits are possibly affected in the same way.

In South India it is the practice to collect *nim* seed from underneath trees frequented by doves, pigeons and crows. This seed is white in colour and gives a much higher germination than seed collected from the *nim* trees themselves. It is still open to question whether this seed passes through the birds or whether they merely depulp it and spit out the seeds.

Pregermination

Good results have been reported with various species of large seed including teak and *Terminalia tomentosa* by 'pregerminating' the seed in dumps in the plantation area, and sowing in the prepared sites only when germination has actually taken place. The dumps are merely kept well watered and aired, and the germinated seed picked out by hand daily.

Special treatment

Some seeds, particularly those with hard pericarps or seed coats, only germinate slowly and irregularly when sown in the ordinary way, and though mature and quite capable of germination, may lie over to the second year or even later. Difficulty of this kind has been experienced with teak, olive, sandalwood, *Acrocarpus*, *Pterocarpus* spp. and various other trees and many attempts have been made to stimulate the seed before sowing to ensure prompt and even germination. Soaking for different periods in various chemicals and organic preparations such as liquid manure, sulphuric acid, hydrogen peroxide, and alcohol. nicking the seeds, and exposing them to a light fire, have all been reported to have been helpful on occasion, but these methods cannot be said to be reliable or practicable enough for general adoption.[20a]

Treatment of teak seed

Alternate wetting and drying is now generally recommended for teak, alternately soaking the seed for 12-hours and spreading to dry for 24 or 48 hours, repeatedly for 2-3 weeks prior to the usual date of the breaking of the monsoon. Formerly various methods of layering the seed in pits were followed, but are more troublesome and less certain and so have been largely abandoned.

In S.Bengal, it is however still usual to apply the pit process. 'A pit about 2½ ft. deep and 3 to 4 ft. square is dug (in light well-drained soil and filled with water. When this has run out, line the bottom and sides of the pit with teak leaves. Soak the seeds for 48 hours in water in a tub warmed by the sun during the day, and put them in the pit with a layer of teak leaves between the layers of seeds and a final cover of 6″ of earth. Before filling up the pit in this manner, 5 bamboo pipes, one in the middle and one at each corner, the latter laid at a slant, are put into position and holes cut in them so that when the pit has been filled up, water can reach all layers. The seeds are kept in the pit for about 10 days and watering is done every alternate day. The pit is then opened, and normally about 10 per cent of seeds are expected to have germinated. Heavy watering must not be done.'

In general, however, teak seed from the water areas such as the west coast and South Burma requires little or no treatment to produce satisfactory germination. It is the small hard teak seed of the drier areas such as the Central Provinces that gives difficulty.[49]

Labour Arrangements

General considerations

Wherever large-scale planting operations are contemplated, efficient organization of the necessary labour supply is as important a factor to success as the supply of seed or plants and the actual planting work. The labour may be employed on a daily wage, or on piece rates directly or through a headman working as a petty contractor, or finally not on wages but by permitting the temporary use of the ground not occupied by the tree seedlings for agricultural crops—a procedure now universally known by the Burmese term *taungya*, though local equivalents are used in different parts of the country (*bankheti* has been put forward as a Hindustani word suitable for adoption over much of the country). These different methods are described in turn below.

Contract work

The initial stages of the preparation of the planting site are sometimes done by the timber purchaser under the terms of his sale agreement. As supervision is easy and the labour already on the spot, this method is quite a good one provided it is done in good time, a matter which may lead to difficulty, as the contractor usually has too little at stake to make him prompt.

The preparation of nursery beds is also sometimes done on contract but this is not recommended.

Daily labour

Where *taungya* cultivators are not available, there is usually no alternative but to carry out plantation work by means of hired labour under departmental supervision, and most of the older work has been carried out in this way. In many places the work has to be done at an unhealthy season and high wages have to be given. Special inducements are necessary to keep the labour on the work, and arrangements for food supplies and medical aid may be essential or at least very helpful. Too small a unit and isolation in areas difficult of access during the rains have been the cause of failure in many cases in the past, and failure with a dozen or twenty men has been followed by success when the work was extended to employ 50 or 100. As such labour has little stake in the success of the tree plantation work, close supervision is essential to success, and costs tend to be high.

Departmental taungya

Use of daily labour does not of course rule out the raising of field crops with the tree seedlings, but this will be done with the subsidiary objects of keeping down weed growth between the seedlings, and getting some monetary return from the area. In many instances, such departmentally done *taungyas* have not been very successful, partly because the forest staff are not experienced agriculturists, and partly because they tend to give too much attention to pushing up the revenue from what should be a purely subsidiary operation : on occasion, however, handsome returns have in fact been recorded, as in a Bengal *taungya* which showed a net return of about Rs. 40 per acre from raising jute seed and fibre. The methods may be undertaken to demonstrate the possibility and advantages of *taungya*, but should be continued no longer than is necessary for this purpose.

In South India departmental *taungya* has often been used to raise food for departmental elephants.

VILLAGE *Taungya*

Origin

In many parts of the country, particularly in the hilly tracts, the primitive agricultural practice of shifting cultivation is still followed wherever it is permitted. It is one of the most striking successes of forestry that this destructive practice has been successfully turned into a method of regeneration so cheap and successful that of late it has been intentionally introduced into tracts where it had died out or been put down at an earlier stage.

Original methods

Where free to do as he pleases, the *taungya* cultivator clear-fells a patch of forest, perhaps leaving a few big tall trees—or only girdling them —and as soon as the felled material has dried out enough to burn, he fires it ; he then broadcasts or dibbles in his field crop with a minimum of soil working. His crops tend to be good as they are being raised on virgin or at least long-fallowed soil, with the additional advantages resulting from the burn.[52] (cf. p. 51). As a rule mixed crops are raised providing the cultivator with practically all his requirements. Cultivation may be for the one heavy initial crop only, but is usually followed by less intensive cultivation and decreasing yields for one or two seasons longer, after which, probably more on account of weed growth than actual loss of fertility, the cultivator considers it worth his while to move to the next patch of forest. Where the pressure of the population on the land is increasing, the period during which a given area is rested before the cultivator comes back to it again is getting shorter and shorter, the second growth scantier and smaller, and the crops correspondingly poorer (as in the Assam-Burma Hills), so that even in the cultivator's own interests, the sooner the abandoned plot is recovered with growth, the better.

Extension to plantation work

Taungya plantation procedure accordingly depends on getting the cultivator to plant or sow a new forest crop with his food crop, so that when he moves on, useful trees and not weeds will restock the area.

Details vary with the part of the country, the type of cultivator and the length of time the work has been going on.[47,49] In a general way, it is necessary to keep the terms of cultivation lenient at the beginning and only gradually to tighten them up to what is necessary for good results. In the Darjeeling hills, the labour employed in the winter on timber and fuel extraction undertakes the *taungya* work also during the summer.

Distribution of the area among the cultivators

The area of *taungya* plantation which can be effectively dealt with by one family appears to vary a good deal with locality, but ranges from one to fifteen acres as illustrated by the following figures :—

Burma, 3-4 acres ; Assam, 1-2½ acres ; N. Bengal, 1½ acres ; Chittagong, 2-3 acres ; Berar, 12-15 acres ; Gorakhpur, 2 acres ; and Saharanpur, United Provinces, 2 acres (actually 3-4 acres per pair of bullocks).

Some classes of *taungya* cultivator are not accustomed to live entirely on the dry crops they can raise in the forest *taungyas*, and expect to supplement these with rice, etc., raised with wet cultivation. This is very generally the case in Bengal and Assam, where the practice exists of allotting each family an area of wet cultivation as well as the forest *taungya*. Provided that the area of wet cultivation allotted is kept down to the minimum for real requirements, there is no harm in this, but it has often happened that an over-liberal policy has been followed by resultant neglect of the *taungya*. One acre of wet cultivation per household is quite enough, and even this should never be given except where local custom already demands it. Occasionally land for dry cultivation without a forest crop is similarly given (West United Provinces). Where cultivation continues for two or more years, it is sometimes customary for each cultivator to be allotted an additional new area every year, and sometimes only on vacating his original area after two or more years.

A good organization calls for an approximately equal new area to be taken up each year, a suitably sited, well constructed and sanitary village with good water supply (the site may have to be shifted every few years with the progress of the work, and some tribes prefer to move annually), and a forest staff sympathetic to and trusted by the cultivators, who are mostly primitive jungle folk. A vacillating policy and frequent changes of staff and methods spell failure though it is possible to make steady and even fairly rapid improvements in methods if they are introduced gradually and tactfully.

Preliminary agricultural cultivation

Usually the cultivator sows his crop directly the area is ready or before the first showers of the monsoon, and the forest crop is sown or planted shortly after. In some localities however it is considered necessary to permit a year's cultivation without any forest crop, the latter being sown only at the break of the second monsoon, and this may happen in any new area in which the method is being introduced, or in which a good deal of work is considered necessary in getting the area ready for tree planting. This is often done in the drier areas in order to get soil in good condition as there is little or no burn, and in these conditions it is often only after the first two or three years that the best crops are obtained.[53] The first year's delay is obviously to be avoided if possible as the tree crop loses the great benefit of the favourable soil and growth conditions of the first season after clearing and burning, and the weeds get a year's start ; it also inevitably lengthens the period of exposure of the soil, which is agreed on all sides to be harmful. It is also a fact that if the practice is once permitted, it is very difficult to stop later on, so it should only be allowed when truly unavoidable. In the Khasi hills, cropping is continued for two years before the introduction of the tree crop (pine), which only takes place when the area is abandoned by the cultivators.

Period of taungya cultivation

As noted above, where there is plenty of forest, primitive peoples tend to take the one crop only before moving on to a new site (Yomas, Burma). Elsewhere, however, there is a tendency to make more of the labour involved in clearing a *taungya* and to continue to cultivate for two or even several years till the labour of weeding for reduced returns outweighs the other considerations. Thus in the Garo hills, 2 years' cultivation is usual, whilst in Gorakhpur it is continued for 5 years and in Berar, Saharanpur (U.P.) and the Burma dry zone *taungyas*, even 7 or 8 years. In Madras [21, 49] and in Java[22] a definite loss of teak growth has been demonstrated for each successive agricultural crop, even including the first. In Burma, it is found that a second year's cultivation increases grass at the expense of woody regrowth and so checks the growth of the teak.

As the tree crop almost everywhere needs intensive weeding in its second season of growth, and as the deterioration consequent on a second year's cropping is not great except perhaps on steep slopes or with heavy rainfall, two years' cultivation can be permitted, and is in fact very general. A longer period than 2 years must ordinarily be viewed as undesirable except perhaps in dry tracts and other special circumstances, and so should be discountenanced.

Agricultural crops

In most centres, the crops raised are fixed by local custom, particularly amongst the self-supporting jungle tribes : thus in Burma a mixture of hill rice, maize and cotton, with some tobacco and vegetables near the houses, is very usual. In the more developed tracts, the cultivators tend to combine meeting their own food and clothing requirements with raising other crops for which a profitable market appears to offer—it may be cotton, or vegetables—and it is possible to regulate to some extent what is grown. This is particularly the case where the method has only recently been introduced, and it is both possible and expedient to disallow the raising of crops which will unduly shade the seedlings (locally sugarcane), will climb over and smother them (some kinds of legumes), or will encourage vermin (sugarcane again and *Cajanus*). The season at which the different crops shade the seedlings and the ground requires consideration for each set of conditions, as any given crop may be harmful in one locality but good in another, sugarcane and *Cajanus* providing examples of this. Generally, the second year's crop is a different one from the first, thus potatoes may be followed by paddy or maize (Khasi hills). An agreement is usually drawn up excluding such crops as are considered harmful, though we have very little information on the influence of different crops on the trees.[24] The range of crops raised in *taungyas* is very wide and includes maize and grain crops, root crops (tapioca, potatoes), a big range of pulses, cotton, oilseeds (*til*, castor oil, etc.) all kinds of vegetables, sugarcane, bananas, papayas and even guavas. Generally the less tall and dense crops, and those which are thoroughly weeded, are preferable, cotton being one of the best.

The terms of the taungya agreements

Apart from the extent of land given out, the possible inclusion of wet cultivation, the period of cultivation and the crops permitted, *taungya* agreements vary considerably in the nature of the work required to be done on the forest crop, and in the question of payments if any. A selection of *taungya* agreements is given in the *Forest Record* on ' Teak Plantation Technique '.[49] In Burma and S. Bengal the practice still continues of making a cash payment at the end of a specified period (1 or 2 years) regulated on the number of plants or the proportion of the area considered adequately stocked ; this payment has usually been about Re. 1 per 100 plants, or Rs. 10 to 12 per acre, with a sliding scale penalizing poor work, but there has been a tendency to reduce it lately. The cultivators also have to leave the lines clean weeded, and there may be an additional clause calling for a free weeding in the following year and even later—or such further weedings may be contracted for at specified rates. In any case, it is usually important to make some definite arrangement for any further cleaning the plantations may need, as other labour may be difficult or impossible to procure. At the opposite extreme, where there is a keen demand for land, the cultivators will readily pay for the privilege of using the land, and a rent of Re.1 or so per acre is paid in some localities (Berar,[25] Gorakhpur[17]). Under somewhat different conditions, in the irrigated areas of Sind, during the recent war a peak rent of over Rs. 100 per acre was obtained.

This was due to abnormal food prices and a gamble on cotton futures.

Seed collection is commonly the responsibility of the cultivator unless it has to be brought in from a distance, and sowing is also done by him. Staking out the area is done by a forest subordinate with or without the free help of the cultivator. Nursery work is nearly always done departmentally except for the small nurseries often maintained by each cultivator near his house for prompt replacement of failures, a practice strongly recommended. Planting work which requires skill and care is usually done by the cultivator under supervision, but is sometimes done as a separate operation. Special attention has to be given to seeing that the sowing or planting is done promptly at the right time, as the cultivator naturally will attend to his own crop first if both need work at the same time ; it is accordingly necessary to organize the work and adopt methods which as far as possible do not coincide with the field crops in respect of the season when they make demands on the labour ; an example of this is provided by the different methods of raising teak, sowing or stump planting—which can be done in April or May—being preferable to entire planting which must be done early in July, just when the cultivator is busy with his own field crop and cleaning in the older plantation is also needed. A rather unusual procedure is sometimes adopted in some of the *babul taungyas* in Sind, where a single crop of oilseeds is raised. The *babul* seed is broadcast before the inundation and the whole area ploughed after it for sowing the oilseed, enough *babul* seedlings surviving the ploughing to ensure full stocking.

As with daily labour, much can be done to improve the conditions of life in a *taungya* village, and examples could be quoted where the application of the principles of rural uplift have been carried to an advanced stage with very satisfactory results (Saharanpur).

It is usual to appoint or recognize a headman in each *taungya* village and to explain matters and give orders to the other villagers through him, but naturally practice will vary with conditions, and not rarely one deals with the individual cultivator.

Spread of taungya methods

Taungya plantations were first started in Burma in 1862, and the greater part of the plantation work there with all species is now done by this method.[5] It was started in Bengal for sal in 1911[16] and for teak in 1912, and is now very generally applied. In extended to the United Provinces for sal plantation in Gorakhpur in 1923[17] and has since spread considerably in other divisions for sal and other species. The Central Provinces are applying it extensively, mainly in Berar with *Acacia arabica* and other species, under the name 'agri-silviculture'.[25] In Madras it is even used in the dry fuel forests,[47] and *taungya* has been the rule for some years in the irrigated plantations of Sind. It has been tried and is practised on a smaller scale and only locally in all the remaining provinces, but conditions are not suitable enough to ensure its rapid adoption. In the hills, *taungyas* with deodar have been tried without great success in the W. Himalayas but have done well in N. Bengal with a variety of species including the Japanese *Cryptomeria*, *Michelia excelsa*, *Juglans*, and *Acer*. In the inundation tracts of Sind, *taungya* is utilized for raising plantations of *Acacia arabica* both on high-lying land irrigated by lift, on clear-felled coupes, and on newly deposited land which has reached a sufficiently high level to make regeneration possible. It should be remembered that these areas are quite different from the irrigated areas referred to above.

Taungya v. Departmental plantation work

From the purely financial point of view, and from the way it gets over labour difficulties, the *taungya* method is unquestionably far preferable to departmental work on contract or wages. It can, however, be criticized in that it involves clear-felling and burning, with consequent exposure and deterioration of the soil, that the agricultural crops rob the soil of much of its accumulated fertility which should go to the new tree generation, and that the working of the soil and clean weeding between the tree lines result in an increased loss by surface erosion ; other objections made to the method are usually directed against artificial regeneration rather than against *taungya* methods as such. Quantitative information on all these points is however, almost nil, rendering a properly based verdict impossible at present, and the *taungya* plantations made in the past must be left to provide a tentative decision, which can only be that, in a general way, they have been an outstanding advance on almost all comparable work preceding them.

The Plantation Time-table

Obligatory dates

The importance of timely work in plantations is so great that it must be separately dealt with.[11d] Many a plantation has failed although the work has otherwise been excellently done, simply because some operation has been done after—or less commonly ahead of—the optimum time for it. A late start is peculiarly fatal, so felling and extraction work *must* be finished by the specified date : if delay is permitted, the burn may be delayed, and if there happens to be an early shower, a clean burn may become impossible, a calamity impossible to remedy. Similarly if sowing or planting is done late, the plants get a relatively late start and casualties and weed troubles are greatly increased, even to the extent of making the plantation more or less a failure. A time-table must accordingly be drawn up for each locality, giving the dates by which each stage of the work should be completed—notably felling and extraction, burning, stacking and reburning where this is done, staking, sowing or planting, first weeding, replacement of casualties and so on—and strict adherence to the programme insisted on. In many localities, it has been necessary gradually to push back the date by which timber purchasers must complete felling and extraction, and sometimes to sell the coupes earlier than had formerly been customary.

Examples

The following are dates by which the burn should be completed in representative localities where sowing or planting is done the same year :—

U. P. and Bengal submontane tract.	End of March or first week of April.
N. Bengal hills . . .	March.
Assam	March at latest. Sowings possible even earlier in U. Assam.
Burma	April 10-15, but earlier in U. Burma.
Nilambur	January, and reburn by the end of March.
Khandesh and Kanara . . .	End of May.

The following are the dates by which operations should be completed for sal *taungya* in Gorakhpur :—

1st year.

April 15	Felling and conversion.
April 30	Extraction.
May 25	Allotment of area to cultivators.
May 31	Burning.
	(Thereafter agricultural cultivation with levelling and stump removal).

2nd year.

May 15	Digging out soil for plant lines.
May 31	Replacement of soil and preparation for sowing.
June 20	Sowing.
July 20	1st weeding.
Aug. 20	2nd weeding.
Sept. 20	3rd weeding.

A typical time-table for raising a teak plantation by stump planting (without *taungya*) in South Coimbatore division, Madras, is as follows :—

Timber felling completed by . . .	October	31
Rubbish felling completed by . . .	January	15
Burning	February	15
Piling and reburning completed by . .	March	15
Aligning and staking completed by .	April	1
Stump planting started	April	10
Stump planting completed by . . .	April	20
Area enumerated by	June	1
All casualties replaced by . . .	June	15

Weeding starts in May or early June and about 6 weedings are necessary in the first year as weed growth is very heavy. [49]

Special Protection Work

General considerations

All forms of damage attract more notice in plantations than they tend to when distributed over natural forests. Although it is not true that they are necessarily or even usually worse, it is usually sound to give plantation areas special protection, especially during their first few years.

Fencing

The need for fencing varies greatly with conditions, species grown, risk of cattle or wild animal damage, etc. In Burma and S. India, where teak is the chief species grown, fencing is never erected ; whilst in Gorakhpur a pig-proof ditch is necessary but adequate round the sal *taungyas*, in Bengal and the U. P. submontane tract, success is hardly attainable without an effective fence reasonably proof against deer, pig and porcupine, and even then constant vigilance is necessary, and an occasional drive required to get rid of the animals that get inside through the gaps made by wild elephant, rhino or driven buffalo ; moreover deer will jump on occasion any fence it is practicable to put up.[26, 26a, 27]

The standard fence now consists in most places of wove wire about 4 ft. or $4\frac{1}{2}$ ft. high, sunk 6″ to 9″ into the ground where pig and porcupine are feared, and surmounted by about five strands of barbed wire up to a total height of 8′. The posts must be strong and durable enough to last at least 5 years, and must not be too far apart or it is impossible to keep the wire properly stretched—15′ is most usual, and over-wide spacing is false economy. Live posts can sometimes be used. Good stretching is most important, as also blocking of stream crossings and prompt repairs of all gaps. Stiles must be provided in appropriate places and are preferable to gateways. A great many makes of wove wire fencing are now available, and the essential for a good make is a lock or weld such that the strands cannot be forced apart. (Bengal recommends Frost Ring lock.) Cost varies with the size of the unit, but this should not exceed about 100 acres or it cannot be kept free of animals. A good fence should last 15 years with one or two shifts. The initial cost amounts to about Rs. 15 per acre including erection, assuming posts are available without cost on the site ; the ultimate cost in view of repeated use, is about Rs. 6 As. 5 per acre (Bengal figures). Where topography and management permit, plantations should be laid out in compact rectangular blocks so arranged that a minimum length and amount of shifting of fences are called for.

Frost

In some localities, experience has shown that even where frost is not generally a serious factor in the forest, as at Gorakhpur, it may become so in clearings made for plantations, and special measures are called for to minimize the damage done to the new young stock. Where local radiation is the chief trouble, an overwood may serve the purpose, but it may be necessary in blanks, etc., to grow a temporary frost-hardy nurse crop, for which castor oil has been suggested, or to use frost-hardy species such as *sissu* and *khair* under which perhaps the more sensitive species may get up later (cf. p. 247).

As far as practicable, steps must be taken to avoid the introduction of conditions likely to encourage the collection of chilled air flowing down a slope or line of low country. Any wall of forest across the line of flow is liable to result in frost damage just above it, and clearing should progress against the flow, leaving unfelled forest above.

Irrigation

Irrigated plantations, in arid tracts incapable of supporting forest growth without artificial water supply, will be described under Afforestation (see p. 268) but occasionally conditions are met with elsewhere under which temporary irrigation is a practical proposition and a great help in getting a plantation well started. Final success depends in very large measure on the stocking and growth obtained in the first season, and irrigation will often result in a very marked improvement in both respects over what is attainable without it. When therefore water is available, it is worth considering whether it would not repay the cost of bringing to the area and distributing. With water, it is ordinarily possible to sow or plant at the beginning of the hot weather and so to gain two or three months' growing season, thereby hastening the time when the plantation will close up, reducing weeding costs and the period of exposure to most forms of damage threatening small plants. Stump planting is particularly suitable for early work with watering, and has given good results with teak, *sissu*, rosewood and many other species, whilst irrigated line sowings of *simal*, bamboo, etc., have done equally well.

Inspection facilities

In the earlier days of plantation work, it was not always realized how important a factor to success is frequent and thorough inspection by the controlling officer. It is a very general phenomenon that the strip of plantation along an inspection path grows better than the parts away from it, and without going into the reasons for this, the deduction is obvious that the laying out and maintenance of a good network of pathways should be a routine measure in every plantation area. This work should be done after the burn and *before* the area is actually planted up. The cost of suitable inspection paths is very small, in fact where *taungya* is practised, the cultivators will usually make and use them during the term of cultivation. Practice varies in different parts of the country ; thus in Tharrawaddy, Burma, there is about a mile of path for every 25 acres, costing Re. 1-4 to make and about As. 4 a year to maintain, and in Bengal the general rule is to lay out an inspection path round every coupe, and crossing every block over 5 acres, corresponding to a unit rather less than half the Burma figure. Apart from the actual inspections, these paths greatly facilitate weeding and similar work, and economize the time of the labour and supervising staff.

Execution of Plantation Work—Preparation of the Planting Area

Felling

In the usual case of clear-felling, the timber trees are generally felled and logged first, and then the remaining growth cut as a separate operation, not rarely even in the following season, though this is to be avoided if possible. Where a market exists, fuel may also have to be converted and extracted by the prescribed date. A few weeks have then ordinarily to elapse before the debris has dried out enough to give a good burn. In Bombay, a method has been developed[11d] based on local agricultural practice : the purchasing contractor has to collect all the debris at once, still with the leaves on it, and stack it in an approved fashion on sites selected by the ranger, planting being limited to the sites of these *rabs*. It is sometimes necessary to take special steps to ensure that enough small material is left on the coupe to give a good burn. In the drier areas only about 3-5 per cent of the grass area is planted up in *rabs* about 40′ by 40′, and the size and proportion of the *rabs* increases with more favourable conditions to continuous plantations. The unplanted portions are restocked by coppice and seedling regeneration.

Burning

The burning is done as soon as the material is dry enough to give a good clean hot fire, the usual method being to start it up the wind and gradually work round the periphery so that the block burns mostly inwards and up the wind with a minimum of risk to the surrounding forest and plantations.

Better results are reported when the *rabs* in Bombay are burnt in January or February, so that they may lie fallow till the planting season in June.[28] A satisfactory burn is absolutely essential to a good plantation almost everywhere ; if it is delayed till rain begins to fall, and only a patchy or feeble fire is possible, the chances of satisfactory development are so greatly reduced that it may be worth considering postponing burning and planting to the next season. In Burma, a few year's fire protection is recommended beforehand to allow combustible material to accumulate, whilst at Nilambur it has been found that an unavoidably light burn can be largely compensated by more intensive soil working, but this, of course, is expensive.

Reburning

In most localities, it is found advisable to collect the unburnt material into heaps and reburn ; elephants are useful for this work, which is rarely necessary where fuel is extracted. Useless large logs are left where they fall, and in limited numbers are little trouble provided they are not cropped up above the ground by stumps of branches or by rocks. If such material is left, planting and inspection work are considerably handicapped, and climbers are apt to get a footing among it and be very difficult to eradicate.

The effective elimination of bamboo clumps is often important and may call for special measures, such as piling branchwood round and even in them.

Stump removal

In some intensively worked areas such as Gorakhpur,[17] the stumps are dug up and converted into charcoal, the sale of which covers the cost of the work, though the main reason for undertaking it is to facilitate ploughing—obviously this is not called for in most places where soil working is all by hand, and it should not be permitted where erosion is to be feared. It is assumed to reduce subsequent risk from root fungi.

Soil Preparation

Hoeing

Good forest soil requires very little working to get it ready for sowing, especially as the burning loosens it and destroys the ground vegetation. A light hoeing is however often done at least in parts, and serves to work the good ash into the body of the soil and improve any overburnt patches. Such operations may be confined to the strips or patches where the trees will be raised.

More intensive work

Soil working is much more intensive where the work is done by people with more developed agricultural ideas, as at Gorakhpur ; here, as mentioned, stumps are dug up, the ground more or less levelled up, and complete cultivation done at first by hand and then by plough. Often the soil to be sown or planted is dug out to about a foot deep early in the season, and filled back free of roots, etc., in time for the sowing or planting ; this is done in the Gorakhpur sal strip sowings and in patch planting in Bengal. Soil preparation by mechanical ploughing usually only comes into question in the afforestation of grassland, etc., but where labour is scarce, it may be worth considering. It was found in the Bengal submontane tract that ploughing with a Fordson tractor cost about the same as hand hoeing with the same thoroughness.

Dry soils

In dry climates, the principles of dry farming should be applied involving deep and thorough soil working, the surface soil being kept loose and mulches used to reduce losses by evaporation.

Level of soil after working

In all cases, as the loosened soil has a larger volume, the prepared strips or patches will naturally be a little above the general level of the ground. Some soil is however always scattered, and when it again settles in the rains, there is a serious risk that the level round the plants will drop below the general level so that water will stand, to the great detriment of the plants. The earth should accordingly always be raised a few inches by banking it up somewhat from the sides so that no depression will be formed. On the other hand, it is often equally important not to ridge up the soil too high or it will be washed away by the rain, leaving the roots of the seedlings exposed, and considerable mortality may result in the following hot weather. The optimum height will depend on the texture of the soil and on the local climate.

Where drought is prevalent, it is sometimes recommended to excavate the soil and sow or plant in the depressions, but this is rarely successful in India and it has been shown that loose soil in mounds may actually condense moisture from the air and present more favourable conditions than the pits.

The general principles governing the selection of species to be grown have already been discussed on pp. 183 ff. The following paragraphs deal with their application.

Choice of Species

Survey

After the burn is the time when the whole plantation area can be easily surveyed, if this has not already been done, to make the final decisions as to the precise areas to be planted with each species. Preliminary observations must be made before the old crop has been removed as it can give most valuable indications of potentialities and necessities, but it is often difficult to see the area as a whole, and impossible to mark it out at that stage. In Burma, a regeneration plan and map is drawn up in advance, a very sound routine measure. It is to be remembered that conditions are liable to be altered somewhat by the clear-felling, and low-lying ground is liable to become wetted temporarily—only local expereience can foretell these changes.

The canal bank plantations of the United Provinces provide a good example of the application of a preliminary soil classification to plantation work. The soils differentiated are : (1) sandy *bhur* on which *khair* and *sissu* stumps are planted, (2) loamy *domat* on which a variety of species can be sown or planted (*khair* and *sissu* are largely used, but fruit trees are planted on the best soils of all), (3) clay and mild *usar* (saline soil), on which *Acacia arabica* is sown, and (4) wet soils on which *Eugenia jambolana* is mound-planted.

General examples

In the W. Himalayas, deodar should not be planted on hot bare hill sides better suited to blue pine or cypress, nor in damp, flat sites where broadleaved trees should be used. Deodar will not grow on white quartzite sand where pine will flourish and pine is often very inferior on clay soil. In the NE. submontane sal plantations, *Michelia champaca* and *Cinnamomum cecidodaphne* do well on good soil insufficiently well drained for sal, and depressions are filled with *Lagerstroemia flos-reginae*. Teak should not be put on low-lying land as, though it often starts off well, it does not root properly and falls over later ; neither should it be planted on laterite, where mahogany and *Xylia* do much better.

Species suited to special sites

The following lists suggest species which appear best suited to special sites in the northern and central Indian plains and low hills, but it must be emphasized that the terms used are comparative, and in any given locality or year, the intensity of the limiting factor may overstep the powers of resistance of a given species.

DROUGHT-RESISTING SPECIES. (1) *Acacia leucophloea*, *A. modesta*, *Anogeissus pendula*, *Balanites roxburghii*, *Capparis aphylla*, *Ficus bengalensis*, *F. religiosa*, *Hardwickia binata*, *Prosopis glandulosa*, *P. spicigera*, *P. juliflora*, *Tamarix articulata*. (2) *Acacia arabica*, *A. catechu*, *Anogeissus latifolia*, *Eugenia jambolana*, *Lannea grandis*, *Ougeinia dalbergioides*, *Pongamia glabra*.

SUITABLE FOR SANDY SOILS. *Acacia farnesiana*, *A. jacquemontii*, *Casuarina*, *Pongamia glabra*, *Populus euphratica*, *Tamarix* spp., *Vitex negundo*, *Dalbergia sissoo*.

Suitable for Saline Soils. (1) *Acacia arabica, Butea frondosa, Tamarix articulata, Prosopis juliflora.* (2) *Acacia catechu.*

Suitable for Swampy Soils. *Barringtonia acutangula, Bischofia javanica, Eugenia jambolana, E. operculata, Lagerstroemia flos-reginae, Salix tetrasperma, Diospyrus embryopteris, Ficus glomerata, Trewia nudiflora, Butea frondosa, Eucalyptus robusta.*

Relatively Frost-hardy Species. (1) *Dalbergia sissoo, Morus alba, Pinus longifolia, Acacia leucophloea, A. modesta, Salix tetrasperma, Tamarix articulata, Prosopis* spp., *Vitex negundo, Zizyphus jujuba, Dendrocalamus strictus, Broussonetia papyrifera.* (2) *Acacia catechu, Aegle marmelos, Barringtonia, Bischofia, Casuarina, Eugenia operculata, Hardwickia binata, Ougeinia dalbergioides, Schleichera trijuga.*

Suitable for Dry Areas. The species suitable for dry and arid areas have been listed and described in detail under four categories, as possibly suitable for (a) sand binders, (b) arid areas, (c) irrigated plantations and (d) canal plantations,[54]. For details the reader is referred to this work.

Staking

The marking of the planting spots or lines is generally done by the local guard, with the help of the cultivators in *taungyas* ; bamboos are the cheapest and best stakes in most places. Different kinds or length of stake indicate the species to be raised. Stakes should be set up firmly in the first place, and are often taken up when counting the successful stocking at the end of the season, leaving those where replacements are still required or substituting longer ones in their place. Skeleton staking has been recommended as an economy, but is doubtfully advisable. Opinions differ as to the value or desirability of mathematical precision in staking, but uniformity is preferable where soil inequalities are unimportant. In *taungya* plantations, where ploughs are used, a blank strip or headland 8′-10′ wide is left at the end of the lines for turning the plough and clod-crusher.

The usual spacings adopted have been mentioned on p. 188 : they are nearly always measured horizontally on hilly ground. Line sowings are always done along the contours, and usually in broken lines, an inclination of the stake indicating which side of it the line will run. Planting is also done along contour lines as far as the ground permits, as all subsequent operations are thereby facilitated. The inspection paths are usually laid out at the same time as the staking is done, but sometimes much later, though this is undesirable.

Miscellaneous Work

Most areas present minor local features calling for attention. In low-lying or badly drained spots, it may be advisable to cut shallow drains, whilst in the opposite direction, special steps may be taken to catch and conserve as much moisture as possible—this may involve contour trenching, or even diverting shallow streams out of their beds to distribute the water they would rapidly drain away.

Direct Sowing

General considerations

On account of its ease, economy of labour and cheapness, direct sowing tends to be the first method tried, and often remains the best. This is particularly so in the drier areas. Its merits relative to planting are discussed on p. 249 below. Shaking up the seed with red lead (1 lb. with 10 lb. seed) is helpful in reducing loss from birds, rodents and insects. As noted above, many seeds germinate better if first soaked in water before sowing, but this should only be done when sowing into moist soil in which germination is required as soon as possible.

Broadcasting

The simplest method of sowing is to broadcast the seed over the plantation area or over selected strips or portions of it. The quantity of seed needed is large in comparison with other methods, but the actual work is easy and cheap. As a rule no steps are taken to cover the seed, though occasionally more or less hoeing may be done to this end. The method has been applied to areas destroyed by forest fires (as deodar) and to abandoned cultivation and landslips ; it has also been tried in heavy grass areas with species believed to be able to establish themselves, as a stage in bringing such areas under forest, and in fuel coupes to improve their stocking, and for introducing accessory species in plantations (cf. p. 244). The best example is however the sowing of *Acacia arabica* on the inundation flats of the Indus in Sind, the seed being broadcast on the recently emerged mud flats, or even into the receding water before it has quite uncovered them. In Assam, natural regeneration of *Terminalia myriocarpa*[29] has been supplemented by broadcast sowing on soil exposed by making an elephant drag stump over the ground. In Burma, teak seed has been broadcasted successfully before felling and burning. Broadcasting seed has been efficiently and very expeditiously done from an aeroplane in other countries. An unusual method is that adopted for Khasi pine in the Khasi hills, Assam, branches carrying unopened cones being stuck in the ground every 7 or 8 yards when the *taungya* cultivators leave the area after two years' cropping.

Dibbling

This method consists in burying the seed in the soil with the help of a dibbling iron or stake at intervals all over the area to be stocked ; it is particularly suited to large seed such as that of oaks and many Dipterocarps, but can be adapted to any smaller seed, a pinch being sown instead of a single seed at a time. It is a very general way of supplementing natural regeneration and so is usually done under a shelterwood. It is very cheap to do, and as the sowing spots are not rendered conspicuous, the seed stands a good chance of escaping vermin. Quite good results have been obtained in this way in S. Bengal with *Dipterocarpus turbinatus*[30] and locally in the W. Himalayas with *Quercus incana.* Pregerminated seed is often used in this class of work, requiring more careful handling as injury to the radicle has to be avoided, but giving more even stocking from the start ; such work is very similar to notching small seedlings (cf. p. 238). Fillings in the Sind babul sowings are done by dibbling in seed after the flood water has receded.

Strip, Line, Ridge and Trench Sowing

The method

Because of its economy in seed, in preliminary work in soil preparation, and in subsequent tending, strip or line sowings are much commoner than broadcasting over the whole area. Line sowing implies a single line or drill of seed, and strip sowing several adjoining lines or a broadcast sowing limited to strips a few feet wide.

Examples

Strip sowing is now the universal rule with sal,[16, 17] and is being done with other Dipterocarps,[30] with *sissu,*[31] *Terminalia myriocarpa,*[32] *Chuckrasia*[1] and other deciduous species, and with chir pine and deodar.[3] In sowing sal, it is recommended to put in three lines of seed 6″ apart with the seed 4″ apart in the lines, and to cover the whole planting area with one line before sowing the second line, and similarly for the third ; this procedure safeguards against complete failure of a part of the plantation if some of the seed collected has lost its viability or in the event of unfavourable weather during sowing and just after. It has also been suggested to sow the third line rather deep for the same reason, but this is not generally done. Under favourable circumstances mainly encountered in afforestation work, mechanical seed drills can profitably be used : the Planet Junior drill has been in regular use in chir pine sowings at the Forest Research Institute.[33]

Width of strip

The width of the sown strip is usually about 2′, but 1′ is accepted in places, whilst the usual width in the Upper Assam moist and evergreen tracts is 6′-8′ with 12′ interspaces, such wide strips being rarely necessary under less luxuriant growth conditions.

Ridges and trenches

In wet soils, or areas liable to periodic inundation, ridge sowings may be preferable, as with sowings of *Eugenia jambolana* and *Terminalia tomentosa* in low-lying parts of sal plantation areas and *Acacia arabica* in swampy areas along the Indus. The soil is usually rather stiff in such places, so that the risk of root exposure is not great, but it is as well to make the ridges of good width. The opposite procedure of trench sowing has been recommened for dry tracts where water conservation is the chief consideration, and should be useful with light soils in which water would not stand. It has given excellent results with *Acacia modesta* and *Dodonea viscosa* in the dry plains of the N.W.F.P. and with *Acacia arabica* in Sind on high ground which receives no flood water.

Interrupted strips

Strip sowings in the plains are almost always done with continuous lines often of great length, but occasionally (sal in the Garo hills),[34] and very generally in the hill sowing of conifers,[3] it is usual to break the lines at frequent intervals—thus 10′ sown lengths alternating with 10′ unsown lengths. The main reason is that vermin such as pig, deer or birds which chance on a long line and feed there, will work along the line and do great and continuous destruction, whereas with the broken lines, even if the same number of plants are destroyed in the end, the damage is much more scattered and so less harmful. Furthermore there is a definite saving of seed, and most of the plants which might have been raised on the unsown intervals would have to be removed in the first thinning in any case. It seems however agreed that where vermin are not too troublesome or can be excluded, especially where weed growth is heavy and early closing up important, the continuous line is to be preferred as it is in fenced sal plantations, but broken lines are as good or better under conditions such as prevail in the coniferous hill tracts.

Patch, Mound and Pit Sowing

The method

Patch sowing or ' sowing at stake ' is perhaps still the commonest method of raising teak in departmental and *taungya* plantations in Burma. A roughly circular patch of soil at each stake is prepared to the extent locally considered necessary, and several seeds are sown in it. Generally only one plant is wanted in each, so any extra ones are used for transplanting to blank stakes. Improved results have been obtained with teak, *Terminalia tomentosa* and some other species by pregerminating the seed in dumps and notching the germinating seed (cf. p. 238), this method providing a transition to planting.

Mounds and pits

Where conditions require, the soil may be raised and mound sowing done, or very rarely it may be excavated for pit sowing, exactly the same considerations applying as for the line, ridge, and trench sowing just discussed.

Merits

The chief difficulty about patch sowing, especially with wide espacement, is that the competing weed growth presses on the seedlings from all sides, and unless clean or at least intensive weeding is continued till the saplings close up, they are very likely to be smothered. There have been many failures in heavy grass jungle areas in this way. Once the weeds have got up, inspection is very difficult, and many of the patches get missed in the weedings. On the other hand, with quick-growing species and *taungya* methods, patch sowing may be both cheap and effective, as it has been with teak. Large patches are often much more effective than small ones in supplementing natural regeneration : thus 5′ by 2′ to 5′ by 5′ and never 1½′ by 1½′ is recommended for deodar, with adjoining patches 6′ apart.[3]

Time of Sowing

The time of sowing is of course important. As a rule, seed should be sown shortly before the normal germination season to ensure the maximum length of growing time—thus chir pine and most of the species of the tropical deciduous forests should be sown just before the rains are due, or after the first shower. Deodar sowings, however, should be done before snowfall, as the results are much better than those from sowings done when the snow melts, and later spring sowings are usually a failure. Walnut sowing is also done in winter.

In the dry fuel forests of Madras, although the North East monsoon (October-November) is the main source of rain, it has been found best to sow with the thunder showers of the South West monsoon (June-July) and to go on resowing at regular intervals of 3 or 4 weeks until full stocking is obtained. This procedure gives the plants their best chance of surviving the crucial test of their first hot weather. [55]

Quantity of Seed

The quantity of seed used per acre in direct sowing is illustrated by the following examples :—

Deodar.—Broadcast, 20 lb. Broken line sowing, 10½ lb. Patch sowing, 10 lb.
Chir pine.—Broadcast 30 lb. Continuous line sowing, 10-12 lb. Broken line sowing, 8 lb. Patch sowing, 6 lb.
Blue pine.—Broadcast 10 lb. Broken line sowing, 5 lb. Patch sowing, 4 lb.
Sal.—Strip sowing, 3 lines of seed, 4″ apart in the lines, strips 10′ apart, 200-250 lb.
Teak.—Patch sowing, 6′ by 6′, 20-25 lb.
Terminalia myriocarpa.—Strip sowing, strips 8′ wide, 12′ inter-spaces, 240 lb.

Depth of Sowing

The depth at which the seed is sown is a matter of importance. Small seed such as *Terminalia myriocarpa* only requires a very thin sprinkling of soil over it and is easily killed by being buried too deeply. Large seed is usually pressed down into the soil till its upper surface is just level with the surface (*Terminalia chebula*), or under the surface by not more than its own diameter (oaks). Deeply buried seed is slow to germinate, and for this reason sowing a portion of the seed deeply is sometimes advocated as a precaution against a spell of drought fatal to recently germinated seedlings. The best orientation of the seed is usually that which it ordinarily attains under natural regeneration, i.e. the long axis horizontal in most seed. Sowing on steep slopes may be done rather deeper than on the flat, to reduce the amount washed down the slope. A safe rule is to sow seed at a depth equal to its own diameter.

Nursery Work

General considerations

Nursery work is not done in India to the extent customary in most temperate countries, and only in a few localities can the standard of work be said to be a high one. With the majority of our species direct sowing has been found to give excellent results, rendering the much greater cost of nurseries and planting unnecessary. Teak is however being raised in cheaply made nurseries to an increased extent, especially with the spread of the use of stumps: [56] deodar is frequently raised with a technique very similar to that of Europe, and nursery work is well developed in the hills and plains of Bengal for a variety of species.[1]

Temporary and permanent nurseries

Most nurseries in India are temporary nurseries used only for one or a few years. The permanent nursery has advantages where large supplies of plants are wanted annually, where communications are good for getting the stock quickly to the planting site, and where suitable sites perhaps requiring water and housing for the staff are difficult to find. The temporary nursery has the advantage of being close to or actually on the planting area, with good new soil, and a minimum trouble with weeds, destructive insects and disease. The following remarks apply mainly to the temporary ndrsery to be used for at most 4 or 5 years, and usually only for one or two crops of seedlings.

Selection of Site

The nursery should be made as centrally for the area to be planted as a good site is available, preferably near a Ranger's or Forester's quarters and a labour supply. A fairly light well-drained soil is desirable, heavy soils being unsuitable. It is a mistake to site a nursery on poor soil because the planting site is poor. In all cases the best-grown most vigorous stock is most likely to succeed if of the proper strain. In the hills a moderate slope should be selected to give good drainage without the expense of much terracing ; a northerly aspect is preferable in the W. Himalayas except at high elevations, but in the wetter E. Himalayas, this exposure is too wet and cold above about 4,000′, and W. or SW. aspects are to be preferred. A water supply is advisable if it can be obtained, but is not essential in most localities. Newly cleared forest land is best, no overhead shade being left except in some hot dry localities where it is known to be helpful : some degree of side shade on the south is however usually advantageous. Nurseries should never be sited on natural blanks in the forest, which invariably have something against them.

Area Required

For 6′ by 6′ planting with plants which are not kept over a year in the nursery, an acre of nursery will ordinarily serve for about 200 acres of plantation, this being the customary figure for teak in Bengal. In South India a standard nursery bed 40 by 4 feet sown with 20 to 30 lb. of seed produces enough stumps of the best diameter to plant 1 acre of teak plantation at 6′ by 6′ espacement and still leaves a sufficient reserve for casualty replacement.[56] For deodar planted out at the same spacing at 18 months, an acre of nursery is needed for about 30 acres of plantation.

Laying out and Preparing Seedbeds

Size and shape

In the plains, the nursery should be rectangular and divided into blocks by permanent paths about 6′ wide ; the beds should be rectangular and separated by smaller paths 2-3′ wide. In the hills, the beds have to be laid out along the terraces, which must be wide enough to allow of at least one full bed-width and a path all round, i.e. about 10 ft. The beds are best laid out with their length east to west as this is most convenient for shading from sun and frost. The most usual width of bed is 6′, though locally 5′ is preferred and the standard width of the deodar bed is only 3′. The length of the bed varies from 6′ up to about 40′, the former figure being usual for deodar, and the latter the maximum in the plains. In Bengal, 12 running feet of bed 6′ wide is the working unit and is termed a *kamra*, though *kamras* may adjoin without an intervening path. In Madras, the standard nursery bed is 40′ by 4′.

Drainage, irrigation, and fencing

Only locally in dry tracts with flood irrigation is the level of the bed below that of the paths, the universal rule otherwise being that the beds should be well raised to ensure good drainage, and such watering as is necessary be done by hand. It is usual to dig up the whole area when laying out a nursery, and to raise the beds by throwing on soil from where the paths will be supplemented, it may be by additional soil or manure. In districts with a long dry hot weather but ample monsoon rain, it may be advisable to have the beds level with or slightly below the general level during the dry season, so that they can be irrigated, and then to lower the level of the paths shortly before the rains—this is the practice at Dehra Dun. The whole nursery must be fenced wherever there is risk of damage by cattle or wild animals, and wire-netted against porcupine and rats where necessary.

Soil preparation

The soil should be dug out to a depth of a full foot in average soils, more in poorer soils, and sometimes rather less in light lose soils. All stumps are removed and stones and weeds are picked out, and if there is much gravel or hard lumps, it may be necessary to put all the soil through a $\frac{1}{2}''$ screen before making up the beds. In Bengal, it is the practice to make up the beds with leaf mould collected early in the cold weather and stored under shelter after sifting ; the beds are made up in February, with a top layer of about 6″ of this leaf mould mixed with screened local soil, some charcoal, and wood ashes. It is probable that the high standard of the Bengal nurseries results in a considerable degree from the care taken over the soil preparation. Where the local soil is inclined to be heavy, it is a good plan to give a liberal top dressing of washed river sand, as is done at Dehra and in Assam. A period of fallow between digging the soil in May and making the beds in December is recommended for deodar nurseries in the Punjab, where also liberal use of leaf mould is made, supplemented in the permanent nurseries by well-rotted cow dung. Burning vegetable debris over the beds before sowing tends to reduce weed growth and so is beneficial for minute seedlings such as those of *Adina ;* on the other hand, it was found to have a definitely detrimental effect on the development of evergreen species in Madras.

The surface of the beds should invariably be quite flat, not convex, still less concave, especially with small seed liable to be washed about when watering is done.

Edging

Raised beds are usually built up about 6″ above the general level, and the sides supported by planks, off-cuts, or poles held in place by wooden pegs. This method is usually the most satisfactory, but it sometimes suffices to pack the sides, as is often done with deodar and teak nurseries which are not rarely raised 9″ or even a foot. Apart from the improved drainage and soil aeration, later handling is facilitated by the raised bed.

Sowing

Methods

Large seed is usually sown individually in drills running across the width of the bed. Small seed may be drill-sown in the same way, but is very commonly sown broadcast over the seedbeds, especially when it is intended to line out the plants in the nursery. The drills are conveniently laid out by pressing down on the prepared bed a *drilling board*, which is a board of the width of the bed, and a convenient length to mark out say 6 drills, battens of the required width, thickness and shape being nailed to the lower side at the required spacing.

Even distribution of seed is greatly facilitated by using a simple *seeding trough* into which is poured the requisite amount of seed from a small measure—or a *seeding lath* which includes its own seed measurer in the form of notches which retain the right amount. The drills are usually spaced 3″ or 4″ (e.g. in Bengal) to 7″ (deodar in the Punjab) or 9″ (teak for stumps in some localities). Sowing of very small seed such as *Adina* and *Duabanga* can be made much more evenly if the seed is mixed with one or two times its volume of soil, sand or wood ashes.

Time of sowing

The aim in nursery work is to have the stock of the right size at the beginning of the planting season, neither too large nor too small for immediate planting. The best date for sowing, and details of treatment as regards watering and manuring, are only to be learnt by experience in each locality. In the plains, various seed such as *Michelia* ripen towards the end of the year and should be sown at once, and others only ripen too late for sowing before the monsoon, but the majority are usually available for sowing from about February to March with several months for germination and early development before they are needed for planting out. Special care is needed for second year stock, which is liable to get too big for use if not ckecked by intentionally late sowing, minimum watering, or transplanting.

Drill sowing takes longer but ensures more even distribution of seeds and seedlings, and considerably facilitates weeding and digging up for planting or transplanting.

Quantity of seed

To determine the quantity of seed to be sown in each bed, preliminary knowledge of the number of seed to the ounce and the probable germination per cent is required, but reference lists are now available in most provinces,[10] and preliminary germination tests may supply additional information. Sowing should not be densely, but thinly enough to give seedlings averaging 2″ or 3″ apart in most cases ; denser sowings tend to give weak stock, difficulty in weeding and great risk of damping off (e.g. with *Chukrasia*, *Adina* and *Duabanga*, cf. p. 229).

Seed covering

After sowing, the seed may be covered by raking over the soil, but with small seed especially it is better covered by sifting over clean sand, fine subsoil or leaf mould. These selected soil coverings, especially sand, may be very helpful later by reducing the tendency of the surface soil to cake when watered, a common trouble. The depth to which the seed should be covered is very generally taken to be the minimum diameter of the seed, but with the light soil coverings recommended should be rather more, thus for coniferous seed $\frac{1}{8}''$-$\frac{3}{8}''$. It is often advisable to consolidate the soil somewhat after the sowing is completed, and this is best done with a light wooden roller made for the purpose—this is recommended for deodar.

Moisture conditions

The soil, if dry, must be well moistened before the sowing is done, and again directly after. Only a very fine rose should be used or the seed will be washed about, and the soil caked. In Europe and America, the newly sown beds are often covered with sacking or other material to conserve moisture till germination commences, but this is rarely done in India.

Protection

It is sometimes advisable to cover the newly sown beds with thorns to keep off birds and rodents, and this is recommended for deodar. Locally rodents are so destructive (as with *Michelia excelsa* in the Bengal hills) that raising the seedlings on shelves supported on posts suitably proofed has been tried and proved successful.

SHADING

Protection from sun

Requirements with regard to shading depend on locality, species, time of sowing and length of time in the nursery, so that it is not possible to give any general rules. Shade is not needed with large seed sown at the break of the rains and used the same season, as commonly done with teak. Shade from excessive sun is very commonly required with seed sown before the monsoon with the object of getting stock of the required size for planting or lining out at the break of the first or second monsoon, which is probably the commonest practice in India. It is required with many species of *Lauraceae* and *Magnoliaceae* which ripen and are sown in the cold weather, as these are mostly unable to stand the sun from March or April onwards. Such shade is particularly necessary with species which normally germinate in the shade and are liable to sunburn (cf. p. 113, shade leaves).

Protection from frost

Shade from early morning sun may be required in the frost period with frost-tender species, but the shades in this case should be removed daily as soon as the risk of damage is over, as the soil will get chilled if the sun does not reach it in the daytime, and damage may much exceed what it would have been without shading, as has been recorded for teak in Dehra Dun.[35]

Protection from rain and hail

Protection from the impact of heavy rain or hail is desirable for all small seed and seedlings in the monsoon, or the seed will be washed away and the seedlings coated with mud splashed up on them—a condition which usually leads to heavy mortality. This danger is common to hills and plains, and to broadleaved trees and conifers. Larger seedlings unlikely to be harmed by splash should not be shaded during the rains.

Types of shade

Common types of shading are thatch, chicks, grass-stem mats (of *kana* or *munj* grass), bamboo matting, split bamboo or batten shades, bark, and sheet metal. Thatch has the merit of cheapness but is difficult to handle. What is used commonly depends on what is easily available locally, but it is a great advantage to use a type that can easily be rolled up and removed or replaced when needed, as it is only then possible to derive the maximum benefit from shading. Where only excessive sunshine has to be guarded against, it often suffices to put a rough leaf shelter over the beds, a rough and ready method which is good enough for small temporary nurseries of relatively hardy species.

Hardening off

When shades have been used over the seedbeds, it is important to harden off the seedlings by removing the shades gradually before the seedlings are lifted for lining out or planting ; the shades should be removed for a gradually increasing period daily, beginning with an hour or two when the sun is fairly low. Shades against sun should be about 3′ higher on the north side than on the south side of a 6′ bed. In a permanent nursery, it is worth while to have the height adjustable at intervals of one foot.

Watering

Under certain conditions dry nurseries are quite practicable—in fact many teak nurseries are not watered—but as a rule skilful use of watering enables one to have the stock the right size at the right time, and in many places with late or uncertain rainfall, it is essential to success. It is however a fact always to be borne in mind that as much harm can be done by overwatering as by under-watering, and it is a fault to which unskilled labour is particularly prone. All watering of seedbeds and small seedlings should be done with the finest rose procurable of the type that throws the water in thin jets *upwards.* The best time of the day to water is usually the afternoon, but with seedlings particularly liable to damping off it may be better to do it in the early morning, as the air is often damp enough during the night without additional watering. Damping off is particularly liable to occur in crowded seedling beds of some species until the stems are lignified, and watering must be very sparing ; slight acidity, such as is obtainable by adding a little acetic acid to the water occasionally, may be helpful as unfavourable to the causative fungi, but formaldehyde appears to be the most satisfactory preventive. In the hills where there is danger of frost, watering should also be done in the morning. Growth of moss on the surface of the soil is usually an indication of overwatering, and is often accompanied by an unduly yellowish colour in the leaves. Watering by percolation is generally better than flood watering, and sometimes, as with *Eucalyptus*, better than using watering-cans. [35a]

Lining out, Pricking out, or Transplanting

Transplanting is defined as the moving of plants from one nursery bed to another and is thus contrasted with ‘ planting out ’ which is the act of transferring nursery stock to the forest. The terms lining out and pricking out are also used with the same meaning as transplanting. Although transplanting is expensive, it is often justifiable or even essential to lift the seedlings from the drills or broadcast seedling beds as soon as they are large enough for safe handling, and to replant them at a suitable spacing in other beds in the nursery. Thin sowing when plants are kept some time in the nursery will not give plants of the same vigour and desirable root system as are obtained by pricking out from the original seedbeds. Transplanting is done with the majority of species in Bengal, and with deodar in the United Provinces and in the Punjab when strong plants with well-developed bushy roots are required for exposed or otherwise difficult sites. The most usual time for lining out is the break of the rains, but with necessary care it can be done at almost any time the seedlings require it. Every precaution must be taken to ensure minimum exposure of the roots.

Methods

A *planting board* is useful for this work. This is a board as long as the bed is wide, with notches at the required distance between plants, very usually 3″, and its width is the desired distance between lines of plants, usually 3″ in the plains, and 6″ for deodar in the hills. The board is placed on the bed and a trench made along the notched side deep enough to take the longest seedling roots without any bending. A seedling is placed in each notch with its collar level with the surface and the earth carefully filled in and compacted again. There are various more elaborate developments of the planting board useful in large-scale work, but they have not yet been used in India—in fact even the simplest form of board is rarely seen in use.

Shading, etc.

As already mentioned, it is important that the seedlings should be hardened off before lined out if they have previously been shaded, and they should be watered immediately after the operation and again shaded for a day or two till they are obviously re-established, after which they require less attention than the seedling beeds. It is for this latter reason that it is sometimes a good thing to make the lining out beds on the planting site when the nursery is at a distance, particularly when any form of planting out is intended which involves much carriage cost ; thus this is the practice with *Casuarina* in Karwar, Bombay.

Second transplanting

Where large plants are required for planting out in the forest, transplanting may be repeated with the desired effect of giving strong plants with a compact root system : thus deodar are sometimes again transplanted to 4½″ by 9″ or 5″ by 8″ in the second year for use on difficult sites where natural regeneration or previous planting has failed.

Nursery practice for teak stumps

It is current practice in South India when growing stock for the production of teak stumps to do no pricking out of the plants in the nursery beds at all. At the time of making the plantation the plants are about 1 year old. The nursery beds are well watered and the larger plants (of a collar diameter of 0·4 in. and above) are pulled out by hand and made into stumps leaving the smaller plants *in situ*. These smaller plants, together with new germination from seed that has remained dormant in the soil during the first year, produce a fully stocked bed of plants of a suitable size at the end of the second year without any resowing. This ensures an adequate reserve of plants to guard against a poor seed year. [49, 56]

Grading

Experience has shown that it is advisable to sort out or ' grade ' the stock and reject weakly seedlings. Such inferior plants are termed *culls*, and though good plants can sometimes be raised from them if they are given a bed to themselves and left longer to develop before use, they undoubtedly tend to include the inherently weaker individuals among a lot that have merely suffered from crowding or chance unfavourable conditions. They are best thrown away.

With teak in both South India[56] and the Central Provinces [57] it has been found inadvisable to use plants with a collar diameter of less than 0·4 in. or greater than 0·8 in. as they give poor height growth and poor survival percent.[58]

Weeding and Soil-working

With very rare exceptions, no weeds should be seen in a well-kept nursery. With beds of very small seed such as *Adina*, which cannot be weeded for some time without uprooting the minute seedlings, it is important to sterilize the bed as far as possible beforehand by burning refuse on it, using a blow-lamp, or by chemical methods. Ordinarily, weeding should be done as soon as germination is completed—earlier in the case of big seed with a long germination period—and as often thereafter as necessary to keep the seedlings free from weed competition. Lined-out beds or drill sowings require weeding about once a fortnight in the plains, to once a month or even less in the hills.

Weeding is usually best done by women, using a pointed stick for the smaller seedlings and loosening the soil at the same time. This work must not be done when the soil is wet, specially on the heavier soils. Where the seedlings stand too crowded they should be thinned out during the weeding. With the 6′ bed width used in Bengal and elsewhere, weeding is done from a plank supported across the bed and about a foot above it on two poles fastened at their end to the uprights of the shades. A caked soil has a marked checking effect on the growth of seedlings, so the surface should be worked as required even if there is no weed growth to be removed ; at the same time, severance of the more superficial roots is liable to result and great care is required in the operation.

Weed control by use of mulch paper as used by pineapple growers and others has been tried in India but does not appear to be a practical proposition here.

Notes for Permanent Nurseries

A few additional matters call for attention in more permanent nurseries, such as measures for maintaining the fertility of the soil and for checking the establishment of harmful weeds and insects.

Manuring

Skilled use of artificial manures may be helpful, but the knowledge and experience of them is rarely available in Indian forest practice and it is better to rely on organic manures. The best of these is undoubtedly leaf litter, which is readily available in temperate forests, but requires special arrangements in the plains, where a large pit should be made and filled with dead leaves as they fall, avoiding those which like sal are tough and slow to decompose ; it must be remembered that a large volume of dry leaves breaks down into a very small volume of leaf mould. To supplement this, or in place of it if necessary, stable manure can be used but must be well rotted, cattle manure being more satisfactory in this respect than horse dung. An excellent material is obtainable with suitable treatment from the vegetable waste from weedings, etc. In essence this method consists of stacking the waste in layers and impregnating with the bacteria which will break them down, either in the form of matured manure from the last prepared stock, or of the specially prepared Adco.[36] This ‘ artificial farmyard manure ’ has been used at Dehra Dun with excellent results.[37] The quantities of any of these manures to be applied must usually be learned by experience.

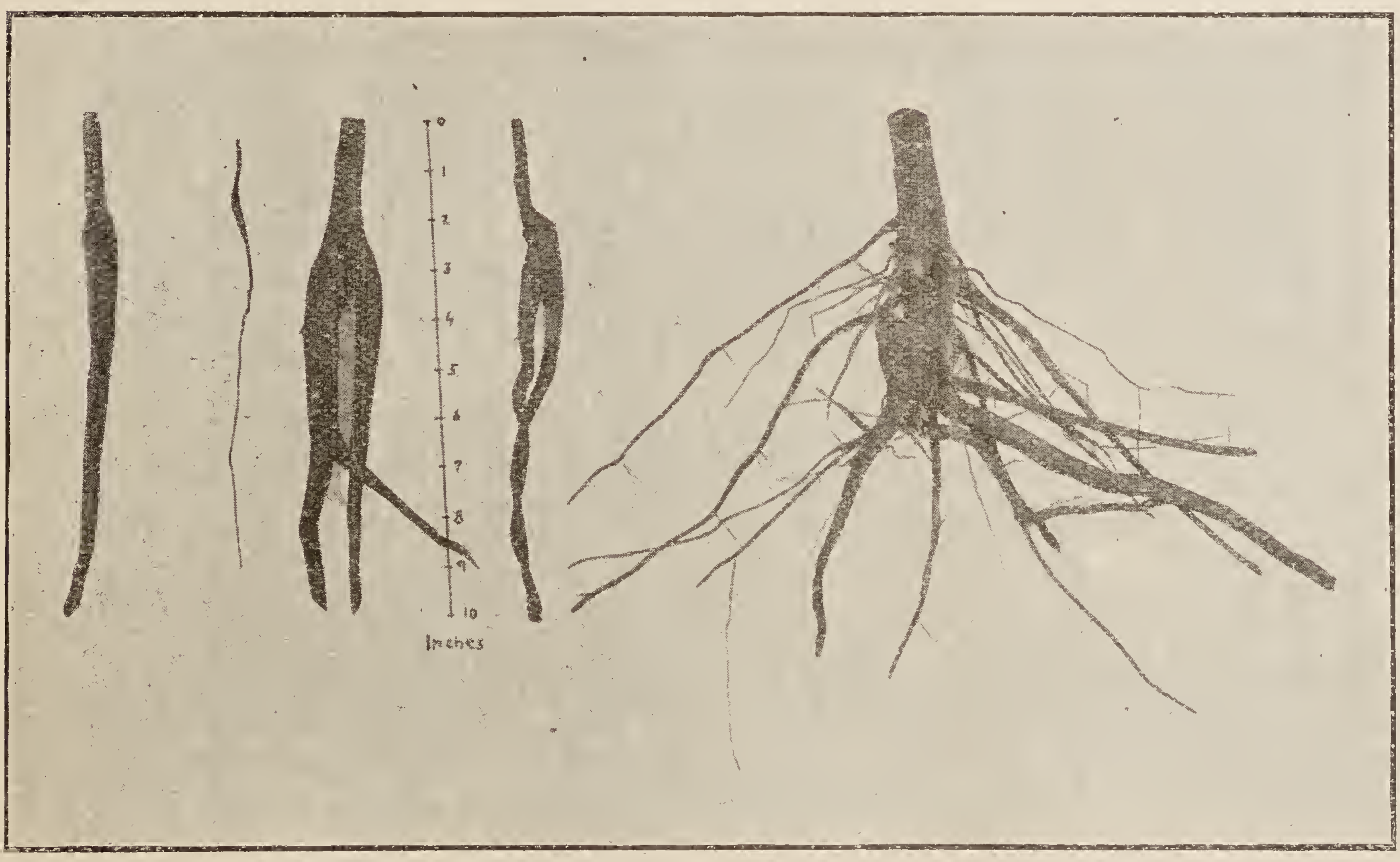


PLATE 16. (*Above*) A teak nursery bed after all the full-sized stumps have been removed. The remainder are left for the second year. Wynaad, Madras. (*Below*) Effect of nursery practice on the suitability of stumps produced. The stumps on the left is the only suitable one. Nilambur, Madras.

Green manures can also be used to advantage ; they are dug in just before the tissues begin to lignify, which with *Crotolaria juncea* is as it comes into flower. Lupins are generally used for this purpose in Europe, whilst mustard and buckwheat can be used where the chief need is for organic matter rather than nitrogen.

Manures tend to force growth, an important point for some species in which stock of suitable size is ordinarily available too soon or not early enough.

Weeding

Permanent nurseries are liable to become invaded by the usual weeds of cultivation which the temporary forest nursery escapes, and are then difficult to keep clean. Especially troublesome in this way are some of the grasses which have extensive underground rhizome systems. It is worth a good deal of trouble to see that such pests never gain a footing but are eradicated effectively on their first appearance. In other countries, the soil is sometimes sterilized with good results with low pressure steam, a blow lamp, or zinc sulphate before or after sowing the tree seed.

Pests

The position is much the same as regards insect pests such as cockchafers, cutworms and termites. There are methods of sterilizing the soil with steam or chemicals, such as crude oil emulsion and calcium cyanide, which it may be desirable to adopt in the case of an outbreak, and a constant look-out should be kept to deal with the incipient stages. A surface dressing of lime, wood ashes, asafœtida or tobacco water is recommended for hill nurseries in the NW. Himalayas.[3a]

Termite attacks in teak nurseries have several times been successfully dealt with in South India by treating the top three or four inches of the soil with a crude oil emulsion.

Register of stock

The beds should be numbered and a proper register maintained from which available supplies at any time can be determined. A seasonal count is generally needed for organizing the coming season's programme in the nursery and the planting area.

The Use of Containers

Conditions for use

As a rule, seedlings are planted out in the forest or plantation area with bare roots as soon as they are large enough to be able to establish themselves with ordinary attention as regards weeding and soil working. Conditions are however not rarely encountered under which a more favourable start must be given them, or under which the benefits of additional help justify extra expense. Planting with a ball of earth, entailing less disturbance of the roots, is one such method sometimes followed, but better still, when it can be done within what can be accepted as a reasonable cost, is to prick out the seedlings into special containers from or with which they can be put direct into the planting pits, or to sow the seed direct into such containers.

Types of container

A large variety of containers has been tried, the chief requirements being for lightness and cheapness. The simplest are perhaps the leaf cups or *donas* used for teak in the Central Provinces.[38, 11d] Sections of bamboo have been largely used (known as *chungas* in Bengal) ; these are about 8″ long without nodes and are usually split lengthwise and then retied together. Light baskets woven from bamboo strips or similar flexible materials are also often used. Light earthenware pots of the same long shape as these baskets and with a large hole in the bottom are often cheap enough but relatively heavy, and so are only occasionally used, as for *Eucalyptus* in the Punjab irrigated plantations and for *Casuarina* in Puri. Of recent years experiments have been made with paper tubes variously treated to make them just strong and durable enough for this class of work, and it is likely that their use will extend in certain localities.[39] Tubes made by rolling thin metal sheeting have been used in the same way (e.g. with *Pinus longifolia* in Peshawar[39a]), and have the advantage that the tube can very readily be slipped off during planting operations without disturbance of the soil round the plant roots.[3]

An additional advantage in using containers is that planting can be done at times of the year otherwise impossible ; in fact with a favourable climate it can be done at any time.

Mossing

Eucalyptus seedlings are sometimes raised in seed-boxes (the more delicate species under glass where frost occurs, as at Ootacamund), and when 3″ to 4″ high, they are ‘ mossed ’ by embedding them with a little earth in a cylindrical roll of moss about 6″ long, bound with fibre. The mossed plants are kept under a leaf shade for 4-6 weeks, being shifted weekly to keep the roots in the moss, until they are required for planting out. This method has been further developed in some places abroad, seedlings being raised in small cubes of special fibrous composition, cutting down weights to be transported, and space occupied.

PLANTING

Transport of nursery stock

The seedlings or transplants have first to be dug up and transported to the planting site, care being required to protect the delicate roots from desiccation or injury. They are usually dug from the beds, working from one end so that the earth will fall away easily—nothing in the nature of pulling up the plants must ever be permitted—and bundled after rejection of culls. The bundles are then packed in wet moss or similar material and put in a basket, which may be kept covered with wet sacking ready for taking out to the site. Depending on conditions, they may be thus lifted in the evening and transported by night ready for the next morning's work, or they may be lifted early in the morning, taken out, and planted all with the minimum of delay. One of the great advantages of the stump planting method described on p. 238 is that transport is exceptionally easy and safe. Oiled paper or paper-lined burlap have been recommended for packing seedlings for transport.

When planting is being done with balls of earth, the plants are usually carried out on shallow wicker or bamboo baskets lined with leaves or sacking, and covered with similar material. Light open wooden trays with a capacity of 100 or less containers are used for transport where tube or basket planting is practised : they can also be used for ball planting.

Planting Stock

Nursery stock

As a rule, the smaller the plant, the less it suffers from the actual shock of being uprooted and replanted, though this is not universally true. Very small plants are however more difficult to handle, and more liable to fatal damage in various ways, so the most common size of plant used is about 3″ to 6″ high. Occasionally much larger plants are used, as for instance 3rd season deodar, and large stock often succeeds on poor sites where smaller plants succumb, but casualties may be numerous before the roots are re-established. Larger stock is used with the stump planting method than with any other, but the plants are pruned extensively.

A few species have proved so difficult to plant out successfully that this method has to be ruled out for practical purposes, chir pine being a rather unexpected example.

Good planting stock has a well-developed branching root system, ample for the above ground parts. The leaf surface should be reduced by plucking off some of the leaves if it is considered excessive for the roots, or conditions are dry and sunny.

Wild or 'jungle' transplants are sometimes used to supplement nursery stock, but are almost invariably inferior to properly raised nursery plants, and from there scattered occurrence are usually more costly in the long run; exceptions to this generalization are reported e.g. from the S. Indian tropical evergreen forests.

Time of Planting

Monsoon planting

Most planting is done at the break of the summer rains, and should be done immediately good showers have fallen and the ground is well moistened; thereafter, every day's delay is a loss from an already short growing season, and late work is generally a failure. Normally, wherever the SW. monsoon is depended on, planting should be completed within 3 to 4 weeks from the first good rain, i.e. in June-July in Bengal, Assam, and Burma, or July in the United and Central Provinces, and nothing should be attempted after the first week of August except replacement of casualties, and even this should be done with extra care. Where the rainfall is exceptionally heavy as in parts of the W. Ghats, rather later planting, after the wettest period is passed, is found to give better results. In the relatively restricted area where the latter NE. monsoon brings an appreciable rainfall, later work is possible, depending on the locality. Deodar in the moist zone of the Himalayas must always be planted in the monsoon. In the dry zone forests of the upper parts of the Sutlej valley planting is altogether impossible.

Pre-monsoon planting

It has of late been demonstrated not only possible but even highly advantageous to plant teak stumps in March or April in localities which can count on occasional hot-weather showers, though not in Central and Upper India with their more severe dry hot weather. [40, 49, 50] With irrigation, planting should be done early in the year, as this results in a much lengthened growing season. It is only lack of moisture in most parts of the country that prevents growth during the summer months.

Winter and spring planting

In the W. Himalayas, ash and walnut are best planted in November before snowfall. In Kashmir, which has a wet spring,

Plate 17. Plantation of *Michelia champaca*, 10 years old, Buxa, Bengal.

Facing P. 236.

PLATE 18. Cover crop of *Tephrosia candida* patch sown between teak, New Forest, Dehra Dun. *Facing p.* 237.

spring planting of conifers is possible as in Europe. In the favourable damp climate of Bengal, certain trees such as *Acer*, *Prunus*, *Alnus* and *Cedrela* can be planted out during the cold weather ; if the plants are in leaf, it is usually advisable to pluck most of the leaves to reduce transpiration till the roots are established. *Bombax* can be transplanted in January-February, even in the United Provinces where nearly all winter planting is a complete failure.

Planting weather

With big-scale work it is not always possible to carry out all the planting work under the most favourable conditions. As far as possible, planting of the more delicate species should be done on dull or even wet days (e.g. *Swietenia*). Ordinarily it is not a good thing to plant when the soil is wet and sticky, but this often has to be done. The chief point under Indian conditions is to get the work completed in good time with a reasonably high standard of actual planting work.

Methods of Planting

Planting with naked roots

The chief points for attention are that the roots, particularly the tap and sinker roots, are not doubled up, that the collar is at the level of the soil, and that the level of the soil is not below its original level. The pits are prepared with spades or mattocks, or rarely special instruments such as cylindrical spades or spiral borers. The planting pit must be fully as deep as the roots are long ; the plant is held centrally, and a little of the soil is then pushed back into place and pressed gently but firmly against the lowermost roots, and the process is repeated until all the soil has been replaced, supplemented if necessary by an additional amount from the surroundings, the roots remaining as far as possible in their original natural position. If the plant can easily be pulled out of the ground, it indicates that the roots have not been properly spread, or the soil not properly compacted. Except on heavy soils, the soil should be well firmed round the plant with the heel as a final step. Light humus should not be used for filling the planting pit, but only good moist mineral soil from the upper layers.

Rougher and readier methods of planting sometimes give satisfactory results, but should only be adopted after clear proof that they do not result in growth in any way inferior to that obtained with the standard methods. Thus with some species on light soils, it suffices to open a notch in the soil with a planting spade—there are several ways of doing this—to insert the seedling with the roots as straight as possible, and to close the soil by again inserting the spade obliquely a few inches away from the notch and pushing till the earth closes on the roots, beginning at the tips. Such *notching* even when done with a dibbling iron is quite suitable for putting out germinating seed as already described for teak. Contorted roots, and unduly compacted soil which will reopen along the same line when dry, are likely to result unless just the right conditions prevail.

As already noted, it is often helpful to pluck off some of the leaves to reduce transpiration while the roots are making new contacts with the soil particles, especially if planting work has to be done on sunny days or in a soil not quite wet enough ; but if it is not necessary, it should not be done, as it will then check growth rather than forward it.

Planting with balls of earth is necessary with some of the more delicate species with which high mortality occurs if the roots are completely exposed ; such are *Michelia* spp. (see Plate 17) and *Cinnamomum cecidodaphne*. The soil in the nursery bed must not be too light or dry to permit of handling without collapse of the ball of soil lifted with each plant—handling must always be by the ball of earth, not by the stem of the plant. It is important to see that there is a proper bond between the ball and the surrounding soil, and as usual, that the levels are correct. Teak is often put out in this way in the Burma *taungyas*, the seedlings being raised from early broadcast sowings on good level patches in each *taungya* and moved when quite small ; time is gained in this way while the rest of the area is being prepared, and the plants grow without the check inevitable with naked root planting. The cylindrical spade can be used for making the planting holes, but is rarely seen in India.

Planting with containers (cf. p. 233) presents no new problems. Often the container is left to rot *in situ*, but it may be removed as in horticultural practice leaving the plant with a ball of earth held together by the roots, or it may be removed after the planting has been done as is possible with any sufficiently rigid cylindrical bottomless form of container.

Stump planting [41] depends on raising rather large nursery stock, usually not lined out, and pruning it down before planting to sticks usually about 10″-11″ long consisting of 9″ of root and 1″-2″ of stem. A clean straight tap root is required. All side roots are pruned off though it is usually best to reject all plants with much branched roots. A thickness between that of the little finger and a pencil is usually best, though the optimum dimensions undoubtedly vary with the species. The best diameter for teak stumps in South India is from 0·4″ to 0·8″ at the collar. [58] A short stem length appears to reduce the tendency to produce several equal shoots (*sissu*), but possibly is unsatisfactory with some species such as mahogany.[42] A shorter root length may be used in climates with favourable moisture conditions, thus a 6″ root length has often been used for teak though 9″ is necessary in drier localities.[60]

It has been found that stumps are able to withstand much more severe conditions during transport than entire plants, and as there are no roots to get doubled up, they are much easier and cheaper to plant. In Madras it has been shown that even in climatically unfavourable years teak stumps will keep for two to three weeks and also travel long distances without deterioration.[56] In light soil (Punjab irrigated plantations[31]) it is even possible to put them out straight into crowbar holes instead of prepared planting pits, but this is another of the cheap methods that cannot be recommended in the absence of demonstrated success in the locality. It is as important as with rooted transplants that the earth is properly compacted round the stump in planting. Stumps send out leafy shoots some time before any new roots are formed, as is readily seen on stumps stored in wet sacking. Ten days commonly elapse and often even twice this time, before the new roots appear ; as a rule, one or more sinker roots are formed at, or a little above, the cut end, and more or less horizontal feeding roots from the same place and higher up. Species which do not take well from stumps, such as sal, may produce quite vigorous leafy shoots which die off as soon as dry conditions set in, as no roots at all have been formed.

One objection to the stump method is that it takes at least 2-3 weeks to restore the original leaf surface, this time being thus lost out of the all too short growing season, but it has been found that this can in many localities be more than made up by planting far earlier than would be possible with entire plants. In fact, pre-monsoon stump planting has become the standard procedure in several localities owing to its marked advantages in survival and growth in the first season.[40, 49, 59] In the northern irrigated plantations of the Punjab, the *sissu* stumps are prepared in February-March and kept in pits till they are wanted in April, and sprout more quickly than newly prepared stumps.

Stumps have also often been found useful for filling in casualties, and sometimes (Assam) for getting in a second line of plants in *taungya* areas where the cultivators have not yet been educated up to close enough spacing in the first year. A large number of the commonly planted species can be grown quite well from stumps, thus teak, *sissu*, rosewood, *Gmelina*, *Albizzia*, *tun*, etc., but there are some notable exceptions such as sal, *Hopea* (most localities), *Magnoliaceae*, and many *Anacardiaceae*. Climate is an important factor, dry climates being much more difficult.

It has been stated that the use of stumps is likely to result in stem or root rot, but all available evidence indicates that this is not so, rot being no more prevalent in plants raised from stumps than entires ; it is possible that the oaks may provide an exception to this generalization. [41]

Stumps have often been successfully used where direct sowings and entire plants have failed, both on saline soils (*sissu*), and in wet ground (*Terminalia tomentosa*), owing to the deeper rooting in a less saline horizon in the first case, and the avoidance of risk of rotting of the seed in the second.

In Europe, intermediate stages between stumps and entires have been used in the form of plants heavily pruned in root and shoot leaving a varying proportion of the root and stem systems. The root pruning may be done while the plants are still in the beds by pushing in a sharp spade horizontally from the side of the raised bed. Oaks are amenable to this treatment, which has nowhere been applied in India on any scale, and does not appear to have any advantages under our conditions.

Branch and *stem cuttings* have only occasionally been successfully used in forest practice. Casualties tend to be very high even after a promising looking start, but *Tamarix articulata* is successfully propagated in this way in the irrigated plantations, willow in the Kashmir plantations, Lombardy poplar in Ladakh and Central Asia generally, *Ailanthus glandulosa* in the Gallis, N.-W. Frontier Province, *Bombax* in Assam, and *Poinciana elata* in Madras. Figs, *Erythrina*, *Larnea*, *Broussonetia*, etc., which are sometimes required as shelter to a more valuable crop, have also been reported as suitable. Size of material and season of work are important and vary with species. Large stakes or posts of these trees sometimes give better results than smaller material, and the best time for putting them in the ground appears to be before their usual time for leafing out, not during the monsoon as might have been anticipated.

Sections of roots will sometimes strike successfully, and may present a practicable method of regeneration in a few species ; thus sections of the taproot of *Bombax* and *Stereospermum* seem to take as well as the stumps prepared from the same plants.

Mixture of Species in Plantations

Advantage of mixtures

This subject has already been touched on p. 183. Although it has long been admitted that on theoretical grounds at least it is

PLATE 19. Alternate line mixture of *Alnus* and *Bucklandia*, Darjeeling, Bengal.

Gmelina plantation underplanted with *Dipterocarpus turbinatus*, Chittagong Hill Tracts, Bengal.

Facing p. 240

PLATE 20. Strip sowing of sal, one season old, in heavy grassland, Goalpara, Assam.

Facing p. 241

desirable to have more or less admixture of species in plantations rather than pure crops, especially of light-demanders such as teak, and although early efforts in this direction may be seen in various places, e.g., in the *Artocarpus hirsuta* in some of the old teak plantations of Travancore, experiments with mixtures have very rarely been a success.[11a, 49] Even in England, it has been stated that 'nearly all mixtures are risky'.[43] The commonest causes of failure have been lack of silvicultural knowledge of the species it was proposed to mix, resulting in unsuitable mixtures or method of mixing, and animal damage resulting in the destruction or severe check of some constituent of the mixture—as with *Gmelina*, or rosewood among teak. These failures have tended to result in the continuation of raising pure plantations with attempts to meet the objections by introducing an underwood naturally or by planting at a later stage—again not very often successfully. Attention is now again being given to the subject and many experiments are in progress.

Methods of mixing

The chief methods of mixture are by alternate lines (rarely satisfactory ; *see* Plate 19), alternate strips of different widths, and groups of some other species in a matrix of a major species. Various combinations of shade-bearers, partial shade-bearers and light-demanders have to be tried, and the time of introduction and relative spacing introduce further complicating features. A mixture of teak and *Xylia* in alternate lines is said to be gaining popularity in Burma, reducing the urgency of early thinnings and resulting in a better stem form for the *Xylia*.[13] The same method of mixture has been successfully used in the N. Bengal hills with alder and *Bucklandia* or *Cryptomeria* (Plate 19).

Mixed line sowings of certain species are looking promising in several provinces, and given a correct tending technique seem likely to meet requirements as well as anything that has been tried. Group sowing and planting, with groups about 50 yards square, have been recommended for mixed coniferous forest in the Punjab.

It is the general experience that it is best to keep mixtures in timber plantations as simple as possible and to have one species definitely receiving chief consideration. Deviation from these principles generally leads to confusion in tending at some later stage.

Cover Crops

General notes

By cover crops are understood crops of subsidiary species usually low shrubs but on occasion small trees or even herbs, intentionally introduced into a plantation with the primary object of restoring a cover to the soil as quickly as possible, and so minimizing the known deterioration consequent on exposure. The cover crop should thus check surface erosion and restore humus to the soil, and crops of the best habit and species for these purposes are constantly being sought by planters of tea, rubber and other economic crops, foresters tending to profit from the result of their experiments.

Tephrosia candida

Leguminous shrubs appear most promising, and of these *Tephrosia candida* (*boga medeloa*) has been most used in forest plantations, especially in Bengal and Assam. (*See* Plate 18.) An important additional advantage of the use of such cover crops is that the ground between the tree lines is occupied by a plant selected for its properties instead of by undesirable weed species, or still worse by climbers or grass. Full knowledge of the rate of growth and habit of an intended cover crop is necessary before it can be introduced, or the results may be the reverse of beneficial to the tree crop ; thus *Tephrosia* must not be introduced in the first year of a sal plantation, but should be for *gurjan*. The best time for sowing is usually with the last field crop with *taungya*, or in the second year with departmental plantations, but it may be advisable to get it in earlier where it is required to give shade the next hot weather, as with *gurjan*, *Artocarpus*,[30] and *Lauraceae*. Cover crops such as *Tephrosia* have in any case to be carefully watched to ensure that they do not suppress the plants, but are trimmed or cut back as necessary. A common practice with *Tephrosia* between sal is to cut it back to 6″ from the ground at the beginning of the second or third growing season (depending on its vigour), and in the following seasons, if necessary, cutting rather higher each time as the new shoots are mostly from the green wood ; in some localities topping and trimming are preferred.

Other cover crops

Other species worth consideration as cover crops are *Tephrosia purpurea*, *Indigofera tinctoria*, *I. endecaphylla*, *Crotolaria juncea*, *Mimosa* and *Desmodium* spp.[44] It should be remembered that most of these green cover crops are turned into the ground in rubber and tea estates, where many others have also been used, including *Phaseolus*, *Dolichos*, *Centrosema*, *Clitoria*, etc., which on present scanty evidence are unsuitable for forest work, mostly on account of their climbing habit. Napier grass (*Pennisetum purpureum*) a tall useful fodder grass, has been tried successfully in Bengal, but requires frequent cutting and is liable to be browsed badly by game—it is really more a *taungya* fodder than a cover crop.

Leucaena glauca should be mentioned as another important cover crop, though hitherto not much has been done with it in India. It is a much bigger plant than *Tephrosia*, and itself can yield fuel ; it has been used as a part of the standard teak plantation routine in Java[12, 45] with good results. Its feeding roots are mostly below those of the teak, and so its root competition should be relatively slight, and it improves the physical properties of the soil and the growth of the teak. On good soils, there is now a tendency to prefer a mixture of *Leucaena* and jungle regrowth, but on poor soils its superiority is pronounced. Like all cover crops, it must be cut back periodically as the tree seedling growth requires.

Lantana undergrowth

The effect of a *Lantana* undergrowth on teak in Java [42a] has been found to be definitely detrimental, reducing crop increment by 33 per cent.

Experiments in India in this subject have been in progress for a number of years but sufficient time has not yet elapsed to be definite about the magnitude of the detrimental effect.

Accessory tree species

Certain accessory tree species have been used in much the same way, thus *Stephegyne diversifolia* (*binga* [5]) and *Anogeissus acuminata*[13] broadcast in teak *taungyas* in Burma, but this practice has not become widespread. *Adina cordifolia* and *Lagerstroemia flos-reginae* have been sown successfully under similar conditions both with teak and with *pyingado* (*Xylia* [11c]). The experimental sowing of rosewood with teak in parts of Madras may be mentioned in this connexion.

Effect on soil moisture

It is sometimes mistakenly deduced that a cover crop must conserve moisture as the surface of the ground often appears moist beneath it. Actually it usually transpires more water than would be evaporated from a fallow surface, and so may be detrimental in drier climates and soils. Any comparison should however be made with the growth which would otherwise take its place, and the indirect advantages it confers in improving the physical and chemical properties of the soil, in giving shade to the tree seedlings, and in keeping out injurious grass and other weed growth, usually far outweigh this occasional disadvantage. Exclusion of *Imperata* grass is usually one of the chief objects in introducing cover crops..[46]

Methods of introduction

The usual method of sowing a cover crop is in a single strip centrally between the seedling lines, of a width varying with the conditions, tending to be wider on the poorer sites, where broadcasting the whole width may be substituted. Locally, a drill on each side of the seedling lines is preferred. In general, dense sown lines are much easier to deal with than the branchy plants resulting from thinly sown lines or broadcasting. Soil working and even weeding may be necessary to establish a cover crop, but the expense may be justified by results. The mistaken idea that these cover crops require no attention whatever is very widespread.

UNDERPLANTING

General considerations

In Europe, the underplanting of pure crops of light-demanders such as oak has been much advocated and practised, on the grounds that it prevents the deterioration of the soil which would otherwise take place, and makes fuller use of the productive capacity of the site. In more recent years, however, evidence has accumulated showing that the claimed benefits are only to be reaped under the right conditions, and that elsewhere underplanting may have a definitely detrimental effect on the overwood, evidently through its root competition.

Execution

Underplanting cannot be attempted in a plantation till the canopy has lifted sufficiently to let in enough diffused light to permit of the growth of the new planting, and a fairly heavy opening is usually necessary. Most Indian experiments have failed to realize how essential this is and the work has failed for this reason. In a series of experiments in Java, [12], [42a] the teak was opened out to only about 100 stems per acre at an age of 15 years, the cleaning of the boles being left to the new underwood.

Establishment difficulties

Underplanting is nearly always a more difficult operation than original planting, the reduction of weed competition being more than counter-balanced by the slow growth in the relatively weak light.

Underplanting teak plantations

The practice has naturally been applied to teak as a pronounced light-demander, and many attempts have been made to introduce an underwood to teak with very little result. An extensive series of systematic tests in Java, [12, 42a] showed clearly that there, though the underplanting was successfully accomplished, it resulted in every case in a loss of increment to the teak and therefore was not an economic proposition. These experiments do not cover a sufficient period of time to show whether the check of surface soil erosion, which the underplanting should also bring about, may not in time justify its cost by preventing a loss of increment from this erosion, but it would probably still be true that the natural regrowth obtained at no cost would be just as effective.[48]

Bamboos with teak

From the observation of the frequent association of good teak growth with a bamboo underwood, it has been deduced that it might be helpful to encourage or introduce bamboo beneath teak plantations, and various experiments are in progress. On the Javan data, the shallow-rooted bamboos would be expected to be harmful wherever competition for moisture was at all severe, but it is quite possible that in moist types of forest it may do what is hoped of it. (Cf. the Arakan procedure described on p. 190.) There are a few examples of the successful introduction of bamboo under teak, *e.g.*, *Cephalostachyum pergracile* in Katha division in Burma, from underplanting a 27-year-old plantation after a fairly heavy thinning. (See Plate 13.) More recent direct sowings have also been successful in Burma and Madras.[11b, 48]

Underplanting in mixed deciduous forest

Hopea parviflora has been extensively underplanted and sown under mixed deciduous forest in Madras, with the intention that it shall ultimately largely replace the latter. It has given quite satisfactory results at reasonable cost in some localities.

Underplanting valueless second growth

Crops of low value such as the *Macaranga*, etc., which come up naturally in clearings in wet evergreen forests, may be underplanted with more valuable species ; *Cinnamomum*, *Phoebe*, *Artocarpus*, etc., have been successfully raised in Assam under such a cover, which is thinned out when the planted trees are about 6′ high, and will be entirely removed when they are about 10 years old and no longer need any assistance. A similar type of growth of *Macaranga* etc., establishes itself in grasslands in Bengal and Assam with fire-protection, and though attempts to get up sal through it have hitherto failed, there are obvious possibilities in this direction.

Tropical evergreen species

Many of the more pronounced shade-bearers of the moist tropical evergreen forest including *Hopea* appear to develop better under shade in their early youth,[11e] and so might be underplanted below natural or planted crops of light-demanders, though all grow better with full light in their later stages. When such an overwood so underplanted is mostly or entirely removed later on, it is termed a ' nurse crop ' and is discussed in the next section. *Gurjan* has been successfully underplanted to *Gmelina* in S. Bengal [30] ; only a few trees of *Gmelina* may perhaps be retained to merge with the *gurjan* in the final crop. See Plate 19.

Irrigated plantations

Dendrocalamus strictus has been underplanted under 9-year old *sissu* in Chichawatni, Punjab, and it has been found there that mulberry can be introduced by sowing and planting under the shade of *sissu* though it is difficult to raise in the open.

Nurse Crops

General considerations

Nurse crops are those which are raised with the primary object of helping up a less hardy species, and are usually removed at an early stage as soon as they have served this purpose. They may be used for the benefit of shade-bearers as mentioned in the foregoing section, and they may also be desirable in localities in which ground frosts are experienced when the species it is desired to grow is frost-tender as a small plant. Such conditions prevail in many parts of Upper India, sal being frost-tender to this extent.

The value of a nurse crop capable of establishing itself in heavy grass, to be followed by underplanting with a more valuable species, suggests itself, and as has been mentioned, attempts have been made to use *Macaranga* for this purpose.

Tropical evergreen species

As the investigations aiming at artificial regeneration of the shade-bearing species of the tropical evergreen forest showed that some at least of them require or benefit from some degree of shade in early youth, experiments have been made to raise them under nurse crops of *Gmelina*, etc., sometimes with quite promising results ; thus *Dipterocarpus turbinatus* line sowings between 4-year old *Gmelina* lines started well, though the *Gmelina* had to be very heavily opened out from the start and will practically all disappear in a few years.[30] Patch sowings under a 2-year old plantation have also done fairly well. Latterly, however, it has been found possible and more expedient to make use of the shade of cover crops such as *Tephrosia* sown at a time suitable to ensure shade for the evergreen tree lines during the season they most need it.

Temperate forests

In the hills, birch and alder are available as nurses, as in Europe, but it is usually found preferable to raise them in mixed plantations with the species they are intended to shelter such as *Michelia* and *Bucklandia*, as being very rapid in growth they quickly form an overwood to the latter. See Plate 19.

Protection against frost

Castor oil has been tried as a nurse crop for frost-tender species. *Cajanus* (*arhar dal*) and *Tephrosia* are themselves not hardy enough to be of much use for this purpose, and it has been found that if they are dense enough to shade the ground heavily, they definitely increase frost damage.[35] Most frost-hardy species in N. India, such as *sissu* and mulberry, are leafless during the winter, and so cannot be used as nurses for other trees, and a serviceable nurse crop has still to be discovered.

Protection against insect damage

In Madras where mahogany suffers much damage from the shoot borer (*Hypsipyla robusta*) and the collar borer (*Pagiophloeus longiclavis*) general practice is now to grow the mahogany under a nurse crop such as *Trema orientalis* which is found greatly to reduce the incidence of attack. Both the nurse crop and the mahogany are regenerated artificially either at the same time or else the nurse crop is given a slight start.

Gap Regeneration

The artificial regeneration of small gaps, already present or created by fellings in forests under selection working, presents some special features necessitating modifications of the methods applicable to plantations.[11f] Such work used to be done in Madras, where gaps about 60′ square were planted up with 25 teak stumps at 6′ by 6′ after piling and burning slash and debris ; other species have been tried alone and round the teak but have given poor results owing to browsing and suppression by weeds. These patches were tended, usually by the beat guard, for the first two or three years, and then left to themselves, the intention being that ultimately one or two trees would take the lead and restock the gap. The method has however largely been given up both in wet evergreen forest and in mixed deciduous forest as it has been general experience that such gaps cannot compare with small plantations from the aspects of silviculture, management or finance.[61]

Replacements

Hundred per cent successful stocking from the first sowing or planting out is rarely attained except with the more elaborate methods or with stumps, and the casualties have to be replaced to give good results. The sooner this ' infilling ' or ' beating up ' is done the better, and as most of the deaths occur soon after planting or sowing, it is often the best procedure to effect replacements in the first planting of the season as soon as the last is completed : in any case it is necessary to do it by the end of August in most localities as plants put out later have little chance of survival. It is a good practice to have a small nursery close to each cultivator's *taungya* house, from which replacements can be made directly failures are noticed. Where sowing or mixed sowing and planting is done, surplus plants from well-stocked patches are used for filling blanks elsewhere. As noted before, stumps are on occasion useful for filling work. The mistake is sometimes made of filling up blanks in a plantation with a different unsuitable species which will not blend with the original major species—thus the fire-tender strong-growing *Michelia champaca* among the hardier and slower sal.

It is rarely worth going on filling up casualties after the first year or at latest the second : most of the replacements fail to survive, as the original causes of failure probably persist as a further handicap beyond those attendant on delayed planting, and an occasional blank stake is of no significance after a year or two. The aim should invariably be to make the plantation a success in the first year, for the more that has to be done later, the poorer the end result and the more it will have cost. There is a dangerous tendency in some *taungya* plantations not to pay much attention to getting the best possible start, on the grounds that the cultivators are under agreement to do all necessary filling in their second year before vacating the area ; the result is inevitably a far lower standard than might be attained.

Sowing v. Planting

It is now possible to compare the relative merits of the two chief methods of artificial regeneration. Sowings present the advantages of quickness and cheapness of the work, the absence of interference with the roots and the consequent check on growth, and the ease with which any desired mixture can be introduced ; against this must be counted the large amount of seed required ; the ease with which sowings may be smothered by weeds or destroyed by animals, insects, and damping off in the early stages, and the often slower development as compared with plants given an early start and every attention in the nursery.

Planting is, as a rule, a surer operation, using the minimum number of plants required to stock the area and so permitting of individual care, and the plants are given a valuable start in their struggle with the plant and animal factors of their new environment : many species which are difficult to raise from seed, including those with slow and irregular germination, can be easily raised by planting out from a nursery, and the same applies to the stocking of difficult sites. Against this has to be set the almost invariably higher cost of planting (incidentally far less marked in *taungyas*), the poor results with certain species such as *Amoora*, *Artocarpus*, and *Xylia*, the greater demand for labour, the greater skill needed, and the need for maintaining nurseries.

Conclusion

It may be concluded that sowings should ordinarily be done wherever they have been shown to give as good or nearly as good results as planting, whilst planting should be resorted to for difficult species and sites. Stump planting combines several of the advantages of both methods and is recommended for adoption with suitable species where the high percentage stocking and rapid development it can give, combined with its cheapness, give it advantages over entire planting or sowing.

WEEDING

Importance of weeding

Although the soil is cleared of weeds before sowing or planting is done, it is not long before they spring up from seed or rhizome fragments, and regular and efficient weeding is one of the most important factors in the success of a plantation. As in the nursery, the first weeding of sowings should be as soon as possible after germination is more or less finished, and thereafter as often as necessary to keep them free from undue competition. Only rarely is it advisable not to weed, as for chir pine and *Pterocarpus marsupium* in grass, and in patch sown deodar on exposed sites where exposure may be more harmful than competition. It is however definitely possible to overweed so that the seedlings suffer from mud splash, root exposure or insolation, and the work may require check by observation of the reactions. When first weeding small seedlings such as *Terminalia myriocarpa*, it is sometimes better to cut the weeds, as uprooting them is liable to uproot the seedlings also.

Weeding full plantations

Very little extra work is required in *taungya* areas where the plants get weeded with the agricultural crops, and the chief thing to watch is that the latter themselves are not allowed to smother the seedlings. The position is rather different in the absence of *taungya* crops, and regular weeding is necessary at least twice and often three times in the season, and it is usual to keep a gang continuously employed working round the area : it is here that cover crops offer the greatest field of usefulness. In older plantations in the hills, one weeding a year in July or August for 3 or 4 years suffices, except on cool slopes with heavy weed growth where two weedings are needed, in June and August. Bamboo clumps which have not been killed in the burn must be carefully watched and dealt with ; systematic removal as low as possible of all new shoots is usually effective. Unnecessary work such as cutting down all growth between the planted trees when it is unlikely to do any harm is not infrequently done, but should be avoided.

In some teak plantation areas where weed growth is serious as many as six or eight weedings are sometimes necessary in the first season.[49]

Weeding cleared lines

Still more in need of attention are plantations in which the interspaces between plants or lines of plants are not cleared or cultivated, and carry a heavy weed growth from the start. Two or three weedings are essential, and care must be taken that the removal of soil with the weeds does not result in lowering the soil level round the plants.

Value of soil loosening

The additional benefit of the soil working involved in uprooting weeds, as compared with weed cutting, has been the subject of experiments which indicate that local experience is necessary, as sometimes the gain is considerable, whilst at other times, perhaps mainly with light soil and only moderate weeds, it does not help much though costing considerably more. A marked gain can be seen in the Bengal *taungyas* where growth may be 50 per cent better with Garo cultivation than with the much less intensive working of the Madeshias. On the other hand, it has been found in Madras on good teak soils, that severance of the weeds just below ground level ('scraping ') is as effective as full digging and far less expensive, saving Rs. 3 to Rs. 5 per acre for each operation.[12] As with other early stages in artificial regeneration, it is a mistake to over-economize, and all should be done that definitely promotes regularity and quick closing.

Use of mulches

During the dry season and on dry sites, it is often helpful to small plants if the surface is covered with a ' mulch ' of easily decaying vegetation such as *Ageratum* or the finer grasses, cover with soil ; even a layer of fine loose soil reduces evaporation losses. Under certain conditions, as with line sowings, special cultivators such as the Planet Junior are useful, but have rarely been used in India.

Thinning out crowded sowings

In dense sowings, the plants should be suitably thinned out at a fairly early stage, when it is easily and cheaply done. In coniferous plantations, it should be remembered that dense regeneration is liable to be wiped out by fire where plants spaced well apart may survive. On the other hand, in moist tropical forest it is recommended that strip sowings should be kept rather dense till they are safe from weeds and grass (*Terminalia myriocarpa* in Assam). This thinning out is particularly important in the dry areas.

Duration of weeding operations

The number of years during which intensive weeding has to be continued under different conditions and for different species can only be determined by experience. With *taungya* plantations, the most usual procedure is for the cultivators to hand over the area after a final thorough weeding at the end of the second year, and with fast-growing species very little tending is necessary for the next two or three years, though a careful watch has to be kept for climbers. In departmental plantations at least one weeding is usually needed in the third year, and this will generally hold for all plantations of slow-growing species or in poor localities.

Use of grazing

In many cases, as with deodar, light grazing may be helpful in keeping down weeds and should be permitted, as also the cutting of grass and bushes, as soon as the young plants are reasonably safe from trampling.

Special Measures against Climbers, etc.

Damage done

It is possible for well-stocked plantations to be ruined in a matter of a few months by a heavy growth of climbers, as with *Mucuna* or *Dioscorea* in sal strip sowings. These appear to get a footing about the third year, especially in *taungyas*, and to be able to multiply surprisingly rapidly.

Control methods

It has been found advisable to pay special attention to removing all climber tubers and roots possible before the labour leaves the area by paying a special reward or by other means, as it is very difficult to cope with climbers once they are established, the customary cutting back after much of the damage is done neither helping the broken plants very much nor reducing the incidence in the following year.

Where it is practicable, special sources of infection on the periphery of a plantation should be dealt with ; thus the fencing round a plantation should not be left festooned with dangerous climbers, and it may be worth while to eradicate isolated patches of dangerous species such as *Lantana* and *Eupatorium* adjoining a new clearing. It is largely on account of these pests that it is practically impossible profitably to restock a failed area till the regrowth is enough to give a clean burn for a fresh start altogether.

Eupatorium odoratum

This naturalized American weed, known as *Assam lota* or *blzat*, calls for special mention. It is liable to form almost impenetrable masses in open plantations and to scramble over and pull down young poles even 20 ft. high. Where it occurs, it becomes doubly important, if not vital, that the plantation should close up before this weed has become established, for it requires a good deal of light, and is unlikely to give trouble in a closed crop. It is not as a rule a practical proposition to keep a plantation entirely free from its seedlings where it is common in the vicinity, owing to its abundant minute wind-carried seed, but it is shallow-rooted and very easily pulled up, so that it can at least be prevented from flowering and seeding inside the plantation.

Lantana

This is another plant introduced from America equally dangerous in many of the drier parts of the country it calls for very similar treatment. With a good standard of work, it should never be allowed to get a footing in a new plantation during the first year or two, and thereafter should be unable to do so. If once permitted to get out of hand, above all in a poorly stocked plantation, the cost of dealing effectively with many of these pests becomes prohibitive, and it may be better to write off the plantation as a failure. Various methods of controlling *Lantana* have been tried including the introduction and encouragement of insects feeding on it and spraying with chemicals, a sodium chlorate spray having recently been reported from Madras as quite effective.[63]

GENERAL PROTECTION

Grazing and browsing

The possible need of fencing has been considered above on p. 210 and the necessity of constant patrol and maintenance in effective repair of all cattle-, game-, and rodent-proof fences must again be stressed. If gaps are left for even a short time, many animals may get inside the fencing, and with much cover even a well-organized drive may be inadequate to clear the area. It must be anticipated that breaches will occur in even the best-constructed fences, for elephant, rhino, and driven buffaloes or deer will get through or over any fence.

Insects, etc.

It is often possible to deal with insect outbreaks in plantations in their early stages before they have gained much headway, as they are likely to be noticed early, and control measures are relatively easy in regular crops. The same applies to *fungus* attack, and incipient outbreaks should be dealt with as they are in plantations of other economic crops. *Loranthus* is another pest which should be dealt with in this way directly it is noticed.

A particular case of the silvicultural control of insect damage is that of defoliation in teak plantations. Here much can be done by encouraging a suitable undergrowth from the very first stages.[48, 49, 50]

Fire-Protection and Controlled Burning

Fire lines, etc.

Owing to the capital sunk in them, special fire-protection of plantations is often advisable, the usual method being to burn a strip round the periphery or to burn the adjoining forest outwards from the periphery, additional internal lines or traces being maintained as required. Isolation strips of more or less fire-proof evergreens can sometimes be put down to break up a large inflammable area, and where a suitable species is available this practice is to be recommended. Evergreen acacias have been so used, particularly in South India.

Burning after first season's growth

In one or two districts (Coorg, Myitkyina) it is the practice to burn over the whole plantation at the end of the first season, stronger and more even growth being obtained by this practice. Obviously this should only be done where very clear proof of its advisability is available, and it is likely that a gain can only be shown where the first year's growth is a good deal poorer than it might be. Apart from the direct damage to the young crop, the great danger of a fire killing it back is the stimulus given to grass and climbers which may prevent recovery. It is usually best to cut back all seriously fire-injured parts of a plantation to get new clean shoots.

Controlled burning in young plantations

It is sometimes recommended for plantations as for natural regeneration to put a controlled ground fire (cf p. 169) through as soon as possible as a fire-protection measure where the fire risk is great, as often with chir pine and locally with teak and sal. Local circumstances will indicate whether this should be done, but it must be remembered that it is a question of a choice of evils, not the direct good of the plantation. The position is different with regard to burning through sal plantations in climates which are damp for the species, i.e., where sal is only a fire preclimax type ; here it is quite possibly desirable to burn the plantations at least occasionally to check progression to the much damper climax type in which sal does not remain healthy ; the matter is under study, especially in Bengal. Obviously the fire must be put through under suitable and controlled conditions as it is easy to injure the young poles considerably by too hot or untimely a fire. Burning of young teak plantations was for long a controversial matter, but it undoubtedly results in increased surface soil erosion and in the injury of the more superficial roots exposed by this erosion, and so has been dropped everywhere. It is also particularly damaging to the undergrowth which is so much needed for the control of defoliators.[48]

COSTS AND FINANCING

Costs of departmental plantations

It is difficult to get truly comparative costs for different plantations as the hidden costs may be anything from *nil* to several times the recorded cost. For departmental plantations, the true cost may be as low as Rs. 5 per acre for an easy type such as chir pine patch sowings. For fairly typical plains forests, Rs 25 to Rs. 50 per acre is about the usual range, of which Rs. 15 to Rs. 30 may be used for preparation of the area, Rs. 2 to Rs. 4 for the seed and nursery work, Rs. 2 to Rs. 6 for planting or sowing and Rs. 8 to Rs. 11 for tending. Of course on occasion the costs have been much higher, but anything over Rs. 50 calls for special justification. The Punjab irrigated plantations cost about Rs. 20 to Rs. 25 per acre. Teak plantation costs have been intensively studied all over India.[47]

Fencing costs

Fencing may be an additional item which should not exceed Rs. 20 per acre, including purchase of materials. Cf. p. 210.

Costs with taungya

Taungya work reduces the costs very greatly, especially where it is not necessary to pay any reward for established plants : only the fencing, if any, and the weedings and cleanings for a year or two after the cultivators have left the area remain to be paid for, and Rs. 15 to Rs. 25 is the usual cost.

Charges on revenue

In some districts it is the custom to require the timber purchaser to do more or less of the work of preparation of the felling area for regeneration work. Although it is true that he probably estimates his expenditure on this work and deducts it from his bid or tender, the work is probably more economically done this way.

ABSTRACT OF EXPENDITURE (Average per acre)

Notes
Av.—Average per acre.
T. Av.—Total average to the end of year.

Rajabhatkhawa Range, *Rajabhatkhawa* Felling Series

Year of planting	1926						1927						1928					
Wire-fencing	Rs. 17						Rs. 17						Rs. 17					
Species	Sal		Mixed		Bamboo		Sal		Mixed		Bamboo		Sal		Mixed		Bamboo	
Area in acres	40		10		4		18		22		5		60		45		15	
Year of work	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.	Av.	T. Av.
	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.	Rs. A.
1st Year	16 2	16 2	15 12	15 12	35 0	35 0	59 7	59 7	74 6	74 6	40 6	40 6	43 6	43 6	45 4	45 4	24 7	24 7
2nd Year	13 5	29 7	13 14	29 10	12 5	47 5	8 14	68 5	5 8	79 14	2 11	43 1	11 12	55 2	17 7	62 11	15 11	40 2
3rd Year	5 10	35 1	3 15	33 9	2 12	50 1	8 10	76 15	4 8	84 6	3 10	46 11	14 13	69 15	21 0	83 11	11 9	51 11
4th Year	6 8	41 9	3 1	36 10	5 12	55 13	17 0	93 15	4 11	89 1	0 6	47 1	6 5	76 4	6 4	89 15	9 12	61 7
5th Year	10 12	52 5	3 4	39 14	1 4	57 1	9 5	103 4	1 6	90 7	3 5	50 6	3 3	79 7	2 11	92 10	12 11	74 2
6th Year	4 12	57 1	..	39 14	7 11	64 12	5 8	108 12	2 0	92 7	4 11	55 1	2 13	82 4	2 8	95 2	0 7	74 9
7th Year	2 11	59 12	0 13	40 11	1 2	65 14	3 12	112 8	2 3	94 10	..	..	3 5	85 9	0 11	95 13	0 4	74 13
8th Year	1 0	60 12	0 9	41 4	..	65 14	3 6	115 14	0 13	95 7	3 3	58 4	0 12	86 5	0 13	96 10	4 2	78 15
9th Year	3 10	64 6	1 13	43 1	3 15	69 13	2 0	117 14	1 13	97 4	2 13	61 1	..	..	..	..	..	..

PLATE 21. (*Above*) Dry fuel forest, line sowings of *Cassia siamea*, Ayyalur, Madras. (*Below*) Line sowings of *Acacia arabica* with cotton, Hyderabad, Sind.

Facing p. 257.

Records

A full record of all work done and costs should be an essential part of all plantation work, and special forms have been devised and standardized for this. The Bengal forms are probably as good as any and an example of the abstract is given opposite. The clear representation of the total cost and the year to year changes render them most useful in controlling the work and in determining where economies may be effected.

The Dry Fuel Forests

Particular mention must be made of the artificial regeneration of the dry fuel forests of South India which has long been one of our outstanding and most difficult problems. These essentially local forests are vital to the villager for his fuel, small timber, agricultural implements, grazing, etc. and are usually worked on a simple coppice system on a 30 or 40 year rotation. It has been found that natural regeneration practically does not occur and at each coppicing there is a stool mortality of some 10 to 15 per cent.

In the last 15 years methods of regenerating these forests have been perfected.[47, 55] After the fuel felling, the slash is collected into lines or patches, compacted and burned and the new crop raised by direct sowing. Intensive soil working and thinning out of the seedlings in the lines are essential operations.

It took many years of both district and research work before the technique was perfected. Success in the work can only be obtained by paying great attention to the details of each operation in the early stages of the formation of the crop. Where there is land hunger the work is also done by *taungya* methods.

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VII

AFFORESTATION

General Notes

Extent of denudation

Although it appears that the vegetation climax throughout India, with the exception of the extremely dry desert tract in the W. and NW., is forest, the destructive activities of the population spread over several millennia have resulted in the present very uneven distribution of forested and deforested land. This is illustrated by the figures given in the following table.

Area of forests under Government control during 1940-41

Province		Forest area in square miles				Percentage of forests to whole area of province
Name 1	Area in sq. miles 2	Reserved 3	Protected 4	Unclassed State 5	Total 6	7
Ajmer-Merwara	2,367	73	..	..	73	3
Andamans & Nicobars	2,508	1,498	..	691	2,189	87
Assam	55,445	6,655	70	16,116	22,841	41
Baluchistan	52,925	1,745	..	473	2,218	4
Bengal	78,708	6,339	877	5	7,221	9
Bihar	69,348	1,355	662 312	2 1	2,332	3
Bombay	76,026	10,560 1,606	160 594	..	12,920	17
C.P. & Berar	98,573	19,432	..	3,642	23,074	23
Coorg	1,582	517	26	292	835	53
Madras	125,163	15,330	304	3,174	18,808	15
N.W.F.P.	13,099	266	..	12 182	460	4
Orissa	32,398	1,395	871	1	2,267	7
Punjab	96,830	1,487 505	3,209 63	823 214	6,301	7
Sind	47,155	1,043	92	..	1,135	2
United Provinces	106,248	5,241	527 8,075	432	14,275	13
Total	858,375	75,047	15,842	26,060	116,949	14
In round figures	858,000	75,000	16,000	26,000	117,000	14

(Out of the total Government forests, viz., 116,949 sq. miles, 23,763 sq. miles are not under the control of the Forest Department, but are managed by the Revenue Department, ryots, panchayats, municipalities, etc. Roughly, half of this is 'Protected forest' and the other half 'Unclassed' forest most of which is mismanaged and is disappearing.)

The actual position is even worse in many large tracts, as the residual forest area is concentrated in certain parts leaving the rest almost entirely without woodland ; thus in Upper India the forests are almost all collected in a strip along the foot of the Himalayan range, and in Peninsular India the forests are often limited to the more hilly tracts less suitable for cultivation.

Forest areas in other countries

For comparison with the managed forest area in India, below is given a table of the forest areas of some European countries most of which are much more settled than this country and in which scientific forestry started and has been carried on for centuries.[17]

Country	*Forest area as percentage of total land area*
Austria	38
Belgium	18
Czechoslovakia	34
Denmark	9
Finland	74
France	19
German Reich (including Austria)	24
Great Britain	6
Greece	19
Hungary	13
Italy	20
Latvia	27
Netherlands	8
Norway	21
Poland	23
Portugal	22
Roumania	24
Russia (European)	44
Spain	14
Sweden	23
Switzerland	55

Need for afforestation

The disadvantages to a rural population of the complete disappearance of forests are perhaps fairly generally realized. Until the last few decades, however, the initiative has been lacking for improving the position by reforestation.[17]

Canal colony plantations

In the extensive new colonies brought into existence by the great irrigation works of the Punjab and Sind, the need of rural populations for a proportion of woodland has been recognized, and the allocation of suitable blocks of land for afforestation here provides the best example we have in the country. Actually, these irrigation colony afforestation works differ from all others in that owing to the bringing in of water, the climate, at least the soil climate, is entirely altered rendering possible the raising of a type of vegetation far superior to that originally on the ground—in other words, the climax vegetation has been changed.

Counter-erosion work

Experience has taught that with India's climate characterized by heavy monsoon showers, denudation is almost always followed by serious soil erosion. This is to be seen everywhere in hilly country and under certain conditions is even more spectacular in the alluvial plains, as in the ravine country of the Chambal drainage. This has led to a second important class of afforestation work, viz. soil fixation and reclamation operations, of which we have examples in many parts of the country, e.g. in Etawah in the United Provinces, the Pabbi hills in the Punjab, the Bombay Deccan, and the plains of the N.W.F.P.

Afforestation of water catchments

Linked with this is the afforestation of the catchment areas of water supplies with the object of protecting these supplies and regularizing them, a forest cover and above all a deep forest soil being the best and cheapest means of effecting this. These supplies may be needed for domestic use (e.g. town supplies as for Simla), industrial use, or for generation of hydro-electric power (Jogindranagar, Punjab).

Æsthetic and hygienic value

In a more or less treeless country, the amenities afforded by a plantation of trees are quickly realized and utilized both for health and recreation, and it is certain that this will be more and more realized in India as time goes on, just as has happened in western countries. The supplies of good grass for stallfeeding, of smallwood for fuel, and of timber available close at hand, are all incentives to afforestation in any tract, urban or rural, where there is now little or no natural forest.

Plantations for matchwoods, etc.

In a few places, it has appeared an economic proposition to make plantations to meet special demands such as that for matchwoods, but it is very doubtful whether any extension of such work is likely to occur outside existing forest areas.

Afforestation of Cultivated Land

Available land

The question of the afforestation of fairly recently cultivated land arises, usually on a small scale, under various circumstances. In many forest reserves there are included patches of varying extent, often on the best soils and sites, which have been cleared of their forest growth for arable cultivation and subsequently abandoned; it is a common occurrence that such fields have been repeatedly cultivated in periods of pressure on the land and abandoned after war, epidemics, or reduction of population by any other means, or often merely because their fertility has fallen off. These isolated patches of cultivation in reserved forest are usually a great hindrance in forest management, and so are bought out, exchanged or acquired during forest settlement procedure, and their afforestation is desirable both to utilize the land, and to lessen the likelihood of a demand for their reoccupation. Precisely the same conditions may arise along the outer forest boundary where the inclusion and afforestation of small areas of cultivation may be desirable for the simplification of the boundaries, for more efficient fire-protection, etc. Less frequently the question arises of the afforestation of larger areas when the cultivated area of a forest village is abandoned or when cultivated land is acquired for the express purpose of raising plantations. Examples will be quoted in the following paragraphs.

Site conditions in cultivated land

Although it has not been fully realized till recent years, the most important site factor on abandoned cultivation is undoubtedly the radical change in soil biology as compared with a forest or a recently cleared forest area, consequent on the withdrawal of the annual contribution of humus, on the exposure and erosion of the top soil, and on the destruction of the normal structure of the upper layers by the processes of cultivation. Though Indian data are almost entirely lacking, it is known that many forest trees require to be associated with specific soil organisms for their satisfactory development, and these organisms are likely to be absent from soils which have been under agricultural cultivation for any length of time.

The physical properties of the soil may also be changed in a direction unfavourable to tree growth, particularly as regards drainage and aeration, and the difficulty is naturally increased where the surface has been terraced to hold up water, and perhaps intentionally puddled for rice crops.

The ground will also be full of the weeds of cultivation, varying with locality and soil. The present section will not deal with old cultivation which has been invaded by heavy grass growth, though as this may happen very quickly in some localities, the distinction is an arbitrary one.

The new plantation will have to be raised with full exposure to light and sometimes to frost and damage from wild animals. On the other hand, the soil may still retain some of the lightening effect of the cultivation it has received, and is likely to be of better quality than heavy grassland or worn-out grazing land.

There can be no question but that the planting up of old cultivation which has been lying under grass and weeds for some years, and perhaps continually trampled by grazing cattle, is a far more difficult proposition than the raising of plantations on recently cleared forest land : that this is so can be deduced from the frequent failure of natural regeneration to re-occupy such sites in gaps in the forest even after a period of 50 years or more.

Soil preparation

The extent to which special soil preparation will be necessary will largely depend on the period which has elapsed since the last agricultural crop, and it is obviously, a great advantage if the forest crop can be introduced immediately the land goes out of cultivation, though this is rarely possible. As noted, weeds will already be in occupation and harmful grasses are particularly likely to give trouble. If it can be arranged to carry straight on from agricultural occupation to *taungya* plantation, the work stands for greater chances of success and may be done far more cheaply, so no chance of this should be missed. A still further help is sometimes possible where irrigation facilities may be available to get the new tree crop started, and any reasonable additional expense for this purpose will usually be amply justified. Special attention must always be given to ensuring adequate drainage, and all old irrigation blanks must be thoroughly broken through, and old terraces at least eased off ; omission of this work spells failure, at least partial. Where *taungya* is not possible, strip cultivation is often the most satisfactory method. Ploughing can usually be done, and under favourable circumstances, including a sufficiently large area to be dealt with, the use of mechanical tractors calls for consideration. If grass is already heavy or to be feared, the ploughing should be done at such a time that the grass and weed roots turned up will die during the hot weather and can be thrown out at the time of sowing or planting.

Choice of species

As a rule, the species used for this class of afforestation work should be the hardiest and most easily raised local indigenous species, especially those which are known to stand exposure and belong to a rather earlier stage of the local natural succession. In view of the special difficulties, a mixture is on the whole preferable to a pure plantation, unless there is an obviously suited species available with advantages over all others. In the sal tract of Upper India, sal *taungya* may appear most attractive, or on younger or lighter soils, a mixture in which *sissu* and *khair* largely predominate. Observation of the species which naturally recolonize such abandoned cultivation will often provide a suggestion as to species likely to succeed ; thus in the W. Himalayas it would be noted that chir and blue pine are more suitable than the other less hardy conifers. Often a weed species first re-occupies the ground only to be followed later by useful trees, as with *Wendlandia* in abandoned coffee estates in the south.[2]

Method of stocking

With the ground whole-cultivated or ploughed in strips, any desired method of sowing or planting is possible, but on the whole, strip sowing is most likely to succeed : at the same time, staking at the appropriate spacing and planting up with entires or stumps may be just as good or better. Irrigated lines will sometimes be made, and as already stressed, adequate drainage must be continuously assured.

Tending, etc.

Weedings and cleanings will be required as in artificial regeneration work on forest soils : climbers are likely to be less abundant but grass may give even more trouble. It is a common occurrence for the plantations to make a good start owing to the soil working, but to fall off considerably later on as the soil recompacts and the biological deficiencies begin to make themselves felt ; the reasons are not yet understood, but it also seems true that plantations raised on old cultivation tend to be more liable to contract fungoid and other diseases than those made on forest land. It should be considered that such plantations have fulfilled one of their chief functions if they have restored to the soil its former characteristics, even if their timber outturn is poor.

PLATE 22. Farm forestry. (*Above*) A road avenue and windbreak of *Dalbergia sissco* and *Acacia arabica*. The cotton stalks are used for fuel. (*Below*) A farm wood lot. Both photographs, Denisat, Sind.

Facing p. 264.

Farm forestry

In recent years more and more attention has been turned to the forest needs of agricultural land. This work has come to be known as *farm forestry* and has been defined as 'the practice of forestry on farm lands, generally more or less integrated with other farm operations'. From the economic point of view every farm should be self-supporting for its fuel, timber, grazing and fodder for its animals, and manure leaf for its fields. Every farm is also dependent on the indirect benefits of forestry for its protection against damage to the crops by winds whether hot, cold, or desiccating, or destruction by storms and the hail and snow they bring with them, and against erosion, whether sheet erosion by wind or gully erosion by water.

A balanced farm forestry policy is important in lands and climates which are completely suitable for agriculture but it becomes of vital necessity in what is commonly called marginal farm land, i.e. the lands and climates which are doubtfully suitable for permanent agriculture, and where bad farming may exhaust the soil and render it unfit for cultivation in a comparatively few years. This process is usually accompanied by wind and water erosion and the last stage may even be desert.

The general opinion is that for efficient management some 10 to 15 per cent of the farm should be under forest. This includes shelter belts and wind breaks, live hedges, and the 'farm wood lot' which should supply local timber and fuel needs and grazing.[18]

As in India most farm land is treeless or nearly so the subject is most suitably dealt with under afforestation.

Afforestation of Grassland

Grasslands available for afforestation

As noted above, heavy grass growth often invades abandoned cultivation, even making recognition of its real origin difficult. Grassland also comes into existence on both the old and new alluvium of the great Indo-Gangetic plain as a result of biotic factors, notably fire, grazing and fellings, preventing the normal succession to closed forests, and its afforestation is sometimes undertaken. Such grassland is conspicuous in the moister parts of the sal belt, extensive tracts that might carry this type of forest being at present under heavy savannah grass, e.g. the higher *phantas* of Kheri and *chaors* of Haldwani in the United Provinces. A different type of grassland is met with in the hills of southern India, where subtropical or montane temperate forest appears to have been destroyed and its place taken by grass, the natural recolonization of which is almost entirely prevented by burning ; this grassland apparently partly owes its existence to the extensive clearing for economic crops, notably coffee, during the last century, but in part at least to the gradual extension by fire of originally small clearings made by the aboriginal population now dependent on grazing. In the W. Himalayas, fairly extensive grassy slopes are encountered, nearly always on steep dry southern exposures, which probably likewise owe their continued existence to periodic fires.

Site conditions in grassland

Grassland presents the same conditions as old cultivation in respect of the full exposure and the unsuitable biological conditions of the soil. Aeration and drainage conditions may be the same or not, but the continued occupation of the soil by grass usually seems to render it additionally unfavourable for tree growth, though sal provides a contrary example in that it appears able, in some districts at least, to establish itself better in grass than under a forest cover. Many grasses, among which *Imperata* stands foremost, form a very dense mass of roots and rhizomes close beneath the surface which appears to check aeration, and to deprive the deeper layers from all benefit of light rain and subsidiary sources of moisture. Many possess extensively ramifying rhizome systems which are very difficult to remove effectively even after extensive cultivation, as any fragment is capable of developing into a new plant: such are the *kunda* grass (*Ischæmum filosum*) of the cotton soils of Berar, and various species of *Andropogon* in the sal belt. Owing to these characters of grasses and their typically rapid and dense growth exceptionally inimical to tree growth, thorough weeding becomes more than ever essential and expensive ; it also often introduces an additional factor of greatly increased fire risk, the grass itself, being an annual growth, taking no harm from the burn or even being invigorated by it, making conditions even more difficult for the new shoots of the burnt saplings. Grass is also more liable to harbour vermin such as pig than more open growth.

Soil preparation

Patch cultivation rarely succeeds in grassland, and strip cultivation is very generally necessary. Opportunities for mechanical ploughing arise, and it has been done in several localities in the

Gangetic plain ; such ploughing should be deep and may result in eliminating much of the grass. The strips must be fairly wide or the grass on the interspaces will cover them over ; it is possible to plough or work a rather narrow strip, say 3′, if the grass is kept well cut back on each side, but it is usually better to work a wider strip wherever the grass is tall like the 12′ grass typical of the Tarai tract. In Assam, the prepared strips for sal sowing are made only 2′ wide with interspaces 6′ wide.[3] The soil working is best done before the hot weather, and reworked by hand removing all grass roots shortly before the sowing is done : this latter operation must be thorough if the work is to succeed.

In hill grassland, whole cultivation with *taungya* cultivation of potatoes or buckwheat is sometimes possible, but usually patch planting or sowing is done, the grass not being so tall or fast-growing as in the tropical plains.

The grasslands of the South Indian Hills, where the grass is usually of a shorter type, are much easier to deal with and simple ploughing is usually sufficient for the introduction of Eucalypts and wattles.

Choice of species

If expenses are to be kept down to a reasonable figure, it is essential in afforesting grassland to use fast-growing species which will quickly form a closed canopy and kill out the grass. Grass growth exerts so inimical an effect on tree growth that the latter must be kept free of it for proper development, and keeping plants clean weeded of grasses is difficult and expensive, so that the period during which it is necessary must be made as short as possible. For this reason the raising of sal in the drier parts of its natural distribution, where it is very slow-growing at first, is not to be recommended, though it is quite successful (given fire-protection) in moister Assam.[3] See p. 144. In the United Provinces, strip line sowings of the species typical of the newer alluvium such as *sissu*, *khair* and *simal* are most suitable,[4] whilst in Assam, broad strip sowings of *Terminalia myriocarpa* with various subsidiary species such as *Morus laevigata* and *Lagerstroemia flos-reginae* have given good results[5] ; most of this work, however, is done on cleared forest land.

In the Nilgiris, the indigenous species of the temperate evergreen forest are all very slow-growing, and *Eucalyptus* has been effectively used instead, mainly the blue gum, but also the more valuable timber species on a smaller scale. Several of the wattles have also been successfully introduced.

Methods of stocking

Strip sowings have generally given the best results, mainly as they give a closed canopy more quickly than other methods. Even with fairly wide spacing, the plants are at least free from grass competition and shading in the direction of the lines.

Patch sowings or planting at stake are more suitable to hill grassland.

Nurse crops in grassland

Under some conditions, it may be possible and helpful to get up a cover of a nurse crop which is able to establish itself, or which it is possible to raise more easily and cheaply than more valuable species. There are not many trees which are capable of becoming established as a crop in dense grass, but much depends on the climate and the ecological status of the grass. In parts of Bengal and Assam, mere fire-protection may suffice to get up a growth of *Macaranga*, etc., which is capable of closing up and killing out the grass. By suitable methods, timber species can then be introduced which could probably never have been raised directly in the open grassland (cf. p. 144). Inconclusive experiments have been made to hasten this conversion by broadcasting the seed of *Macaranga* directly in the grass. This would be useless in recent sandy alluvium with quite different soil and grasses. *Wendlandia* and *Vitex* spp. have been reported able to establish themselves direct in heavy grass in certain localities.

Drainage

Grassland is often badly drained in the rainy season, and many attempts at afforestation have failed for want of appreciation of this fact, largely owing to the very different appearances during the cold and dry hot weather, and to the failure to realize the significance of the predominant grass species. Thus *Saccharum procerum* can be taken in the U.P. at least as indicating conditions too wet for sal (cf. p. 29).

Afforestation of Dry Tracts with Irrigation

Irrigated tracts

The outstanding examples are the irrigated plantations of the Punjab,[6] and in the Lower Indus tract in Sind now commanded from the Sukkur Barrage. The canal strips of the United Provinces are conveniently included here, though climatic conditions there are more favourable.

PLATE 23. Afforestation of desert land with irrigation. (*Above*) The scrub cleared and trenches dug, Chichawatni, Punjab. (*Below*) Plantations of *Dalbergia sissoo* (*L*) and *Acacia catechu* (*R*) after three growing seasons, Khanewal, Punjab.

Facing p. 268.

PLATE 24. Afforestation of coastal sand with *Casuarina*. (*Above*) Seaward edge of a plantation 9 years old, Puri, Orissa. (*Below*) A 10-year old plantation after the second thinning, Karwar, Bombay.

Facing p. 269.

Site conditions in irrigated desert land

The country taken up for this afforestation work is mostly thorn scrub locally known as *rakh*, in which *Prosopis spicigera*, *Capparis aphylla*, *Salvadora oleoides* and *Tamarix articulata* predominate. It has generally been heavily grazed, browsed and lopped. The rainfall is from 15″ downwards, mostly from the summer monsoon in July-August, and the plantation work depends entirely on the canal water supply which is mostly only available from 1 April to 15 October, the amount being limited to 2½′ (Changa Manga) to 4′ during the year. The ground is fairly level, being all alluvium, but naturally shows higher and lower variations of importance in organizing effective irrigation : locally mounds of blown sand occur.

Soil

The soil is mostly sandy or clayey loam, 4 to 20 feet deep, overlying pure non-retentive sand. Sometimes there is a layer of stiff clay at some distance below the surface which is helpful in checking the downward seepage of the water, and locally a limestone pan which prevents proper rooting of trees. Owing to the dry nature of the climate, upward movement of water tends to predominate, resulting in the concentration of soluble salts in the upper layers, and where this tendency is strong, highly saline patches of *kallar* soil are found on which growth is poor or absent till irrigation has remedied conditions. These *kallar* soils are loose and with a high content of sodium chloride and calcium sulphate in contrast with the hard, impervious and unculturable *rappar* soils highly charged with sodium nitrate. Some of the *kallar* is dark in colour and contains much sodium carbonate as well as chloride, and is even inferior to the white *kallar*. Along the canals in the United Provinces, there is a fair proportion of good loam soil, varying to clay and saline (*usar*) soils.

Frost

The tract is mostly subject to sharp frost in the winter, which severely limits the selection of species to be grown, and it is also exposed to violent hot dry winds during the hot weather which cause a good deal of windthrow and bending in the older crops, and intensify the damage consequent on any interruption of the water supply.

Soil preparation, etc.

For an effective irrigation organization, thorough levelling, removal of stumps, etc., is required, and this is accomplished by giving the area out to cultivation for a year or more before planting up, a step which not only results in this necessary preliminary work being done free of cost, but also brings in a considerable revenue (Rs. 12 per acre) to help balance the costs of formation. The laying out of the canal mains, *khals*, *pasels*, and trenches, is now standardized as a result of long experience,[6] and need not be described here except to note that the water is run from the *khal* into the smaller *pasels* which run parallel to it and 10′ away, and from the *pasels* directly into the trenches which are 90′ to 144′ long. A *pasel* is also dug all round each uncommanded patch of high ground, notably round the sand hills. Plate 23 illustrates these methods. The trenches are 1′ wide and 12″ or 6″ deep, the old method of flood irrigation having been almost entirely given up a wasteful of water and slow. At least in the new and young plantations, frequent shallow irrigation has been found to be far more economical in water, as well as better for growth and quicker to carry out, than the former practice of fewer and deeper irrigations. Trenches 6″ deep which can be quickly filled, requiring an amount of water equivalent to a depth of 3″ over the whole area (the *delta*), are now usual, and 12 such waterings are generally given, i.e. a *delta* of 3′. *Kallar* areas require more water, especially at first. It has however been found that this procedure results in too superficial a root system with risks from windthrow and drought.[16]

A 'berm' or flat ledge is left between the edge of the trench and the base of the ridge formed by the soil thrown out. In trenches which are 12″ deep, notches are sometimes prepared at intervals so that planting can be done at a lower level.

Choice of species for irrigated plantations

The pre-existing growth on the area can as usual provide useful indications as to the suitability of the soil for the various species which may be grown. *Prosopis* and *Capparis* indicate soils fairly free of salts and so suitable for most species, whilst *Salvadora* and *Tamarix* usually indicate poor *kallar* soil. The grasses also provide indications in the same way. As noted already, only frost-hardy species can be used, especially in the first crop, a measure of protection for the early stages being provided once there is cover on the ground. *Sissu* is practically the only species used in the initial stages, though *Tamarix*, *Acacia catechu* and *A. modesta* have been tried on a smaller scale. See Plate 23. Mulberry is even more frost-hardy than *sissu*, but cannot be raised with full exposure ; it has become most important as a filler and mixture with the *sissu*, over which it has several advantages both economic and silvicultural. Trials with a number of other species have not led to any important changes, but *Eucalyptus rostrata* is being used on an increasing scale with good promise.

Species suitable for canal banks

Along the canal banks in the United Provinces, fruit trees are planted on the best soils ; *sissu*, *Acacia catechu* and other species on the loams ; *Acacia arabica* on the milder saline (*usar*) soil ; and local wet patches of soil are planted with *Eugenia jambolana*.

Method of stocking

Formerly the *sissu* was all sown thickly along the berm of 12″ trenches. Up to a maund (82 lb.) of seed per acre was used until the drawbacks of the resultant dense hedge of competing seedlings were realized, and the amount gradually reduced to the 3 to 5 seers now customary. The use of stumps has gradually extended of recent years, till now only enough sowings are done to provide the required number of cuttings the following year, 1 acre of sowing sufficing to stock 10-15 acres with stumps leaving plants spaced 5′ along the original sown lines. Seed and sowing cost about Rs. 2 per acre. The best results are obtained by January-February planting where water is available, but the usual time for planting is April. The stumps are often prepared in February-March, and stored buried in pits till required, a practice not suited to the hotter southern plantations where too much sprouting takes place. Replacements can be done at any time, even upto the end of September.

Sowing cannot be done in *kallar* soils, but stumps, the roots from which can usually reach the deeper less highly salt-impregnated layers, can be successfully planted, and even after a poor start tend to improve as the watering leaches out the salts.

Mulberry comes in naturally, brought by the water and by birds in the 4th or 5th year of the *sissu* plantation, and its arrival is hastened by planting it along the *khals*.

Eucalyptus is planted when 3″-4″ high in bottomless pots, the seed being sown directly in the pots in a nursery, and watered by percolation : it appears to want rather more water than *sissu* and is liable to damage by termites, against which nicotine solution (as *huqqa* water) is found helpful.

Planting on canal banks

Along the canal banks in the United Provinces, *khair* and *sissu* are put out as stumps supplementing natural regeneration, which is often good, especially in the form of root suckers of *sissu* after the old trees have been felled below the surface. *Acacia arabica* is line-sown as also is *A. catechu* where fairly large areas are concerned, and *Eugenia* is planted on mounds.

Subsequent work, etc.

Sissu does not require a great deal of weeding, and in the first year 1, 2, or 3 weedings are done according to locality, nothing being required as a rule in the second year. It is however of great importance to keep out the *kana grass* (*Saccharum munja*) owing to its interference with the irrigation work, and the fire risk its presence involves : the cost need not exceed about as. 2 per acre per annum, though eradicating it once it has been allowed to get heavy is naturally a good deal more expensive.

It is found that the trenches require reopening over about a quarter of the area each year costing about Re. 1-4 per acre. Although proper designing of the mains and *khals* greatly reduces silt deposition, a certain amount of silt removal work is always necessary and must be done systematically.

Records

Maintenance of records of the work done is more important in these irrigated plantations than in any other type. Only from careful record of the amounts of water used and the area covered it is possible to control the work efficiently and to effect economies in the use of the water, for the water is the chief item of expenditure, amounting to about Rs. 100 per acre over 20 years.

Costs

It is estimated that with 10,000-acre units, the total formation cost (over 20 years) is about Rs. 4 per acre. It is not claimed that the plantations can give a higher direct revenue than is obtainable from agricultural use of the land, their justification being on grounds of general public utility ; they actually tend to require rather more water per acre than agricultural land.

Afforestation of Dry and Arid Areas

The afforestation of the dry and arid areas has been receiving increasing attention in recent years and in places has met with great success. The necessity for this work will be seen when it is realized that they occupy about one-third of India and that the Great Indian Desert and its surrounding desert conditions alone occupy about 200,000 square miles.[19]

The work usually consists of direct sowing combined with some form of contour trenching. Although it is only in its early stages, great success has been obtained in some areas, notably in the trans-Indus plains of the N.W.F.P. The commonest species used so far are *Acacia modesta*, *Prosopis juliflora*, *Nannorrhops ritchiana* and *Dodonca viscosa*. The essential conditions for early success have been found to be (*a*) complete closure to grazing animals such as camels, goats and sheep, (*b*) a contour soil working before sowing either by trenching or in lines 6″ by 6″ in section, (*c*) sow plenty of seed, sow it early and sow in contour lines. Do not broadcast seed, (*d*) work the soil in between the lines after each shower of rain but do not disturb the plants. *Never* let the soil surface cake, (*e*) keep down the weeds in the lines but do not disturb vegetation which appears naturally between the lines, (*f*) thin out the plants in the lines as and when necessary.[17]

Afforestation of Denuded Hill Slopes

Occurrence

Denuded hill slopes are encountered in all parts of the country, but there is not usually any demand for their afforestation in the moist tropical regions, where natural regrowth maintains a soil cover of sorts and the destructive effects of erosion are less apparent. The matter has become locally important in the drier parts of Central India, as on Chamundi hill at Mysore and in West Bengal, and is an urgent problem in the dry northwest in the Pabbi hills, the Salt Range and the Siwaliks. In the Himalayas, afforestation has also become important, especially in the chir pine zone, and though a great deal has not yet been done, it seems evident that in the future much more will be required. The chir pine plantations of the three north-western provinces, especially those of Kumaon, provide examples.

Site conditions

The chief feature is the exposure and shallowness of the soil consequent on the erosion of the greater part of the original depth ; sometimes only the surface soil has gone down the hill, sometimes the subsoil has gone too, leaving almost bare rock with only a little soil caught up in the inequalities of its surface, much depending on the nature of the underlying rock, the gradient and the climate.[7] Forest denudation has usually been associated with and followed by excessive grazing, and closure to grazing and effective protection is usually essential to effective afforestation. The full exposure to sun and drying wind limits work to the hardiest species, and may necessitate special planting methods and protection. The areas to be afforested are generally near centres of population, which renders protection more difficult but has certain advantages : thus the produce from the plantations is likely to be in keen demand, and even before they have come into bearing, they may bring in revenue from the good grass growth usually obtained on closure. The damage done to cultivation below the eroded slopes by the unchecked run-off, floods, deposition of sand, gravel and boulders is immense and notorious in the Punjab[8] and West Bengal.

Soil preparation, etc.

Denuded hill slopes are usually stocked by patch sowings or planting at stake. The soil is worked beforehand, regular spacing having to give way to siting on the best available spots. In exceptional cases, soil may even have to be brought in with the plants. Only local experience can show what is possible, as sometimes what appears impossibly rocky soil may still have cracks and pockets with sufficient depth of soil and moisture to support trees, whilst a much better looking site may prove to be worse. Where the subsoil is left, contour trenching is helpful, both in checking run-off and further loss of soil, and in providing suitable sites for sowing and planting work.

Choice of species

The surviving indigenous species will almost always indicate best which are likely to succeed, though some hardy species will have been exterminated if they happen to be good fodder or to be exposed to selective destruction in any other way. Often the chief problem is to restore the forest cover irrespective of species, as at Chamundi, and figs and the like may be the best to use, at least at first. Chir pine is a very hardy species fortunately well adapted to reclothing badly denuded and eroded slopes within its distribution. In the dry north-west, the indigenous *Acacia modesta*, *A. catechu*, *Olea*, and the exotic *Prosopis juliflora* have been mostly used. Higher in the hills, *Pinus excelsa* is obviously the best suited species, but is rather difficult to get up from seed or transplants. Under unfavourable conditions, as in the Punjab Siwaliks, full use should be made of hardy shrubs such as *Dodonea*, and grasses.

Method of stocking

Direct sowing is much the best method for the acacias, *Prosopis* and chir pine. Sowings, however, do not succeed with most other species under the severe site conditions in question here, and planting out of nursery stock is almost always necessary, extra strong well-rooted stock being required. Planting with a ball of earth is not usually practicable, but planting in special containers often repays the extra cost through the much higher survival (cf. p. 233). Shrubs and grasses are usually sown broadcast, but cuttings (*Ipomoea*) and planting (tufts of *Saccharum munja*) may also be successful.

Tending, etc.

As a rule, the sites are not very weedy, and weeds and grass are often cut for fodder, but owing to the usually slow growth, weeding may be necessary for several years. It must however be done with considerable caution, for the extra exposure may easily result in more harm than benefit being done to the small plants. Marked slowing off of growth even after a promising start must be expected when the growing plants require to draw on deeper soil layers which do not exist, and casualties in dry years are almost certain to occur. With stock naturally lacking in vigour, disease is also liable to work havoc ; thus *Peridermium* mortality is exceptionally high on the chir pine raised on the very shallow soils of denuded tracts in Kumaon. On the other hand, it not rarely occurs that after a long struggle for establishment, definite improvement sets in as a cover is created and the effects of closure and protection become apparent. The building up of any appreciable depth of soil is of course an extremely slow process.

Afforestation of Ravine Land

Occurrence of ravine lands

Where the larger streams deepen their beds in their own alluvium, the gradients for the run-off are increased and there is a strong tendency for gullies to form ; these steadily work back at their heads, eating their way into the alluvial plateaux or terraces and developing a tortuous ravine system. This process has taken place very extensively along the Jumna and Chambal rivers, where large-scale reclamation and afforestation work has been undertaken.[9, 10] Any causes which increase the run-off, chief among them being forest destruction, will intensify the process and make it the more difficult to check. It is stated that the area mentioned formerly carried thick high forest in place of the present thorn scrub, and that the destruction of the forest has been the chief factor leading to the ravine formation, but if this is true the climate itself must have changed, for the rainfall is insufficient to support anything better than transitions between thorn and dry deciduous forest even with a much higher water table : denudation and over-grazing must however have aggravated the position.

Site conditions

In the tract mentioned, the soil is all alluvial but naturally varies considerably, from sandy to stiff clay. It contains a good deal of lime which tends to occur as concretionary deposits of *kankar*, sometimes of considerable thickness and completely preventing the penetration of roots to the deeper layers. The average rainfall is low, about 30″, but down to 10″ in the worst years, and falls almost entirely as short heavy monsoon showers. These conditions favour erosion and ravine formation and also result in a tendency for the concentration of soluble salts in the upper layers, forming saline infertile soils. There is a shortage of water for all purposes during the long dry season, an important factor in connection with grazing facilities. Frost is experienced and may do much damage in some years.

Choice of species

As before, study of the surviving original flora provides valuable indications of possibilities, and disregard of these indications has not rarely led to failures after a misleadingly promising start. This largely limits one to the acacias over much of the area, with groups or patches of more mesophytic species including *sissu* on the deeper moister soil (usually the result of redeposition) on some of the lower ground. The exotic *Prosopis juliflora* has also shown satisfactory growth. Much of the earlier work was done with *Acacia arabica*, but most of it has died out or stagnated after several years of good growth, the reasons being apparently the severe frosts and the striking of the *kankar* pan referred to ; *A. catechu* var. *catechuoides* is rather hardier and largely survived in mixed line sowings where the *A. arabica* with it was killed back.

Soil preparation

One of the main objects of the work is to check erosion and in particular the constant working back of the heads of the ravines into the remaining level ground. This calls for the easing off of the gradients and the diversion of the water to allow as little concentration as possible, and operations to this end equally well serve the second purpose of retaining as much as possible of the limited precipitation in the soil for the benefit of the vegetation it carries.

The most effective method is contour trenches of limited length, so shaped and disposed as to catch the maximum amount of water and to allow any excess after they are filled to run off without cutting channels. The heads of the ravines are rounded off, and any surface drainage running into them diverted as far as possible. At the same time, the gradients of the smaller ravines are reduced by the construction of barriers of various materials. Experiments have been made with larger dams which might serve the additional purpose of holding up water for the drier months. The contour trenches provide prepared soil for reclothing the slopes of the ravines.

On the more or less flat tops, dry farming was practised with *taungya* methods, the necessary soil preparation for the forest crop being done by agricultural cultivators in return for the free use of the land for crops. Ridges gave the best results, with the soil deeply and thoroughly worked, and the maintenance of the soil in proper tilth was found to be of the greatest importance till the trees were well established.

Method of stocking

Line sowings have given the best results. The seed is sown in June shortly before the monsoon is expected, one species such as *Acacia arabica* being chiefly used, and other species added at suitable intervals along the line. If any planting is done for special species or as fillings, it must be done at the very first opportunity as the monsoon is very short, hardly extending beyond August. As noted, *taungya* methods proved best in caring for the weeding and keeping the soil in a well-worked condition.

Results of afforestation

Most of the work was originally done as a famine relief measure, for which it is excellently suited. The areas taken up have proved of very great value and brought in a good return from the fine growth of fodder grass which they produced. The afforestation work looked extremely well at one time, but has fallen off a great deal since owing to the combined effects of frost and drought after the crops had got beyond the stage in which the well-worked upper soil could suffice to meet their needs : the *kankar* pan undoubtedly contributed to the falling off in many places. On the better soils the plantations are still quite good, but in the poorer parts there has been a reversion to the original thorn scrub. From the point of view of reducing the rate of erosion and of fodder production, the operations have been a success, but it is now realized that the grass cover under protection can largely take care of this and afforestation can only add a fuel supply, the tract being unsuitable for timber production.

Afforestation of Loose Sand

Sand dunes

Blown coastal sand is encountered all round the coasts, especially near the mouths of the big rivers as on the sea face of the Sunderbans, near Puri, at various places along the east coast as at Nellore and Vellore, and along the west coast as at Karwar and Alibag in Bombay. Blown sand is also met with over considerable areas along the big rivers as exemplified by the *bhur* wastes of the Ganges in the United Provinces. Finally there are desert sand dunes in the Indus plain, especially the more southern parts of it.

The Great Indian Desert

The biggest example we have of blown sand is the Great Indian Desert of Sind and Rajputana which occupies some 100,000 sq. miles. This sand originates in the Rann of Cutch and blows in a north easterly direction. Recent survey research conducted in conjunction with the Survey of India has shown that in the last 50 years the desert has extended in a north and north east direction at the rate of about half a mile per year. This means that roughly at least 300 sq. miles of fertile land are being converted into desert every year. It is true that in recent years thin fingers of irrigation have also extended into parts of this desert fringe but in comparison with the general problem they are negligible.[17, 19, 20]

The desert itself in many parts contains a fair vegetation of such species as *Prosopis spicigera*, *Acacia senegal*, *Tecoma undulata*, *Acacia jacquemontii*, *Commiphora mukul*, *Euphorbia nerifolia* and *Salvadora oleoides* and it is only where local overgrazing occurs that the vegetation has gone and sand that has been fixed for centuries is on the move again.

The problem of the desert is in general one of control of grazing and it is only locally that the afforestation of loose sand is mainly needed. The problem of the north and north eastern edge of the desert, the desert fringe, is largely one of fixing the shifting sand by means of afforestation. There are many species that can be used and the reader is referred to current literature for details.[17, 19, 20, 21]

Site conditions

The instability and the excessive permeability to water constitute the chief characteristics of the soil in all cases, but the several occurrences mentioned differ greatly in the depth of the water table and in climate. As a rule, the sands of the seashore have a relatively high water table, sometimes only a few feet, so that open wells are quite a practicable proposition despite the looseness of the soil, and the water contrary to expectations is usually only slightly or moderately brackish. The atmospheric humidity is relatively high, and along most of the coast the rainfall is ample during the monsoon though it falls very low to the extreme west in Sind. Along the big rivers, too, the water table is not generally very deep, but atmospheric moisture conditions are much more unfavourable, both through the lower rainfall and the hot winds ; animal damage is also much greater. In the deserts, moisture conditions are so unfavourable that sandy tracts are usually excluded in the afforestation work, as most of them are uncommanded by the water supply, and in any case their consumption of water is excessive. In parts of the Great Indian Desert wells as deep as 800 ft. are used. The coastal sands are entirely free from frost, but the river and desert sands commonly experience winter frost, often severe, every year.

Soil preparation

In so loose a soil, no sort of soil preparation is called for, though coarse grasses may occasionally require thinning out in places—usually they are helpful in binding the soil and providing protection against sun and wind. Watering till establishment, which may mean until the roots have reached the water table, may be necessary, in which case a certain amount of preparation of the planting spots may be required. Temporary protection for the plants to be put out may also be needed against sun, wind, drifting sand and frost.

Species suitable for sand dunes

Almost the only species used on the coastal sands is *Casuarina*, which is as universal as is *sissu* in the Punjab irrigated plantations It is surprisingly quick-growing considering the site, and is hardy and relatively easy to raise. Many other species have been tried with it but are all left far behind, being checked by the hot salt-bearing winds to which they are exposed, and by the dryness and general poverty of the soil. *Calophyllum inophyllum* occurs naturally in such sites, but is very slow even with much more watering than the *Casuarina* requires. *Pongamia glabra* and *Anacardium occidentale* can sometimes be grown successfully. Coconut and palmyra palm (*Borassus*) can sometimes be grown in the shelter of the *Casuarina*, functioning as a wind break, as at Puri and in Tinnevelly.

Fixing blown sand

It is sometimes necessary or helpful to stabilize the sand to some extent with the help of *Opuntia* and *Pandanus*, *Calotropis*, and herbaceous species including creeping *Ipomoea* (especially *I. biloba* and *I. pes-capreae*), and soil-binding grasses such as *Spinifex* and *Aristida pennata* : *Caesolpinia bonducelli*, *Tamarix* spp., and *Clerodendron inerme* are also worth consideration for such work.[11, 17] Not much has been done in this way in India except for *Opuntia* hedges, nor with artificial barriers of brushwood, etc., as has been found necessary in other countries where drifting sand is a serious menace to cultivation.[12, 13]

Species suitable for riverain sands

In the *bhur* areas, *Casuarina* has been tried but does not do well, perhaps mainly because of frost and drought. *Sissu* and *Albizzia procera*, *Acacia arabica* and *A. catechu*, and *Pongamia glabra* are useful, with some admixture of the other species natural to young alluvium, provided they are frost-hardy. *Baib* grass (*Eulaliopsis binata*) has also been successfully raised. Afforestation is reported as not difficult unless the climatic factors are unfavourable, as unfortunately they usually are, frost being very prevalent.

Method of stocking

Casuarina is usually planted out at stake from nurseries, usually with naked roots but sometimes with or from containers. It is always watered for its first year, and where the water table is deep, for two or even three years. The planting is done in July when the plants are 15″-18″ high, and watering is done from January to June twice a week, about a gallon per plant in Puri. The cost is about Rs. 30 per acre in Puri and Madras, and Rs. 40 to 50 on the Bombay coast.[22]

Afforestation of other Special Sites

Landslips

In a few instances, as at Nainital, United Provinces, work has been called for on the stabilization of loose screes and prevention of further landslips. This involves a combination of engineering work and afforestation. Details cannot be given here of the former, which deals with the erection of fascines and solid barriers to hold up the loose material, but the importance of starting high up near the source of the trouble may be mentioned as it underlies most counter-erosion work, and is a necessary preliminary to the forest

PLATE 25. (*Above*) Sandhills in the desert fringe. Vegetation of *Acacia senegal*, *Prosopis spicigera* and *Euphorbia*, Dharbo, Sind. (*Below*) Arid area afforestation with *Prosopis juliflora*, Dera Ismail Khan, N.W.F.P.

Facing p. 280 .

part of the work. Afforestation may be commenced at once on the more stable denuded slopes, aiming at rendering them safer and providing centres from which stabilizing vegetation can be extended on to the unstable parts. It is also often possible to use green stakes for the fascines, especially of species such as poplars and alders which are known to be able to strike root as stakes, and sometimes to put such plants out directly as cuttings. Full use should always be made of the local shrubs, climbers, and grasses which observation on the spot show as likely to be helpful, both directly and as nurses or precursors to tree species. Effective protection against grazing, above all of goat grazing, is an essential without which afforestation work is certain to be a mere waste of money and labour.

In the Punjab, *Ailanthus glandulosa* cuttings 3½′ long with 2′ in the soil have been found useful, and *Aloe*, *Agave* and *Opuntia* have been found effective on active slips and at the heads of ravines.

Swampy ground

The necessity for adapting plantation methods, especially with regard to the species used, in the swampy portions frequently encountered in any large plantation area, has already been mentioned In the sal tract, *Lagerstroemia flos-reginae* and *Terminalia tomentosa* were recommended. In teak areas, *Lagerstroemia flos-reginae* (N. India and Burma) and *L. lanceolata* (S. India) are similarly useful, and it has been found in Madras that *Dalbergia latifolia* transplants survived flooding even better than the *Legerstroemia. Eugenia jambolana* can be grown on ground too wet for most other species throughout N. India, whilst *Barringtonia* will stand very long submersion. On very low-lying ground in Tharrawaddy, Burma, *Legerstroemia hypoleuca* and *Pterocarpus dalbergioides* have done fairly well in *taungya* plantations, *Terminalia tomentosa* and *Xylia* promising well on slightly higher levels. Planting or sowing on ridges and mounds provides the usual method of stocking, the object being to minimize the time the plants are actually submerged during floods, and to improve root aeration and drainage. It has been reported that *Barringtonia* has even been successfully planted out under 4′ of water in Sylhet.

Saline soils

Some notes have already been given on the special conditions offered by the *kallar* areas of the Punjab irrigated plantations, and it was seen that although *sissu* sowings were a failure, stocking was possible with stumps, and the growth improved in time as the excess salt was leached out by the irrigation. In the mild *usar* areas of the United Provinces canal bank plantations, *Acacia arabica* has been raised from line sowings, but the worst soils are left. In Unao district, it has been found that rigid closure to grazing during the rains suffices to raise the cut grass crop from $2\frac{3}{4}$ to 5 mds. per acre after three seasons, and continuous closure raised it to 9 mds., but there is no record of the amount of fodder cropped by the grazing animals before the closure. Extension of grasses over bare areas was found to be very slow.

It has recently been found that the addition of molasses, a waste product of the sugar refineries, to alluvial soils has a very beneficial effect in neutralizing the alkalis, especially if lime is added at the same time to flocculate the clay particles and improve permeability. The effect is much quicker than with the gypsum or sulphur formerly used—6 months as compared with 4 years to bring the soil into satisfactory condition, and good crops now grow on such land in the United Provinces and Mysore.[14]

Black cotton soil

The peculiar features of black cotton soil, particularly its deep cracking and impermeability, render afforestation work on it rather different from that done under other conditions. *Acacia arabica* is the best species to use, and line sowings the best method of stocking, but it sometimes suffers very severely from insect attack, and in any case some admixture of other species is usually desired. *Azadirachta indica* (*nim*) has been used a good deal, and does indeed do quite well from sowings, but it is very badly browsed. It seems quite possible to raise *Gmelina*, but it is equally badly browsed. *Prosopis juliflora* is reported to be promising.

Taungya plantations are the usual and most satisfactory way of afforesting these rather difficult soils with a long period of agricultural cultivation (Berar[15]). *Kunda* grass (*Ischaemum filosum*) is one of the chief troubles and needs continuous and thorough weeding to keep it from smothering the plants.

Laterite

There is much confusion in forest literature and practice between tropical red soils and laterite, but pronouncedly lateritic soils are far less suited to good tree growth, above all to teak, and their stocking is liable to prove difficult. This is particularly the case where they have been denuded, as laterite is given to hardening on exposure, and even with heavy rainfall to produce markedly xerophytic conditions most difficult for young trees. *Xylia* and mahogany are well known in S. India as thriving more than any of their associates on such soils. They are likely to outgrow all others which may be tried, except *Anacardium occidentale,* which can be recommended. Teak should definitely not be grown unless a thin low quality crop will be acceptable, and natural invasion by *Xylia* is likely to occur. *Cleistanthus collinus, Phyllanthus emblica* and *Chloroxylon* are other species typical of lateritic soils and so suitable for afforestation work on them.

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VIII.—TENDING

GENERAL NOTES

In the foregoing chapters on natural and artificial regeneration, the young crop has been followed as far as the sapling stage, more or less above the reach of herbaceous weeds and grass, with the crowns beginning to close up. Although the regeneration is then through its most critical stages, it requires a good deal more attention before it is safe from serious damage by woody weeds and climbers. Even after this, the new crop will not develop satisfactorily without periodic skilled selection of the stems which will be retained for further growth, and felling operations to ensure their optimum development.

Definition

Tending is defined as 'operations carried out for the benefit of a forest crop between the seedling and the mature stages'. It includes weeding, cleaning, thinning, and climber cutting (all of which are discussed in the following sections), but excludes soil working, drainage, burning, etc., which have already been considered.[1]

Necessity for tending

As with animal populations, including humanity, continued healthy existence and progress is only possible in tree crops with adequate sanitary measures involving the removal of diseased individuals, and of the causes of disease and the conditions favouring their propagation and spread. Tending operations, especially thinnings, provide good opportunities for ensuring proper forest sanitation, and neglect is extremely likely to result in the spread of disease as well as in a lowering of individual development and stamina.

Need of standardization of terms

It is not very easy to describe the operations required in terms admitting of only one interpretation by the various individuals to whom they may be entrusted, in fact experience has shown that misinterpretation of the intentions of silvicultural directions included in working plans or issued by executive authorities is extremely common. Although it is true that no verbal descriptions are adequate without practical demonstration, it is also true that if any method is to be stabilized and kept reasonably uniform as between a number of independent workers, standardization of terms and descriptions of methods is essential, and this is the reason for most of the terms and classifications that will follow under the head of thinnings below. If such standardization is necessary for divisional practice, it is doubly important for research work which aims at scientific testing of the claims made for alternative methods, and at providing the statistical data necessary to support or dispute them : such investigations have to be maintained over long periods and pass through many hands, so that it is essential to find objective methods of working.

Weeding and Cleaning

Definitions

The removal or cutting back of competing growth in seedling crops is known as *weeding*, whilst the term *cleaning* is used to imply the removal or topping of inferior individuals or species from a sapling crop, i.e., a crop over 3′ high.[1] Cleanings merge with thinnings as the saplings grow into poles.

Weeding and cleaning natural regeneration

Natural regeneration of the desired species is almost always accompanied by regeneration, both seedling and coppice, of less desirable species of trees, shrubs, herbs, and climbers. As mentioned in the last chapter, weeding and cleaning are accordingly very generally necessary from an early stage, and continue with decreasing intensity for a period of years depending on conditions.

In mixed coniferous regeneration, the dangerous weeds are chiefly woody shrubs such as *Rubus* spp., *Indigofera*, etc., though sometimes silver fir, blue pine or oak have to be removed in cleanings when deodar requires assistance.

In moist sal regeneration, repeated shrub-cutting of *Mallotus*, *Kydia*, *Clerodendron*, *Sterculia villosa*, etc., is necessary, especially where burning has not largely replaced them with grass.

In teak forest, bamboo may have to be cut back repeatedly, and sometimes competing inferior tree species also, though teak can usually hold its own unaided.

In evergreen forest, there are usually rapidly growing weeds such as *Macaranga*, *Callicarpa*, *Melia*, etc., as well as ground shrubs such as *Strobilanthes* from which the regeneration must be protected till large enough not to need further help, and neglect may result in malformation and stagnation of the regeneration.

The amount of such cleaning which must be done has to be determined separately for each type and set of conditions, as it is possible to expend much labour and money on unnecessary or even occasionally harmful work. It is evident that knowledge of relative rates of growth of the species it is desired to retain is essential, or it may be found that the secondary overtops the chief at a stage when it is difficult to remedy the position—e.g., *Terminalia tomentosa* in sal, and blue pine in deodar. Not rarely it is desirable to retain these secondary species as an admixture with the major species, but to keep them to the lower canopy layers and to places unsuited to or without the chief species, and this can often be effected by cutting them back to coppice, or, if they are not timber species, by topping them.

In the Punjab and elsewhere, the term 'cleaning' is taken to include the spacing out of dense young regeneration under 4" diameter, a work often combined with the removal of weed species.

Weeding and cleaning artificial regeneration

The weeding of plantations has already been described to some extent since the earlier stages—removing mainly herbaceous weeds—form an inseparable part of the establishment of a plantation (cf. p. 249). Many of the tree weeds which come in by seed are the same as with natural regeneration, e.g., *Anthocephalus* ; and there is sometimes a good deal of coppice from still living stumps, especially if the burn has not been a good one. Treatment is exactly as for natural regeneration, but is often facilitated by the availability of *taungya* labour.

Climber control in young crops

Climbers are a great menace to young regeneration, and must be closely watched, as in the course of a month or two they may pull over the saplings, break the leading shoots, and smother the crowns ; their removal constitutes a regular part of weeding operations. The heavy foliaged soft climbers such as *Mucuna pruriens* and *Dioscorea* spp., are usually the most dangerous, but tough woody species such as *Ischnocarpus*, *Millettia auriculata*, *Zizyphus oenoplia*, and *Bauhinia vahlii* may become equally bad.

Cutting back is not usually very efficacious, and it is often more economical in the long run to trace back the climbing stems to the rootstocks and dig them out. Such measures should be taken before the seed has set and before the season of maximum growth, which usually means during the rains, when also the ground is soft. Serious damage by climbers is difficult and expensive to remedy both in seedling regeneration and in coppice coupes and may render the latter almost entirely unproductive, as the bigger perennial climbers such as *Acacia* spp., *Combretum* spp., etc. are capable of preventing any tree shoot from getting above them.

The methods of dealing with climbers in young plantations have already been considered in Chapter VI, where also the two major pests, *Eupatorium odoratum* and *Lantana* are discussed. (cf. pp. 252-3.).

THINNING IN REGULAR CROPS

General Notes

Definition

Thinning is defined as 'the removal of excess stems from a crop beyond the sapling stage, with the objects of diminishing adverse competition and affording more light and growing space'.[1] Whereas the main object in view in weeding and cleaning is the removal of undesirable elements from a crop, thinning is chiefly concerned with promoting good growth in the stems that are retained.

General Considerations

Onset of root competition

It has been mentioned (p. 100) that at least on the drier soils competition between adjoining trees probably first begins in the soil, but as the roots cannot be seen, the onset and intensity of the competition must be judged from the appearance of the crowns. In profuse natural regeneration and in dense sowings, competition often sets in the second year, sometimes even in the latter part of the first, but in plantations the initial spacing provides against direct competition for several years.

Early spacing out of plants

For this reason, almost the first tending operation in dense young regeneration is a more or less mechanical spacing out to a spacing comparable with that of plantations, an operation which as mentioned above is generally considered as part of the cleaning. The age or size at which competition with other trees of the same or other major species begins can be controlled to some extent by the initial spacing in plantations, or as a result of an early spacing out of denser growth, but it cannot be carried very far without the introduction of other undesirable factors such as inferior branchy form and the encouragement of weed growth. These considerations have led to the very general adoption of an initial spacing of 6′ by 6′ for the majority of species unless definite reasons call for a closer, or more rarely a wider spacing (cf. pp. 188-9). The first spacing out of dense seedling growth is usually somewhat closer than this, thus 4′ for deodar.[2]

Tree Classification

Canopy classes in regular crops

Competition for air, space and light results in the differentiation of the crowns into various types. A standard classification for regular crops or groups has been adopted for use in India from among a number of not really very different alternatives which have been put forward at various times.[1, 3] This classification is as follows :—

I. *Dominant trees* (*D*) including all trees which form the uppermost leaf canopy and have their leading shoots free. These are sometimes subdivided into (1) *Predominant* trees comprising all the tallest trees which determine the general top level of the canopy, and (2) *Codominant* trees which fall short of this (averaging about $\frac{5}{6}$ the height).

II. *Dominated trees* (*d*) which do not form part of the uppermost leaf canopy, but the leading shoots of which are not definitely over-topped by the neighbouring trees (their height is about $\frac{3}{4}$ that of the Predominant trees).

III. *Suppressed trees* (*s*) the leading shoots of which are definitely over-topped by their neighbours or at least shaded on all sides by them. (Their height is about ½ to ⅝ that of the Predominants.)

To these are appended :—

IV. *Dead* or *moribund trees* (*m*) including bent-over and badly leaning trees.

V. *Diseased trees* (*k*) including those which are infected with parasites to such an extent that their growth is seriously affected or that they are a danger to their neighbours. These may be subdivided according as to whether they are : (*a*) dominant, or (*b*) dominated or suppressed.

It has recently been suggested that two more classes should be added. These are—VI. *Reproduction* and VII. *Overmature*.[18]

Canopy classification in young crops

In dense young crops it has been found that this classification does not go quite far enough to meet practical requirements in differentiating crowns cramped to varying degrees by their neighbours, and there is some difficulty in differentiating between the codominants and dominated trees.[3] In open crops it is difficult to decide for any spot what to take as the top level of the canopy. The matter is further considered on pp. 314-5.

Crown classes in regular crops

The crown of the trees of each canopy class will tend to have a shape characteristic of that class, the predominants having large, often rounded branchy crowns, the codominants rather smaller, narrower and less branchy crowns, the dominated definitely narrow crowns, and the suppressed trees small crowns which may be fairly compact and narrow or else thin and straggling. The standard classification[1] of crown classes is as follows :—

Dominant trees

(*a*) Trees with normal crown development and good stem form.

(*b*) Trees with defective stems or crowns, for example :—

(1) trees with crown space cramped by neighbouring trees ;

(2) badly-shaped old advance growth ;

(3) trees with forked leader and similar defects.

(*c*) Trees with very defective stems or crowns, *i.e.*, with the same defects as (*b*) to such an extent that they are of little or no present value or promise.

(*d*) Whips, trees with very thin bole and very constricted crown, incapable of existence without the support of the neighbouring trees.

Dominated trees

(*a*) Trees with normal crown development and good stem form.

(*b*) Trees with defective crowns or stems.

The reason for such a canopy and crown classification is not merely or primarily its convenience for descriptive purposes, but it is found essential for giving any intelligible description of different methods and intensities of thinning, as will be apparent later. It is considered by many that a simple classification of crowns uniformly for all canopy classes into good, medium and bad is adequate for all practical purposes, easier to carry in mind, and simpler for a poorly educated staff.[3, 3b] At the same time the merits of uniformity are such that the standard classification reproduced must continue to be used till it is changed by general agreement.

Size and shape of crown as a guide to thinning

The relative size and shape of the crown provides a useful indication as to the need for more growing space, the relation of crown length to total height being readily observable. Crown length is usually measured from the top of the tree down to a point midway between the lowest branch and the lowest point at which the crown is developed on all sides of the bole.[4] In well-thinned sal, crown length is slightly less than $\frac{1}{4}$ the total height, and the crown width approximately the same ; for deodar, crown length should be about $\frac{1}{2}$ total height till the latter reaches 60′, and should then slowly fall off to $\frac{2}{5}$ width being about $\frac{1}{2}$ length throughout, and so $\frac{1}{5}$ to $\frac{1}{4}$ of total height.

Reduction of Stem Number

Number of trees surviving to maturity

The scope for the selection of the stems which will be kept till the final felling at maturity is illustrated by the figures given on p. 102 and by the following figures for the number of trees standing on an acre of mature crop at common rotation ages :—

Species	Quality	Age in years	Number of stems per acre
Tectona grandis[19]	I	80	26
	II	80	32
	III	80	41
	IV	80	59
	V	80	125
Shorea robusta[20]	I	150	34
	II	150	39
	III	150	43
	IV	150	47
Cedrus deodara	2	140	91
Pinus excelsa	I	120	108
	II	120	132
	III	120	156
Pinus longifolia	II	120	48

If a crop of any of these trees is raised from a plantation with 6′ by 6′ spacing it means that the final numbers shown in the table are the survivors from 1,210 and so in nearly all cases are less than one-tenth and in some even only a twentieth. Quick-growing species are down to similar numbers at a much earlier age, *e.g.*, *Duabanga* to 65, *Gmelina* to 90, and *Alnus nepalensis* to 100 stems at 20 years of age.

Retention of finest stems

All the rest of the stems, 90 to 95 per cent of the initial number, will have died or been removed, so that it should easily be possible to retain to maturity only the finest stems which will give the maximum financial return. If the crop is naturally regenerated, the opportunity is even greater, for the starting, number will usually be at least four times as great, say 4,000 or 5,000. It is this selective reduction of the number of trees in the growing tree crop that gives to the thinnings described below their great importance in forestry, and provides the forester with one of the most effective means he has of applying his technical knowledge and experience.

Thinning Methods

The methods available

The following methods require to be distinguished :—

(1) Mechanical thinning.

(2) Ordinary thinning.

(3) Crown thinning.
(4) Free thinning.
(5) Maximum thinning.
(6) Advance thinning.
(7) Selective thinning.

The chief points of difference lie in the canopy layers from which trees are removed and in the importance attached to freeing the trees retained from competition in or above the ground.

Maintenance of closed canopy

No thinning may make lasting breaks in the general canopy. Obviously a recently thinned crop has many small gaps where growing space has been provided for the remaining trees, but these gaps are quickly reoccupied by the latter. The intensity of the thinning will depend on the objects of management, the species and the interval to elapse before the next thinning. In a general way the canopy should close up again after about $\frac{2}{3}$ of the thinning cycle, so it is evident that just after a thinning the crop is bound to look decidedly open, particularly with a long cycle and heavy intensity . It must be stressed at this point that thinning can only be learnt by experience in the forest, but the principles involved are relatively simple for most types of thinning. Intelligent Forest Guards can be taught to do quite good work in well-stocked forests. The work is much more difficult in more irregular and unevenly stocked types, and considerable differences of opinion will always exist as to the best procedure.

Mechanical Thinning

The method

In the newly established crop there stand, as already noted, an enormously larger number of stems than will ever reach saleable size. The first requirement is to space out the stems so that all which are retained have enough growing space to enable them to grow without excessive weakening competition with their neighbours. Before canopy and crown differentiation have set in, there may already be appreciable competition for space above and below ground, and the obvious way of reducing and regulating this is to space out the plants more or less evenly over the area. This may be done from the earliest stages as part of the cleaning operations, and after the canopy has lifted is generally known as a *mechanical thinning*. At this early stage, the differences between individuals

PLATE 26. Thinnings in plantations. (*Above*) *Sissu* after a D-grade thinning at 10 years of age. Chichawatni, Punjab. (*Below*) Teak 38 years old just thinned, Tharrawaddy, Burma.

Facing P. 292.

PLATE 27. Unthinned and well-thinned pole crops of chir pine, Rawalpindi, Punjab.

Facing P. 293.

tend to be due to chance circumstances rather than to inherent quality, and so the spacing out can reasonably be done largely mechanically without much regard to these differences, naturally rejecting any individuals which appear in any way unhealthy, injured or definitely badly shaped, even if this rejection results in minor departure from the standard spacing adopted. For deodar in the Punjab, it is prescribed that the cleaning operations among the young plants should gradually space them out until they are about 4′ by 4′ when 6′ high, spacing being estimated by eye [2].

After this stage, crops produced from natural regeneration, sowings and plantations are all much alike, and as a rule one or more additional thinnings will have to be carried out before crown differentiation is very marked or the produce is saleable (except perhaps as low grade fuel). These early thinnings in crops up to at most 8″ diameter are also often done more or less mechanically as spacing still tends to be more important than individual form.

Stick thinning

A common method, espcially in the Punjab,[2] is the *stick method*; according to which whenever a stick of prescribed length cannot be passed horizontally between two stems, one of them is cut unless specified reasons exist for retaining both. The length of the stick depends on the average diameter of the crop, and on the species. For deodar, it is 8′ for crops averaging 8″ diameter,[2] and for sal, 3′ for crops 1″-2½″ diameter and 4′ for crops of 2½″-4″ diameter. Various rule of thumb measures have been applied for determining the length of stick to be used or the spacing to be aimed at ; these are generally expressed as multiples of the average girth in feet or the diameter in inches of the trees of the groups under thinning. Thus in the example last quoted, the instructions might have been for stick or spacing four times the girth in feet, or 1½ times the diameter with the spacing expressed in feet and the diameter in inches.

Young teak plantations

In regularly spaced plantations such as teak at 6′ by 6′, a thinning may similarly be carried out semi-automatically by prescribing the removal of every alternative stem along the lines unless there are definite reasons to the contrary, and, applied with a little intelligence, the results can be quite good. Both the first and second thinnings in teak plantations are commonly done with at least this principle as a guide, reducing the number of stems per acre successively to 600 and 300, and the spacing to 8½′ by 8½′ and 12′ by 12′;

Unintelligently done, these semi-mechanical thinnings are harmful, and in any case they require fairly full and even stocking, See Plate 27.

Young sissu strips

In line sowings, mechanical thinning to a prescribed spacing in the lines is very commonly done with satisfactory results ; thus, in the irrigated *sissu* plantations with lines 10′ apart, the first thinning is often done at 5 years with 6′ spacing in the lines, a wider spacing being adopted if the thinning is delayed to a later year. The same method has been applied to sal strip sowings. With both species the question has been raised as to whether it is necessary or advisable to incur the cost of cutting back the already dominated and suppressed seedlings. It has been suggested that, in the irrigated plantations, such trees take up valuable water which should only be utilized by the main crop.

Ordinary Thinning

The method

After the initial stages described under the last heading, mechanical thinning ceases to be a practical proposition owing to the unequal development of the trees and their smaller numbers, and other methods are required. In the past, the most usual way of approaching the matter has been to view each group of trees independently and to remove those which appear to have already proved their inferiority by dropping behind, taking first the suppressed trees, then the dominated ones and finally some of the dominants with restricted or otherwise inferior crowns. As this method begins with the removal of the lowest canopy class and then works upwards, it has been called *Low Thinning*, but it is now very generally known, on account of its former widespread application, as *Ordinary Thinning*. The smaller dominated and the suppressed trees are usually removed, but particularly, with the heaviest intensities, they may be retained as soil cover and as insurance against casualties among the larger trees stand ng over them—or simply because it is not worth spending money on felling them. Four intensities are recognized in the standard Indian scale which is appended, but it is now generally realized that the two lightest hardly affect the growth of the dominants. Most foresters tend at first to thin very lightly, removals corresponding to something between B and C grades, but after more experience they mark more heavily, say a full C-grade, and very often go to its heavier extreme or even to D-grade[5].

It is stressed that if the term ' heavy thinning ' is used at all, it should always imply the C-grade thinning as here defined, but it is preferable to avoid altogether the use of a term which has been applied to so wide a range of intensity, and to use the grade letters.

Standardized grades of Ordinary Thinning[1]

[The symbols used for classes are those given for canopy and crown classes on pp. 288-90.]

(1) *Light thinning* (*A-grade*)

This is limited to the removal of dead, dying, diseased, and suppressed trees, i.e. classes V, IV and III. Grade A is of no practical use, but forms a convenient initial stage, especially in comparative research on the effect of thinning on increment.

(2) *Moderate thinning* (*B-grade*)

This consists in the further removal of defective dominated stems and whips. Branchy advance growth which it is impracticable or not desirable to prune or lop may also be taken, i.e. classes V, IV, III, II(*b*) and I(*d*), and an occasional I(*c*). B-grade also is of little use in ordinary practice, having little influence on the increment of the remaining stems.

(3) *Heavy thinning* (*C-grade*)

This consists in the further removal of the remaining dominated stems and such of the defective dominants as can be removed without making lasting gaps in the canopy, i.e. classes V, IV, III,* II and I(*b*), (*c*) and (*d*).

(4) *Very heavy thinning* (*D-grade*)

The distinguishing feature of this grade is that it also takes some of the good dominants, subject to the same condition of not making any lasting break in the canopy. The trees selected for removal are such that the remaining crop consists as far as possible of trees with good boles and crowns, well and evenly distributed over the area and with space for further development, i.e. classes V, IV, III,* II, I(*b*), (*c*), (*d*) and some I(*a*).

For research purposes, it has been found necessary to make

* V, IV and III may be left if their removal is of no economic or hygienic value.

ordinary thinnings even heavier than the standard D-grade, removing more of the dominant stems even if in Class I(*a*), so that all retained have ample room for further development. This extreme grade, which goes as far as possible within the rule for avoiding permanent gaps in the canopy, has been termed E-grade, and appears likely to be useful in divisional practice also.[5]

It is often obviously inadvisable to make a full C- or a D-grade thinning in a dense crop in which thinning has been unduly delayed. The first thinning in such cases should be a light or full C and the heavier thinning desired should follow in the next cycle.

Application

Ordinary thinning is best suited to pronounced light-demanders such as teak (Plate 26) and chir pine (Plate 27) in which the dominants require plenty of room, and the trees which drop down into the lower canopy classes practically cease growth and die. *Sissu* also must be well thinned from its earliest youth, whereas mulberry must be kept close in order to eliminate side branches.

Crown Thinning

The method

The benefit conferred by the removal under ordinary thinning of those trees which have already dropped behind in the struggle, on the rest of the dominant crop is very questionable, and the retention of some of them may be desirable for the protection of the soil and as an insurance against accidents. Another method of thinning has accordingly been developed, which looks first of all to the dominants, and removes such of them, beginning with the least promising individuals, as are hindering the further development of the best available individuals, due ragard being paid to obtaining as even a distribution of good dominants over the area as possible. This method is known as *Crown Thinning* and is steadily gaining in popularity though its application is checked by the skill required in carrying it out.

Crown thinning should be started as soon as crown differentiation has progressed far enough to permit of it. It is not usually possible to change over to crown thinning from ordinary thinning as the lower canopy layers have already been removed. It should be noted that the removal of some of the dominants gives light and room for some of the dominated stems to develop, and a certain number of these may later take their place among the dominants ; an example is indicated in the diagrams.

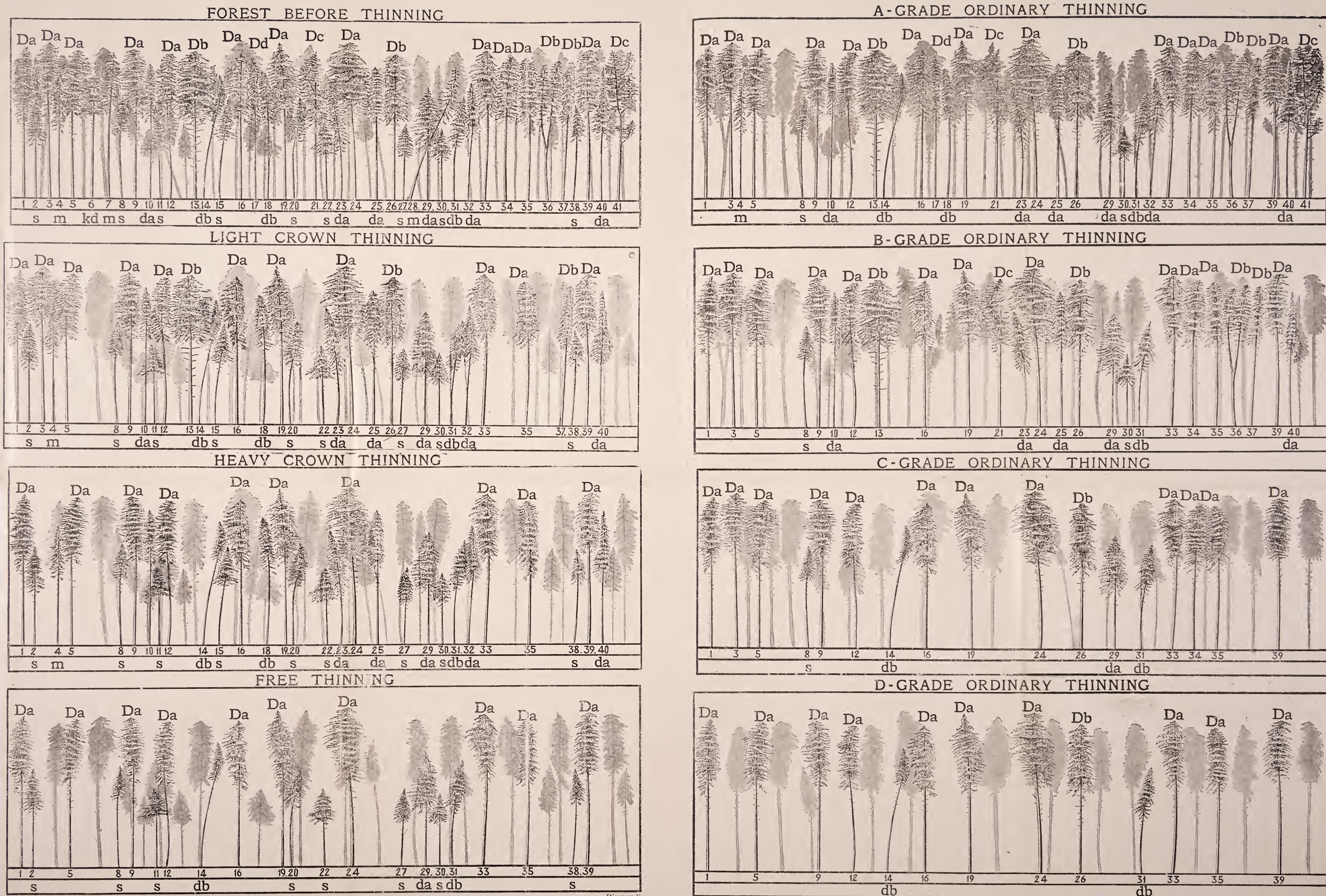

Diagram V.

Thinning methods.

Facing page 296.

Grades

Only two intensities of crown thinning are standardized[1] : they are defined as follows :—

(1) *Light crown thinning (L.C. grade)*

This consists in the removal of dead, dying and diseased trees,* with such of the defective, and after them the better dominants, as are necessary to leave room for the further development of the best available trees, evenly distributed over the area, i.e. classes V, IV, I(*d*), (*c*) and many of 1(*b*) and a few of 1(*a*) ; but not III and II.

This is very similar to D grade, but retains all III and II, and is not quite so heavy on I.

(2) *Heavy crown thinning (H.C. grade)*

This pays even more attention to favouring the selected best stems by removing all the remaining (1)*b*, which can be taken without creating permanent gaps, and more of I(*a*), i.e. classes V, IV, I(*d*), (*c*), most of I(*b*), some of I(*a*); but *not* III and II.

Application

Crown thinning is particularly well adapted to shade-tolerant species in which the retention of the lower canopy trees presents no difficulty. It is well suited to sal and deodar, but is not suitable for teak, chir pine and most of the light-demanding species of our plantations, such as *Gmelina*, *Alnus*, *Duabanga*, *sissu*, etc.

Free Thinning

The method

Attention may still further be concentrated on the selection of the stems, evenly spaced over the ground, which are to be retained to maturity or till the last thinning or two, and the thinning operations may accordingly be directed primarily to the removal of other stems hindering their optimum development. This method of thinning lacks a standard name but is typified by Heck's *Free Thinning*.[3, 6]

Crops thinned on this method do not differ very greatly in appearance from those subjected to crown thinning, nor does the actual operation differ very much, but the outlook is different in that attention is concentrated on the trees to be retained rather than on the

* V and IV may be left if their removal is of no economic or hygienic value.

trees to be removed (just as in a seeding felling). These *elite* or *alpha* stems are first selected in number appropriate to the size or age of the crop with special regard to their stem form and to their even spacing, it being held that crown form can be controlled—and improved, if necessary—by the thinning operation. Codominants, or even dominated trees of perfect stem form and standing in the necessary position relative to neighbouring elite stems, may be preferred to quite fair but less acceptable dominants. The remaining trees are then considered from the point of view of their reaction on the eli .e, and the benefit to be derived by the latter from their removal ; if their removal will help the elite, then they are marked ; in the alternative, they remain as soil cover or filling. Obviously, considerable variation as to intensity is possible, and much depends on the frequency of the thinnings, but these details have not yet been standardized and remain matters of opinion, awaiting practical demonstration.

Pruning of the elite is considered essential by the originator of the method (Heck) ; it is realized that fast-grown wide-ringed timber must result, but it is held that, even so, with few exceptions the financial return is higher than with other methods.

The amount of work done may also vary with the funds available for the operation. Thus the selected stems receiving special attention may be reduced even to approximately the small number likely to be retained as seed trees in the regeneration fellings, and limited funds can be made to cover a considerable area in this way. Under this method it is advisable to give the selected stems a distinguishing mark such as a ring of white paint for future guidance.

Application

The method deserves consideration in forests where there is little or no demand for small or medium sized poles and a big price increment for large clean timber, conditions prevailing in much of the chir pine belt.

MAXIMUM THINNING

The maximum thinning method associated with Gehrhardt's name (his *Schnellwuchsbetrieb*)[3,7] may be looked on as a further development of the last, like which it has the well-defined objective of putting as high a proportion as possible of the total potential increment of the area on to the elite stems. Their number must obviously fall with rising age, but from an early stage onwards the aim is to retain the minimum number that can fully utilize the growing space. Length of crown provides a good index as to whether the trees have all the space they can use or not, independent studies on free standing trees revealing the maximum relative length to be 2/5ths for *Picea excelsa.* The crops are then thinned so that the trees just retain this maximum length for their height, all competing individuals being removed. This method requires a species with powers of quick adjustment to the additional growing space made available, and is only silviculturally possible on sites of good quality ; on poor localities it results in site deterioration and loss of increment. It is obvious that though diameter-increment may be greatly enhanced—even to twice its normal rate--the relatively open canopy must result in poorer form and larger branches extending a long way down the timber bole ; artificial pruning is therefore recommended. Wide-ringed timber of course results, with an effect on the money return depending on species and markets.

Application

With the increasing insistence in Indian forestry for shorter rotations for timber logs, the method calls for trial, but has not so far been taken up. It should be more applicable to hardwoods than conifers, and after the earliest stages, would not differ appreciably from the heaviest ordinary thinning.

Advance Thinning

The extreme limit in thinning out young crops appears to be reached in the methods recommended by Craib and O'Connor for wattle and pine plantations in S. Africa.[8, 9, 21] The number of stems per acre is reduced to an extent which in India would certainly lead to heavy grass invasion and site deterioration. The exceptionally rapid rate of growth obtained apparently results in the thinned crop closing up again fast enough to prevent such unfavourable reaction. The underlying idea is that thinning should be done *before* suppression sets in, not after it has already become apparent, as in the older methods, and the term 'advance thinning ' is suggested as it is done in advance of any apparent need on the criteria used hitherto. Statistical support for the method is obtained by close study of the current increment of plots of different density, watching for any inferiority of a denser crop in comparison with the opener one growing under otherwise identical conditions. In carrying out a thinning, the prescribed number of stems is the main consideration, naturally with the best crowns and most even spacing possible. It thus practically works back to the mechanical thinning first described.

Experiments on advance thinning in India have been carried out with young teak and chir pine plantations. They so far show that this type of thinning although producing exceptionally rapid growth and fair form is probably rather too drastic for these species under Indian conditions.

Selection Thinning

Mention must be made here of the *selection thinnings* of Biolley, Schädelin and others, one of the objects of which is the conversion of the uniform type of canopy to the selection type. These thinnings do not greatly differ from a crown thinning, but more attention is given to favouring the good elements of the lower stories and an early merging of the canopy layers. The method is further discussed on p. 315.

A Mathematical Check for Thinning

Relation of yield from thinnings to total yield

For a given rotation and quality, the relation between intermediate and total yields can be obtained from published yield tables for the grade of thinning to which they correspond. Thus for sal, excluding branchwood, our yield tables, considered to correspond to C-grade ordinary thinning, indicate a 30, 32 and 34 per cent relation at 120 years, for qualities I, II and III respectively. For deodar at 140 years, the intermediate yields for B-, C-, D- and E-grade thinning in all qualities are approximately 20, 30, 40 and 50 per cent respectively of the total yield, with variations not exceeding 5 per cent in any one quality.

Again, it has been demonstrated that the total production per acre of forest is proportional to top height (cf. p. 71) irrespective of age and quality, so that after determination of top height, a crop can be thinned in such a way that the total intermediate yield to date corresponds to a prescribed proportion of the total production.[10]

Interesting as these figures may be, they are not of much help in carrying out a thinning in a given crop of which the past yields are not known, and other methods have to be devised. In experimental work, a mathematical check on the removals marked on the descriptive prescriptions, given in the preceding sections, is almost essential to provide the means of deciding doubtful cases, and to

PLATE 28. Climbers (*Bauhinia vahlii*) overgrowing untended sal forest in Nepal.

Facing P. 300.

eliminate as far as possible the personal factors which enter into thinning practice almost more than into any other forestry operation. Suggested procedures mostly apply only to variations in intensity of a single method. Two examples will serve as illustrations.

Numerical check by number of stems and average diameter

First of all, trees are tentatively marked under the descriptive rules for the desired grade of thinning. The number of stems per acre which would thus be left is then compared with the number given in the yield table for the same average diameter and quality (this *n/d* relation may or may not vary with quality). For C-grade thinning, the number of stems marked is then increased or decreased to bring the *n/d* relationship to that given in the yield table, always keeping within the prescriptions for the grade with the usual minor exceptions due to uneven stocking. If a thinning is being made heavier or lighter than that on which the yield table is based, the number of stems standing after the thinning should be similarly adjusted as far as is possible within the prescriptions, to a predetermined percentage range of the yield table number for that quality and diameter. This is the method followed in most sample plot work,[4] for which it has been found that the yield table figures correspond fairly well to C-grade thinning, and B-, C-, D- and E-grades can be taken as having approximately 130-110 per cent, 110-90 per cent, 90-70 per cent, and 70-50 per cent respectively, of the yield table number.

Numerical check by relation of spacing to height

Another method, worked out for teak plantations in Java, [11] is as follows :—

The average height of the tallest trees of the crop, the 'top height', is determined, and the number of dominants and their average spacing is worked out. The percentage relationship between the average spacing after thinning and the top height, termed the *thinning degree*, then provides an expression of intensity, and the thinning can be done to any prescribed degree. Our sal yield tables which are stated to be for C-grade ord nary thinning correspond to a thinning degree of 20-24 except for the higher ages of the lower qualities ; the Nilambur teak yield tables correspond to a thinning degree of 28-30. The multiple yield tables for deodar correspond to degrees of 16, 18 and 20 for C-, D- and E-grade thinning, respectively, at ages above 80 years ; the degrees are 19, 22 and 26 respectively at 40 years, but fall with rising age.

First Thinning in Young Crops

Limitations of pole crop methods

The methods described above for ordinary and crown thinnings are based on a classification of the trees in the crop into canopy and crown classes, and so naturally they cannot be applicable to young crops in which canopy and crown classes are only beginning to differntiate : attempts to apply them have naturally led to difficulty, and to a demand for other standard methods to be used in their place during this preliminary stage. Alternatives are available in the mechanical and other spacing methods already described in the foregoing section, and these are fully adequate to meet all requirements. They are simply expressed numerically as the average spacing or number of stems per acre, so that standardization for purposes of comparison only requires mention of the average diameter of the crop, or better still that of the dominants. O'Connor's views that thinning should take place *before* adjoining trees check one another's growth should be kept in mind, but require further testing under Indian conditions (cf. p. 299). Risk of wind damage increases greatly with increasing intensity of thinning and must always be kept in mind.

First thinning in natural regeneration

Naturally regenerated crops differ from plantations chiefly in the greater irregularity of height and density, and the usually much higher number of stems per acre : the former condition ensures a rather earlier crown differentiation whereas the latter usually necessitates an earlier thinning (earlier with reference to height rather than age), which obviously must be primarily on a spacing basis—in fact it is just the type of crop to which the mechanical thinning is particularly suited provided the spacing is varied with the height or diameter of the group under marking. It has been mentioned above that in the Punjab, deodar regeneration is thus thinned to a 4′ spacing at 6′ height, increasing to an 8′ spacing at an 8″ average diameter.

First thinning in plantations

Most plantations start with even spacing which is ample for them for at least 4 years and often much longer—for instance 15 years or more in *Cryptomeria* in N. Bengal. This spacing results in even growth with a minimum of crown differentiation so that, as the canopy closes, there is a marked tendency for the crowns to draw one another up. The majority of them remain cramped, and so long a period may elapse before the dominants declare themselves that they have already lost part of their power to respond rapidly to improved conditions of light and space ; teak is particularly sensitive in this way, and suffers more from lack of timely and adequate thinning than any other ordinarily grown species. It is necessary to thin a teak plantation with initial spacing 6′ by 6′ after 3 growing seasons on good sites, after 4 or 5 seasons on average sites, and after 6 to 8 on the poorest sites. At this stage there is often little to choose between the trees, and the rather smaller tree may be as ready to respond to freeing as the bigger one. Spacing out so that the retained trees can develop properly without letting in grass and other weeds can accordingly be done largely mechanically in well-grown and well-stocked plantations, and is in fact usually so done for the first two thinnings, after which marking for C- or D-grade ordinary thinnings gives no difficulty.

The first thinnings in plantations should thus be mainly mechanical with special regard to an even spacing of the best dominants and (as usual) the probable removals of the next thinning. The intensity of the thinning will vary with species, but exclusion of weeds is usually equally important with crown liberation. There is not usually much to be gained at this early stage in signalling out elite stems under thinning methods calling for their special treatment, though this is sometimes recommended by the exponents of these methods.

First thinning in strip sowings

In this type of regeneration, the young plants often stand even more crowded than in dense natural regeneration, and their early thinning is still more important.

What is advisable differs considerably with conditions, and these are strongly contrasted in the line sowings of *sissu* in the Punjab irrigated plantations, and the strip sowings of the wet tropical forests of Assam and Bengal. In the former case, where moisture conservation is a primary consideration, the density of the sowings has been considerably cut down and the seedlings are weeded out at an early stage to a spacing of about 6′ in a single line. In the latter, where ample moisture is present and weed growth between the strips is the chief danger, the plants must be kept dense enough to shade out any weeds in the strips and to close over between the strips as soon as possible—though even here excessive crowding must be avoided.

A mechanical thinning to an appropriate spacing in the length is the obvious and best method to apply and is done in the irrigated plantations. It has been questioned as applied to strip sal sowings on the grounds of unnecessary expense and because it was held by some that adequate crown differentiation did in fact take place. Cutting back of hundreds of more or less suppressed saplings does involve a good deal of labour and expense, but against this a definite economy has been claimed in the cost of later climber cuttings. Thinning in the top canopy also tends to be difficult to carry out when there is a dense lower canopy obscuring the view.

The trees come up with ample lateral space for development but little or no room in the direction of the length of the lines. There is usually good canopy differentiation, many of the seedlings failing to reach the full height, but the leading plants tend to be all approximately equal and cramped.

As regards early declaration of dominance, there is much variation from place to place, but most well-stocked plantations include parts where competing dominants are common and thinning among them is undoubtedly called for. Crown thinning will of course deal with this, and is the obvious alternative to the semi-mechanical thinning. The choice between the two methods should be determined on economic lines unless it is proved desirable to remove the lower storey in the interests of crop sanitation, as seems likely to be required for sal in the wetter tracts.

In the dense and broad strip sowings of Assam, a largely mechanical thinning is recommended as soon as the risk from grass and weeds is past, as by then the trees which are to form the future timber crop are usually badly in need of more room.

Date of First Thinning

Age for commencement of thinning

From the purely silvicultural point of view, the first thinning should obviously be made as soon as direct competition between plants is severe enough to check the growth of those which are to form the future crop. This may occur in the first season in natural regeneration and dense sowings, and as has been seen, is dealt with by cleanings and early mechanical thinnings at a stage when the surplus stems are easily and cheaply removed. This brings these seedling crops into much the same condition as plantations derived from planting at stake and patch sowings.

'Uneconomic' thinnings

As the material from the first real thinning is practically never saleable, and on the contrary calls for actual expenditure, there is a strong inducement to postpone it as long as possible, and to reduce its necessity by using wide initial spacings. It is, however, almost universally accepted where forestry is an advanced science, that this policy is both silviculturally, and in the long run also economically, unsound. If a healthy well-grown crop is wanted, it is a mistake to make what are after all usually only petty economies in the early stages.

Size or age at first thinning

Although the date of the first real thinning should ideally be fixed on the basis of size (best estimated as height), it is usually necessary, for convenience in management to prescribe it by age. The age basis cannot allow for inequality of site quality and inequality of growth due to cultural differences. The best procedure is to prescribe that, as far as possible, the regeneration, natural or artificial, shall be visited with a view to thinning at a given age normal for the area, the thinning being postponed a year or more if its development falls below normal.

The following figures provide examples of present practice for various species in various localities; they are mostly taken from current working plans or executive orders.

Species	Quality	Locality	Age of first thinning in years	Nature of crop
Shorea robusta . .	I	N. Bengal .	5½	Strip sowing, spacing 6′
	III	Gorakhpur .	4½	Strip sowing, spacing 10′
Dalbergia sissoo . .	. .	Punjab .	5½	Stumps 10′×5′
Tectona grandis . .	I	Burma .	4½	6′×6′
	III	,,	8½	6′×6′
		S. Bengal .	4½	6′×6′

In the preparation of the new teak yield tables[19] it was found that in the early life of the plantation the relations of top height with number of stems per acre, basal area per acre, and volume per acre are more or less independent of age and quality. Hence modern tendency particularly in Madras and Burma is for early thinnings to be based on height and not on age. In Madras the first thinning is done in the 3rd, 4th or 5th year according to quality and this roughly corresponds to height of 25 to 30 feet for qualities

II, III and IV. The second thinning is similarly done in the 6th, 8th and 10th years and this roughly corresponds to a height of 35 to 45 feet for qualities II, III, and IV. [22]

Thinning in Pure Coppice Crops

Coppice thinning

Coppice crops, even when mainly of a single species, present practically all the problems of thinning in high forest, and in addition several others. Most coppice coupes are worked for fuel and poles, and if the former brings in most of the revenue, total volume production is likely to be the chief consideration. Now as we shall see (p. 312), maximum production is probably obtained with little or even no thinning. It often happens, however, that the production of poles of acertain minimum size is important, and thinnings aiming at a maximum outturn in this form are called for (e.g. *Cleistanthus* poles in parts of the Central Provinces).

Reduction of the number of stems per stool

Thinning out the number of shoots on one stool to one or two is very generally prescribed where coppice coupes are thinned at all. The benefit of this operation must vary with species, age and size of stock, the class of material most required, and the coppice rotation and has not been adequately investigated in India. Where there is natural tendency to produce many shoots, and where straight poles are required, it is probably advisable to thin them out in the first thinning to one or two per stool. Provided the shoots have enough crown space, however, removal of some does not appear to result in significantly improved growth of the retained stem, at least as far as height growth in the following season is concerned ; where improved crown development results, it is accompanied by improved growth as with seedling crops. The first thinning may reduce the number of stems per stool from many to few, and the second from few to one or two.

Thinning in teak crops of coppice origin

Mention must be made of a recent technique developed in the Central Provinces where their current methods of working are producing large areas of irregular almost pure crops of teak. The crop arises partly from ordinary coppice and partly from seedling coppice. The crop is considered ready for the first cleaning-*cum* thinning operation when the ‘ declared ’ stems have reached a height of 25 to 30 feet. All malformed shoots, interfering shrubs and bamboo regrowth are first cut back to facilitate working. After this the best of the dominant stems, termed *elites*, are selected for retention and given the optimum growing space by felling the inferior dominant and dominated stems interfering with their crowns. By optimum growing space is meant a clear space round an elite of radius R feet where R is equal to the overbark breast height diameter of the stem in inches *plus* 3. Suppressed stems are retained to clear the boles of the elites.

This method which is locally called ' single stem silviculture ' has been successfully used over large areas and it is claimed that with simple instructions it can be carried out satisfactorily by forest guards. It is an interesting recent development which may have application over very large areas of Central India. [18, 23, 24]

Thinning in Mixed Crops

Complications in mixed crops

This is one of the most difficult operations in forestry though the underlying principles are often simple enough. The usual prescription is for a thinning of one or other of the types already considered, supplemented by a list of species or groups of species in the order in which they are to be favoured when their interests clash : there is also often a further proviso with regard to certain species which it is considered desirable to retain in certain proportion in the crop from silvicultural or site conservation reasons.

Need of a definite thinning policy

An all-important essential in thinning mixed crops is a settled policy covering the whole life of the crop ; this does not preclude a gradual change of procedure with the passage of time, in fact treatment during youth will generally differ from that to be applied later on, but it does rule out the application of conflicting principles in successive thinnings. There are many examples, among which that of mixed crops of blue pine and deodar is one of the simplest, where lack of a settled policy has resulted in favouring now the one species, and now the other, to the detriment of the optimum development of either.

Best thinning method

Ordinary thinning is not as a rule suitable to mixed crops except rarely to mixtures of light-demanders of equal rate of growth. Crown thinning is more suitable as it caters for the retention, and if necessary, the helping of the slower-growing species. Most usually perhaps, requirements can be met by carrying out a more or less standard ordinary or crown thinning of the chief species, dominance being referred to the crop as a whole, with special additional prescriptions aiming at the maintenance of the desired mixture of the subsidiary species in the appropriate canopy layers.

Thinning mixed coppice

In practice, the problem is most often encountered in mixed coppice crops, and special rules are usually drawn up having regard to the species mixture concerned, the classes of material required, the need for new stocks and often for standards, and the various other local factors.[12]

Thinning Cycle

Variation with age

Rapidly growing young crops obviously require more frequent thinning than older crops in which the number of stems per unit area has been reduced to only two or three times the number standing at maturity. The most general practice in India for plantation and naturally regenerated crops is to make two or three thinnings at about 5-year intervals, varying somewhat with the individual crop, and then to bring them on a regular 10-year cycle. A 15-year thinning cycle is most usual in crops which have not been obtained by special regeneration operations and are consequently more unevenly and openly stocked.

Typical examples of gradually increasing cycles are from Nilambur where current practice is to thin II quality plantations at ages 3, 6, 10, 18, 30 and 44 years and III quality plantations at ages of 4, 8, 13, 22, 34 and 48 years.[22]

Teak sample plot procedure has been standardized and after the first two thinnings which are mechanical and based on height, as already described on p. 305, the thinning cycles are regulated on an age basis and are the same for all qualities because in most provinces in practice it is not at present possible to thin different qualities on different cycles.[22] The third and all subsequent thinnings are done at the following intervals :—

Age of crop at the time of thinning	Interval to next thinning
Over 5 and under 20 years	5 years
Over 20 and under 40 years	10 years
Over 40 and under 60 years	15 years
Over 60 years	20 years

Demands of management

Silvicultural needs have to be subordinated to some extent to the practical requirements of management, which often find short and variable thinning cycles impracticable.

Relation of cycle to intensity of thinning

The intensity of thinning must be related to the prospective thinning cycle, being heavier the longer the interval to the next operation. An ordinary thinning less heavy than C-grade is of little use with a 10-year cycle, and at least in young crops, D-grade may easily be needed if overcrowding and its ill effects are to be avoided. The well-known dictum of ' light and frequent ' can be accepted as an ideal always to be kept in mind, but most usually in practice should be replaced by ' at as short intervals as possible, and heavy enough to remain effective over the intervals '.

Examples

Illustrations of current prescriptions for thinning interval are the following, omitting the first two thinnings.

Sal :	Gorakhpur *taungyas*, 10 years.
	Pilibhit coppice, 10 years.
	Dehra Dun natural corps, 20 years.
Teak :	Burma and Nilambur, a gradually increasing cycle.
Sissu :	Punjab irrigated plantations, 6 years.
Chir pine :	Chakrata natural crops, 10 years.
	W. Almora plantations, 10 years.
	Rawalpindi natural crops, discretion of D.F.O.
Deodar :	Kulu natural crops, 15 years.
	Lolab, Kashmir, natural crops, 20 years.

For the Dehra Dun sal, thinnings in future are likely to be 5, 10, 15 and 25 years.

Factors Affecting Thinning Practice

Effect of species on thinning

Light-demanders are less tolerant of crowding than shade-bearers, and so thinning is more important for the former.

Teak provides one of the best examples of the need for early and relatively heavy thinning ; without it, growth stagnates and the trees become so 'crown bound' that they are only slowly and imperfectly able to respond to an opening of the canopy made after a period of neglect. Many of the older plantations in most provinces have suffered in this way. As the lower canopy classes suffer disproportionately from being shaded, crown thinnings are not suitable and ordinary thinning meets the needs of the dominants best : an underwood of another species is desirable, and the thinnings may be made even heavier than might otherwise be the case, for the benefit of this underwood.

Chir pine is another light-demander well suited to the heavier grades of ordinary thinning, but does not get so crown bound or lose its leading shoot quite so easily as teak. *Sissu* is again similar.

Shade-bearers can also be given ordinary thinning but, as the lower canopy trees retain their leaders and remain resonably healthy for a long time, they provide good protection for the soil and a useful insurance against casualties in the overwood ; crown thinning is accordingly very suitable and would probably be more generally prescribed if it were not rather more difficult to teach and carry out. If thinning is long delayed in fully stocked crops, it is difficult to introduce crown thinning as the crowns have been drawn up too high and are too small—as is commonly to be seen in neglected deodar plantations.

Deodar is also probably better suited to free thinning and thinning for maximum growth than any other of our common important species, always provided that it is on a good site where appreciable deterioration is unlikely to result from the exposure involved.

Sal.—Despite their persistence under shade, sal trees suffer greatly under suppression, and ordinary thinning seems more suitable for them than crown thinning.

Species with a 'frondose' habit in youth, as exemplified by the Terminalias and *Pterocarpus*, provide a variation, the correct treatment of which has not yet been fully determined. These trees do not produce a well-defined vertical main axis and a radially symmetrical crown for some years ; the leader tends to lean to one side and the crown to be flattened in a way suggestive of a fern frond. If thinnings are done early or heavy the stems become branchy and of poor shape, whilst if they are delayed the crowns are poor and the development of good straight boles and adequate crown seems unduly delayed. It appears likely that the thinning should be done just heavily enough to ensure fair-sized crowns, and then the required type of stem and crown will appear at a stage appropriate to the species.

Influence of site

The chief influence of site quality on thinning practice is the necessity of maintaining a relatively close canopy on the poorer sites. Such thinning methods as involve heavy opening, e.g., thinning for maximum growth, are quite unsuitable to low quality sites. Spacing out widely in the earlier stages is likewise highly inadvisable on hot or dry slopes, on poor soils and of course on all soils and sites where it is liable to result in deleterious grass invasion. For a given crop-diameter, a poor site will support fewer stems per acre than a good one, especially as the crops become older; thus for a sal crop-diameter of 12″, there are 133 stems per acre for Q. I, and only 102 stems per acre on Q. III, whilst for chir pine the difference is more marked, the figures being 170 and 124.

Influence of markets

As mentioned on p. 305, there has been considerable controversy in India for many years over the justification or lack of justification for 'uneconomic thinnings', thinnings the cost of which is not fully covered by the sale of the produce, and there has often been a tendency to postpone thinnings till a certain marketable size is attained, or a special market for smaller material arises or can be found. The consequences, especially with teak and deodar, have often been deplorable, in the former species with definite loss of increment through loss of power of response to the delayed thinnings when finally carried out, and in the latter both by this effect and the greatly increased losses from snow and wind-break ascribable to the badly proportioned crowns. Although the economic aspect must of course be given full consideration, neglect of timely thinnings greatly postpones the harvesting of the final crop and reduces its value whenever large timber is being grown, and so is no economy in the long run.

Where small timber is valueless, it is usually best to make heavy thinnings at fairly long intervals, but the trees that are intended to grow to timber size must be kept provided with enough growing space, and if there is no serious objection to wide-ringed timber, thinning methods such as Gehrhardt's are worth consideration. Where wide-ringed timber is definitely inferior, as with the excessively rapidly grown *Cryptomeria* timber of the lower elevations in the hills of N. Bengal, plantations must be kept dense, and thinning started relatively late and be kept relatively light.

Good markets for small material, whether poles or fuel, should be utilized to the full to reap the advantages resulting from regular thinnings at short intervals, but care is sometimes required to prevent good markets from resulting in heavier thinnings being made than are suited to species and site.

Influence of the underwood

It may be desirable to regenerate an area with a fast-growing species which can be relied on quickly to restore the soil cover but which is not suited to maintain it and to grow to maturity as a pure crop—*Gmelina arborea* is such a species in the plains and *Alnus nepalensis* in the hills. To take over the function of soil protection, and possibly also to form part of the final main crop or even the main part of it, a second species may be introduced either simu - taneously or after a year or two—such as *Dipterocarpus* in the plains, and *Bucklandia* in the hills, with the overwood trees just mentioned. Unless the overwood is thinned out considerably and in time, it is unusual for species which thus start as a lower storey or underwood ever to develop satisfactorily, even if they can persist at all in any numbers. At least a D-grade ordinary thinning is usually required before the underwood species is much checked in growth by the excessive shade. If it should become the practice to raise an underwood in teak plantations, the same considerations would apply, except that the stem form of the underwood would probadly be a matter of no importance compared with the maintenance of a reasonably complete soil cover.

Quantitative Results

Indian data

The only quantitative data collected on a systematic basis in India are the multiple yield tables for deodar,[13] and these can do, no more than indicate probabilities since we have hardly any crops in the country which have been thinned regularly on any definite method, except very young ones.

These tables can also give no comparative data for volume production as it was found necessary to assume that this was approximately the same for all grades, but they indicate the effect of the different intensities of ordinary thinning on diameter and number of stems, as the following figures for Site Quality 2 show :—

Thinning grade	B	C	D	E
Crop-diameter at 100 years . . .	13·8″	14·9″	15·9″	17·1″
Number of stems per acre at 100 years .	336	245	182	124
Number of stem over 20″ diameter .	7	10	15	17
Crop-diameter at 140 years . . .	17·9″	19·1″	20·3″	21·5″
Number of stems per acre at 140 years .	239	180	132	91
Number of stems over 20″ diameter .	45	54	54	46

Comparison of the measurements made on isolated pairs and sets of plots differently thinned—and that only over a short part of their life—is fraught with difficulties and extremely likely to be misleading, and it must be many years yet before we have the necessary figures to prove what method of thinning gives the best return in the long run. We have however very numerous demonstrations of the value of systematic thinning in young crops.

European data

The European data[3] indicate very little difference in standing volume at rotation age or in total volume production whatever the thinning grade. The general conclusion reached with regard to the latter quantity is that the heaviest thinnings so far systematically studied show no appreciable falling off to offset the marked gain in average diameter. If small wood is included, there appears to be a small difference in favour of the lightest or no thinning, but it is so slight as to be doubtfully significant, and is unimportant in comparison with the other factors usually involved in reaching a decision as to the thinning procedure to be adopted.

Price increment

Total volume production might at first appear the best and simplest basis of comparison, but in view of the usual large price increment for larger timber, and the difficulty in disposing of anything below a certain size, it is quite unsuitable, and it seems necessary to compare total yield in standard assortments which can be allotted relative price values per unit of volume at any time.

Increment Fellings

Difference from thinning

We have seen that to fall within its definition, a thinning must not create a ‘ lasting ’ break in the canopy. Where there is a significant price increment to be obtained by concentrating the increment as much as possible on selected good stems, a not uncommon position, it may be justifiable to open up a crop still more heavily near the end of the rotation, in order to obtain this advantage.

Difference from preparatory felling

The term *increment felling* is applied to fellings of this kind provided they are not connected with natural regeneration operations. There will probably be some loss of total increment, and the protection of the soil will be taken over by a natural or introduced underwood. Considerable advantages are claimed for increment fellings by some continental workers both as regards total increment and particularly price increment.[3b] Fellings such as these naturally also bring the advantages of improved crown development, the establishment of advance growth, and a more rapid decomposition of excess humus, where these effects are desired. If natural regeneration is really the main objective, they must be considered as preparatory or seeding fellings ; they may also be necessary on occasion to hasten the growth to the exploitable size in a working circle deficient in mature stands, but an excessive width of sapwood is liable to result.

Relation to D- and H. C. thinnings

Increment fellings follow on as a natural stage beyond the D-grade ordinary thinnings (cf. Diagram V), though as noted an intermediate E-grade might be recognized (as it is in research work) removing the maximum possible without creating permanent gaps. The intensity may be measured by the proportion of the basal area removed, or by the actual basal area per acre retained. With crown thinning, the retained lower canopy trees ensure that real breaks in the canopy do not occur, but in the heaviest forms of crown thinning the dominants may stand spaced similarly as in the standard increment felling.

THINNING IN IRREGULAR CROPS

Tree classification in selection forest

There is no accepted standard tree classification for irregular crops either in Europe or India, and no standard thinning method or intensity. Such a classification is needed if only to ensure continuity of policy[3a]. The difficulty is somewhat reduced in India by the fact that few if any of our irregular forests aproach the theoretical selection forest, tending to fall between this and the virgin forest with its disproportionately large stock of large and over-mature stems. Owing to the uneven contour of the top canopy, trees of almost any height may be free from direct domination, so dominance must be referred only to the immediately surrounding trees and not to any idea of the general top height of the forest. It seems likely that most purposes will be served by a simple classification such as the following, which is in use in research work.

I. *Dominants* with the leading shoot free from overhead or near side shade.

II. *Dominated stems* with leading shoot free but with near side shade from taller trees.

III. *Suppressed trees* with leading shoot definitely overtopped or with near side shade from taller trees on all sides.

The crown classification to complete this would be (a) Large ; (*b*) Medium ; (*c*) Small.

It has been suggested that actual height or height relative to the top height of the forest as a whole might be used instead of height relative to the surrounding trees, but this appears definitely less suited to the prevalent conditions and requirements.

Selection thinning

As selection working, particularly in India, tends to pay special attention to producing a high proportion of the yield in the form of trees of the larger diameter-classes, the most suitable form of thinning will approximate to crown thinning in regular forest, but must also care for the welfare of the most promising individuals of all the lower canopy classes, especially those of middle size which appear likely to reach the full exploitable diameter. European workers in selection forest prescribe the removal of the class of trees which show the following characteristics :—(1) which restrict the development of their neighbours on all sides, (2) which are less valuable than their neighbours, and (3) which are of no special importance with regard to desirable species mixture. Such trees may be of any height-, crown-, or diameter-classes, according to their position in the group immediately affected by them. It has to be remembered that the thinning in the selection forest merges with the regeneration, and groups of regeneration have to be helped wherever they are found. Whereas crown thinning in regular forest concentrates attention on helping the stems which are to provide the final yield, selection thinning aims at obtaining or maintaining the selection composition, with all diameter-classes adequately represented to ensure maintenance of the maximum sustained outturn ; it also aims at continuous improvement by the constant elimination of the most inferior stems in all diameter-classes.

Marking

Selection thinnings are admittedly difficult to mark, in fact in Europe it is stressed that it should invariably be done by the Divisional Forest Officer, as his chief professional duty.

Felling

For various reasons, it is a very usual practice in India to carry out the selection thinning as a separate operation in the year following the main felling of trees of exploitable size. The procedure is often preferable from the management point of view as the markets and extraction agencies may be different, and it permits of modifying the markings to minimize the effects of the damage inevitably resulting from the felling of the biggest trees. Marking the main fellings may involve greater financial responsibility, but marking the thinning calls for far greater technical skill.

IMPROVEMENT FELLINGS

Definition

By improvement felling is understood working over a forest with the object of bringing about an improvement in the general condition of the growing stock by the removal of inferior stems and species wherever this will help better stems or species.[1] The operation does not ordinarily aim at getting regeneration, though it usually includes aiding advance growth and encouraging the filling up of blanks ; above all, realization of revenue should never be considered as one of its objects, any return from the material removed being entirely incidental. It includes the cutting of climbers as described on p. 287, and thinnings where needed. It is, in fact, something between a silvicultural operation and a silvicultural system. Improvement fellings are applied to irregular forests, including the as yet unconverted portions of forests under conversion to even-aged form.

Application

They are also usually prescribed for inferior forest, especially those which owe their poor condition to overfelling, excessive grazing, or burning or any other remediable cause, as offering the best means of bringing them back into regular production. Consequently, many working plans in all parts of India have an ‘ improvement working circle ’ in which such improvement fellings are the chief prescription.

Selection cum improvement

Improvement fellings have also been very generally introduced into the working of better quality virgin or selection forests as a silvicultural operation for the benefit of the growing stock and future production, either with the exploitation fellings of all or selected trees which have reached a prescribed exploitable size, or subsequently. In this form, they have been carried out in a large proportion of the reserved forests of the country, have on the whole proved extremely beneficial and in this way contributed largely to the increase of forest revenue in the last 20 years or so. There is no sharp line to be drawn between improvement fellings of this kind and selection thinnings, but the improvement fellings cover the period during which a hitherto unworked or badly treated forest is being brought into good condition, a period during which the material removed tends to be very inferior and so not to make the contribution to the yield and revenue which selection thinnings should.

Execution of improvement fellings

The carrying out of improvement fellings varies a great deal with forest type and condition, place and time, and most provinces have standing orders on the subject where the working plan is not already explicit. The following operations usually find a place, though some may be omitted or, on the other hand, specially stressed.

(1) Felling utilizable dry trees.

(2) Felling unsound overmature trees which are unlikely to survive, or which will further deteriorate before the next felling, unless they are required for seed, frost protection, or soil cover, and if they are unsaleable, only if their removal will benefit better trees or regeneration.

(3) Felling unsound or badly shaped mature or immature trees where their removal will benefit other better growth. Special provisos are often necessary to prevent this operation from resulting in felling for revenue.

(4) Thinning out crowded groups of trees. This is to be done in the younger age-classes which can benefit from it, and once again, special provisos may be added for the exclusion of the larger trees

which should be retained to contribute to the main revenue-producing fellings to be made later on.

(5) Cutting back badly shaped or injured saplings and advance growth from which better new coppice shoots can be expected to be obtained. Obviously cutting back is useless if done under shade heavy enough to prevent proper growth, conditions varying with species.

(6) Removal of undesirable undergrowth or subsidiary species which are preventing or likely to prevent regeneration or growth of the major species, as with evergreen species in the wet types of sal.

(7) Climber cutting.

(8) Removal of diseased and fig-or *Loranthus*-infested trees.

Where any saleable material is marked in an improvement felling, it is very often sold on lump sum, and the purchaser may be required to do a certain amount of the work of felling any remaining marked but valueless trees. Where there is no sale, or after the saleable material has been removed, the remaining work is generally done by a gang of labour under a trained subordinate.

Superfluous work

Experience has taught that it can easily happen that much money and time can be wasted in doing unnecessary or even harmful felling, cutting back, and girdling, and the point must be stressed that nothing should be done without a clear conception of the resultant benefit to the crop. Examples are provided by the cutting back of suppressed sal without removing the cause of suppression, and unnecessary felling of broad-leaved trees to help young deodar and the blue pine which can grow up through them in any case. It is also generally advisable to apply the dictum ' when in doubt, leave ' to this class of operation.

Girdling

Removal of unsaleable trees may be effected by felling or girdling. Felling is almost always to be preferred to girdling for all trees below a certain size, say 2′ girth, though rarely with weed species the unwanted coppice shoots may be stronger than the shoots sent out after girdling. Effective girdling is hardly possible with some species, especially those with very fluted stems such as *Adina* and *Bombax*, and these must be felled. Some other species require very deep girdling, e.g. *Terminalia tomentosa* and others are very slow to die in any case, e.g. *Kydia*, *Lagerstroemia lanceolata*, *Grewia*, etc. Thin-barked trees, especially those of wet tropical evergreen forest, are usually more susceptible to girdling than thick-barked trees. ‘Poison-girdling’ has not been found very effective with our deciduous species, as although the portion above the girdle is usually killed, the vigour of the coppice shoots is hardly affected : in Malayan tropical evergreen forest, poison-girdling with arsenite has been found to be quick, cheap and effective, the poison being poured from a vessel with a fine spout into a frill made all round the tree with a *khukri* or similar instrument. Blow-lamps have also been used successfully for the same purpose, but are not effective on thick-barked trees. Girdling should never be done along roadsides, as dead trees are easily blown down by wind and are dangerous to passers-by.

In all the opener and drier types of forest, care is required that improvement fellings do not result in increased grass growth and increased risk of fire damage.

Climber control in pole and tree crops

Climber cutting has often been the first tending operation carried out in many of our forests. Forests in which it has not been done, as in the sal along the Nepal border, show how beneficial the effect may be in most types of forest. See Plate 28. Although heavy growth of the giant climbers, such as *Bauhinia vahlii*, *Spatholobus*, *Butea superba*, etc., may have been eliminated from our better high forests, they, and many others even more dangerous to young growth, are always present, and climber control will always be required. It has been seen (p. 252) that in plantations, especially in *taungyas*, climbers appear to get in directly intensive cultivation ceases and before the closed canopy is formed, and that it is worth-while to take special steps to have them uprooted at this stage. In natural regeneration, similarly, climbers are often inconspicuous during the first year or so after the main fellings, and then seem suddenly to multiply ; this has happened in sal regeneration in most provinces, different species of climber giving trouble in different localities. Cutting the climbers may reduce the damage if done in time, but does not greatly reduce their growth in the next season, when they send up new shoots from above or below ground.

Poisoning climbers

Attempts to kill climbers by application of poison in various ways to the cut stems have sometimes been reported to have given satisfactory results, but the work is tedious and expensive, and in any case only applicable to the big species which are often not the most dangerous.

Successful climber poisoning has been done in the dry fuel forests of Madras. In this type the time of year at which the poisoning is done appears to be most important.

Uprooting

The best method of dealing with climbers appears to be to uproot them as completely as possible, which means digging or pulling up when the ground is soft—usually in the rains.

Season of work

Climber cutting in high forest is done in the cold weather. To ensure complete severance a section of the stem should be removed by two cuts and the hanging stem must not remain in contact with the ground or it will probably strike root again. Climber cutting is usually prescribed for the year previous to the felling in climber-infested irregular forest, with the object of giving the stems time to rot so that felled trees will not get hung up, and the damage to unmarked trees will be reduced.

PRUNING

Need for pruning

Until recent years, foresters generally have disapproved of pruning as savouring too much of gardening, and as causing unsoundness by facilitating the entry into the bole of rot-causing fungi. Further, in India, it has been—and in fact still generally is—considered altogether impracticable, though mulberry is now regularly pruned in the Punjab for the production of timber suitable for sports goods. We have already seen, however, that modern thinning methods developed to concentrate as much as possible of the potential increment of an area on selected best stems, and to shorten the rotation for large timber, necessitate pruning for best results, and the necessary stimulus being thus provided, it has been shown that pruning can be done at reasonable cost and need not result in unsoundness.[17] The cost with interest to maturity would rarely exceed about Rs. 2 per mature trees.

Such pruning is of course only done on the elite stems, commencing with three or four times the number expected in the final crop, and is commenced for an early stage, at the second or third thinning, or when the trees are about 6″ diameter.

Method of pruning

Dead, moribund, and sometimes even green branches are cut off close to the bole. A hand-saw is far better than any cutting instrument, the use of the latter, though it should leave a cleaner cut, invariably resulting in this country in damage to the bark of the bole and often leaving irregular stumps to be concluded. Long-handled saws have been tried off the higher branches, but, especially under Indian conditions, the use of a short light ladder with an ordinary hand-saw is preferable.

Forked stems

It is very difficult to remove one fork of a forked tree except at a very early stage, especially in a hardwood like sal, and it should not ordinarily be attemped. It is however often worth doing on low forks of young teak, and is considered an essential part of the cleaning operations in some divisions in Burma ; similarly for low-forking *Cedrela*, *Terminalia*, *Chukrasia*, etc. in N. Bengal.

Height of pruning

The height to which pruning should be carried varies with species and conditions, but in young plantations is usually about one-half to three-fifths of the total height. Pruning is repeated at each thinning till the maximum height which has been decided on as practicable and necessary is reached ; this is very usually about 15′.

In only a few instances has pruning yet been undertaken in plantations in India, but it seems probable that, as in other countries, it will be found profitable to do it where clean high-priced timber is the chief object of management particularly in the case of conifers.

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Finance Budget Publishing Ltd. (R).
General Book Depot.
Imperial Publishing Co., 3, Faiz Bazar, Daryaganj.
Indian Army Book Depot, 3, Daryaganj.
J. M. Jaina & Brothers, Mori Gate.
Knowledge Emporium (R).
Metropolitan Book Co., Delhi Gate.
N. C. Kansil & Co., Delhi Gate.
New Stationery House, Subzimandi.
Raja Brothers (R).
Universal Book & Sty. Co., 16, Faiz Bazar (R).
University Book House (R).
Youngman & Co. (Regd.), Eagerton Road.

DHANBAD—
Indian School of Mines & Applied Geology Store Ltd.

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* For Hindi Publications.
† Has a branch at Khan Market in the name of Behri Sons.

[*Continued on inner side of the back cover.*]

List of Agents for the Sale of Govt. of India Publications as on 7-12-56—*contd.*

[*Continued from inner side of the front cover.*]

DHUBRI (ASSAM)—
The Students Library (R).

ERNAKULAM—
Bharat Stores.
Probhat Book House (R).

FEROZEPORE—
English Book Depot.

GORAKHPUR (U.P.)—
Halchal Sahitya Mandir (R).

GUNTUR—
Bharat Book Centre.
Globe Traders.

GWALIOR—
M. B. Jain & Brothers.
Saraswati Sadan (Loyal Book Depot).
**Supdt., Ptg. & Sty. (M.B.).*

HANAMKONDA—
Deccan Book Stall.

HOSHIARPUR—
Universal Book Stores.

HYDERABAD (DN.)—
**Director, Govt. Press (Publication Bureau).*
Hyderabad Book Depot.
Peoples' Book House, Nizamabad Road.
Swaraj Book Depot, 1368, Lakri-ka-pul.

INDORE—
Rupayama, Rampur Wala Buildings.
Shri Indore Book Depot, 33, Mahatma Gandhi Road.
Wadhwa & Co., 56, Mahatma Gandhi Road.

JAIPUR CITY—
Garg Book Co., Tripolia Bazar.
**Govt. Ptg. & Sty. Dept., Rajasthan.*
Rajasthan Pustak Mandir, Tripolia Bazar.
Vani Mandir, Sawai Mansingh Highway.

JAMMU (TAWI)—
Krishna General Stores, Raghu Nath Bazar.
Students' Stores, Raghu Nath Bazar.

JAMNAGAR—
Swadeshi Vastu Bhandar.

JAMSHEDPUR—
Amar Kitab Ghar, Diagonal Road, P. B. No. 78.

JODHPUR—
Chopra Brothers, Tripolia Bazar.
Dwarka Dass Rathi.
Kitab Ghar, Sojati Gate.
Mahesh Book House (R).

JUBBULPORE—
Modern Book House, Jawaharganj.

JULLUNDUR CITY—
Hazooria & Sons, Mai Hiran Gate.
International Book & News Co., G. T. Road (R).
Jain General House.
University Publishers.

KANPUR—
Advani & Co.
Sahitya Niketan.
Universal Book Stall, The Mall.

KAPASAU (RAJASTHAN)—
Namdhar Brothers (R).

KARNAL—
Malhotra & Co.

KHANDWA—
The Suresh Trading Co.

KHURJA—
Bharati Mandir, 31-C, Nai Basti.

KODARMA—
The Bhagwati Press, P.O. Thumsitelaiya.

KOLAHPUR—
Maharashtra Grantha Bhandar (R).

KOTTAYAM—
The Vidyarthi Mittram Book Depot, P.B. No. 8.

KOZHIKODE—
K. P. Brothers (R).

KUMTA—
S. V. Kamat.

KURNOOL—
Fineland Agencies (Regd.).

LUCKNOW—
Balkrishna Book Co. Ltd., Hazratganj.
British Book Depot, 84, Hazratganj.
Law Book Agency, 29-A, Katchery Road.
Ram Advani, Hazratganj.
Soochna Sahitya Depot (State Book Depot, U. P.).
Universal Publishers Ltd., Plaza Bldgs.
Upper India Publishing House Ltd., Literature Palace.

LUDHIANA—
Loyall Book Depot.
Mohindra Brothers (R).

MADRAS—
Accounts Test Institute, P. O. 760, Egmore.
C. Subhiah Chetty & Co., Triplicane.
Higginbothams.
K. Krishnamurty, Mount Road.
Presidency Book Supplies, 8, Pycrofts, Triplicane.
Simham Publishing Co.
**Supdt., Govt. Press, Mount Road.*
Varadachary & Co.

MADURAI—
E. M. Gopal Krishna Kone, North Chitra Street.
Viveka Nanda Press, 48, West Masi Street.

MANDSAUR—
Sikhwal News Agency.

MANGALORE—
U. R. Shenoy & Sons, Car Street.

MASULIPATNAM—
M. Seshachalam & Co.
Triveni Publishers.

MEERUT—
Hind Chitra Press.
Loyall Book Depot, Chhipi Tank.
Prakash Educational Stores.
Universal Book Depot.

MORADABAD—
National Book Depot.

MYSORE—
Chandra Stores, New Statue Circle (R).
H. Venkataramaiah & Sons, New Statue Circle.
J. Nanu Mal & Sons, Lansdown Bldgs.

NAGPUR—
New Book Depot, Modi No. 3, Sitabuldi.
**Supdt., Govt. Ptg. (M.P.).*
Western Book Depot.

NAINITAL—
Consul Book Depot.

NEW DELHI—
Ajmeri Gate Paper & Sty. Mart, 1/6B, Block Ajmeri Gate Extn.
Amrit Book Co., Connaught Circus.
Bhawnani & Sons, Connaught Place.
Central News Agency, Connaught Circus.
Empire Book Depot, 278, Aliganj, Lodhi Road.
English Book Stores, 'L' Block, Connaught Circus.
Faqir Chand Marwah & Sons, Khan Market.
Hind Book House (R).
Jain Book Agency, Connaught Place.
Jayna Book Depot, Bank Street, Karol Bagh.
Luxmi Book Store (R).
Mehra Brothers, 50-G, Kalkaji.
Navug Traders, Original Road, Karol Bagh.
Oxford Book & Stationery Co., Scindia House.
Raj Book Depot, 1, Bengali Mal Market.
Ram Krishna & Sons (of Lahore), 13/13, Connaught Place.
Saraswati Book Depot, 15, Lady Hardinge Road.
Sikh Publishing House Ltd., 70/C, Connaught Place.
Suneja Book Centre, 24/90, Connaught Circus.
Taneja Book & Stationery Mart, Raisina Road.
United Book Agency, 47, Amritkaur Market, Paharganj.
Venus Sales Corp. (R), Karol Bagh, New Delhi.

ONGOLE—
Shri D. Sreekrishnamurthy, Prop., Abhyudaya Book Circulating Co.

PALGHAT—
Shri V. K. Ramalingam Vabakkanthara (R).

PATHANKOT—
The Krishna Book Depot.

* For Hindi Publications.

List of Agents for the Sale of Govt. of India Publications as on 7-12-56—*concld.*

PATIALA—
Jain & Co., Bazar Shah Nashin.
**Supdt., Bhupendra State Press.*

PATNA—
Book Centre, Near B. N. College.
J. N. P. Agarwal & Co., Padri-ki-Haveli.
Lakshmi Trading Co., Padri-ki-Haveli.
Moti Lal Banarsi.
Novelty & Co. (R).
Pahuja Brothers, Rajendra Path (R).
Scientific Book Co. (R).
**Supdt., Govt. Printing, Bihar.*

POONA—
Deccan Book Stall, Ferguson College Square Road.
Imperial Book Depot, 266, Main Street.
International Book Service, Deccan Gymkhana.
N.R. Bhalerao, 602, Shanwar Peth.
Raka Book Agency.

PUDUKKATTAI—
P. N. Swaminatha Sivam & Co., East Main Street.

RAIPUR—
Kasimud-Din & Sons, Gole Bazar (R).

RAJKOT—
Mohan Lal Dossabhai Shah.

RANCHI—
Ideal Book Stores, Main Road.

REWA—
**Supdt., Govt. State Emporium, V. P.*

ROORKEE (U.P.)—
Cambridge Book Depot (R).

SAGAR (M.P.)—
Students Book Depot (R).

SECUNDERABAD (DN.)—
Hindustan Diary Publishers.

SHILLONG—
Chapla Book Stall (R).
**Supdt., Assam Sectt. Press.*

SIBSAGAR (ASSAM)—
T. Chuttya (R).

SILCHAR (ASSAM)—
Shri Nishith Sen (R).

SIMLA—
Azad Kitab Mahal, Stall No. 13.
J. Ray & Sons (India), Ltd.
Maria Brothers, 94, The Mall (R).
Minerva Book Shop, The Mall.
New Book Depot.
**Supdt., Himachal Pradesh Govt.*

SIROHI—
Milapchand Balbebutmal Haran, Kessar Road.

SONEPAT—
United Book Agency.

SRINAGAR—
The Kashmir Book Shop, Residency Road.

SURAT—
Shree Gajanan Pustakalaya, Lower Road.

TRICHINOPOLY FORT—
Palaniappa Brothers, Teppakulam.
S/S. Krishnaswami & Co., Teppakulam.

TRIVENDRUM—
International Book Depot, Main Road.
**Supdt., Govt. Press, Travancore-Cochin.*

UDAIPUR—
Vidya Bhawan (R).

VELLORE—
S. Venkatasubhan, Law Booksellers.

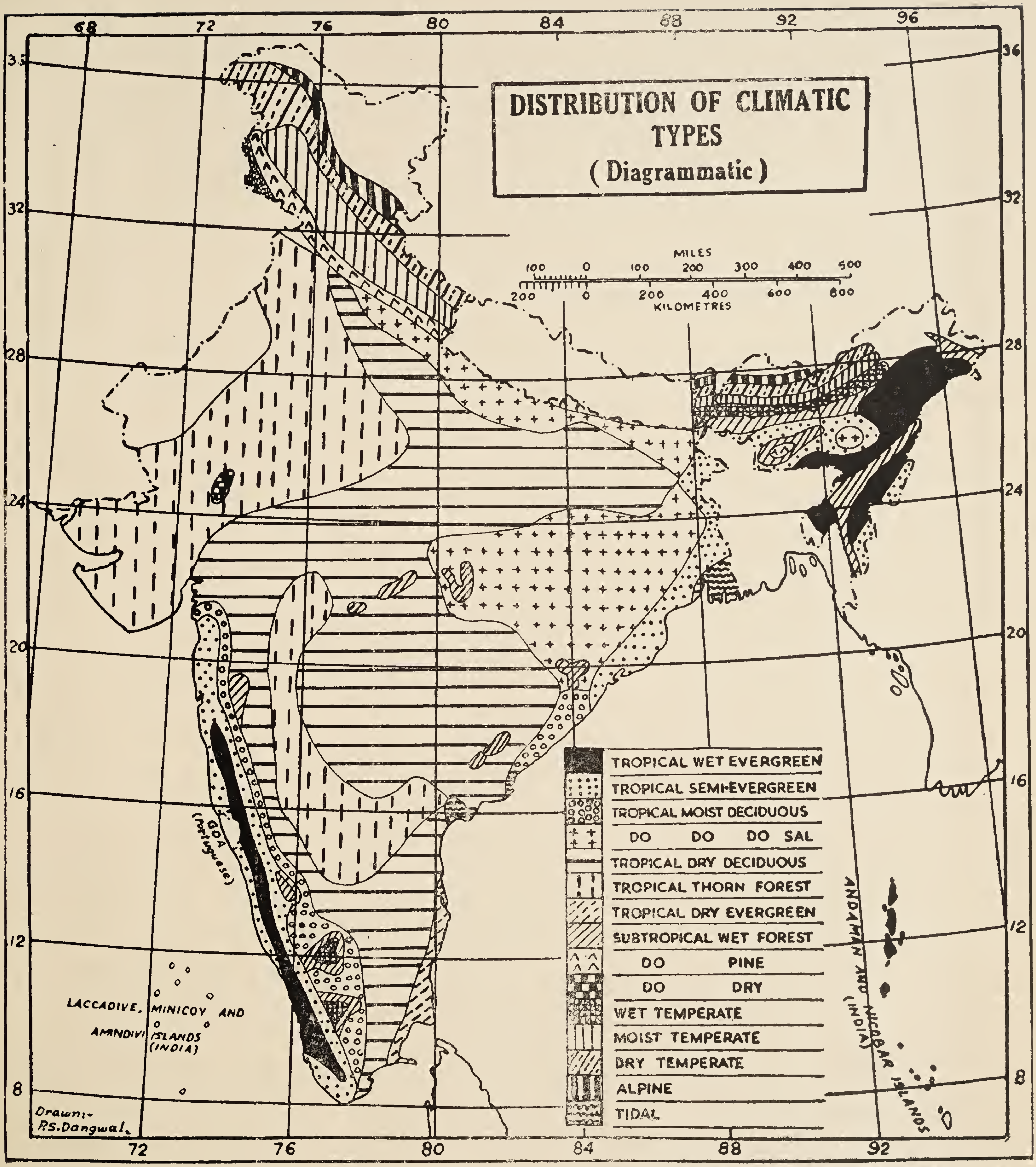
VIJAYAWADA—
Hindustan Diary Publishers.

VIZAGAPATAM—
Book Centre, 11/97, Main Road.
Gupta Brothers, Vizia Buildings.
M. S. R. Murty & Co.

WARDHA—
Swarajya Bhandar, Bhaji Market.

Govt. of India Kitab Mahal, Queensway, Opposite India Coffee House, New Delhi. Govt. of India Book Depot, 8, Hastings Street, Calcutta.	For local sale only.
High Commissioner for India in London, India House, Aldwych, London, W.C.2.	For all enquiries and orders from Europe and America.

* For Hindi Publications.



Sikkim and Bhutan States are attached to India by special treaties