MANUAL OF AFFORESTATION IN NEPAL

Volume 1

by

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July 1994

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Ministry of Forests and Soil Conservation
Kathamandu, Nepal.

This publication was produced under the auspices of the Forest Research and Survey Centre of the Ministry of Forests and Soil Conservation, His Majesty's Government of Nepal. The Centre is supported by the Nepal–UK Forestry Research Project, which is funded by the British Government's Overseas Development Administration.

Jackson, J.K. (1994) *Manual of afforestation in Nepal.* Kathmandu: Forest Research and Survey Centre. 2nd edition.

Cover photo: Timber Corporation of Nepal's *Dalbergia sissoo* plantation at Chiliya, Rupandehi District, Western Development Region. The trees are eight years old and no thinning has taken place.

First edition published 1987
Second edition revised and published in two volumes 1994

Editorial team: Jenny Riley, Manoj Pradhan, Yugesh Kayastha.
Printed by Nepal Lithographing Co. (P) Ltd, Kathmandu.

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FOREWORD TO SECOND EDITION

Although the first edition of this manual was published in 1987, it was based on information available to the middle of 1985. Since then there has been a great deal of activity in forestry in Nepal, and much new information has accumulated. There has also been a change in emphasis from larger-scale plantations to tree planting by user groups and individual farmers, though industrial plantations still have a place in the future development of Nepal. For these reasons quite considerable revision of the original manual has been needed.

In this revision much help was received from an informal working group, consisting of Dr S.M. Amatya of the Forest Research and Survey Centre, Ministry of Forests and Soil Conservation; Mr M. Gautam of the Nepal–Australia Community Forestry Project; Dr I. McCracken of the Community Forestry Development Project; Dr T. Parker of USAID working with the Institute of Forestry; and Mr A. Purakka of the United Mission to Nepal.

In addition much co-operation was received from the staff of the Forest Research and Survey Centre and the Nepal–UK Forestry Research Project in Kathmandu. Particular thanks are due to the Libraian, Mr D. Thapa, and his staff, who spent a great deal of time making available a mass of published material.

To all these sincere thanks are due. All errors and omissions, however, are the responsibility of the compiler.

Chapter 1

INTRODUCTION

General introduction

This manual is a compilation of information on the most suitable techniques, as far as present knowledge goes, for establishing forest plantations in Nepal. Special attention has been paid to simple techniques which can be used in small-scale community forestry plantations, although techniques appropriate to large-scale plantations have also been included, though in less detail. However, community forestry plantations, though extremely important, will not in themselves meet the future needs of Nepal for fuelwood and timber, especially near large towns and in the Terai. Attention has also been given to tree species which provide fodder for domestic animals as these species play a vital role in local farming systems, especially in the hills.

The manual is not intended for use by the lower grades of forestry employees such as guards and nursery *naike* upon whom the success of an afforestation programme so largely depends. It is hoped, however, that it will serve as a source from which simplified instructions for this level of staff, and for user groups, can be compiled in Nepali.

Wherever possible the manual draws on experience acquired in Nepal. It has been obtained from a large number of published and unpublished reports, and from personal contacts, particularly with the working group mentioned in the Foreword. Much help has also been received from colleagues in the Nepal–UK Forestry Research Project, and from many other sources.

There is, however, a great deal of field experience in forestry in Nepal that is never put down in writing, and is lost when the forester with this experience either retires or is transferred to a different type of work or leaves the country. Even the records of some internationally supported projects are extremely scanty. It is important that results from field experience and from trials are written down and disseminated widely. There are various media through which this can be done such as *Banko Janakari* and the *Nepal Journal of Forestry*.

Sometimes reports on forestry activities are prepared but become buried in departmental or project archives. They are not readily available to interested persons. It is recommended that copies of all reports of general forestry interest should be deposited in the Central Forest Library located in the Forest Research and Survey Centre, Kathmandu.

A secondary source of information on forestry practices suitable for Nepal is the large amount of literature available from India, where many species also planted in Nepal have been studied for decades. Here, however, some caution must be used: although India and Nepal are adjoining countries and both cover large stretches of the Himalaya, conditions are not the same in each. In the Indian Himalaya west of Nepal the winter rainfall and snowfall are considerably higher than in most of Nepal, and increase from east to west. Thus certain techniques (e.g. winter planting) and also some species (e.g. *Robinia pseudoacacia*) which are successful in the western Himalaya may not be under the drier conditions of winter in Nepal.

The eastern Himalaya in India, such as Darjeeling and Sikkim, has very high rainfall and a long rainy season. In Nepal similar conditions are only found in a small area in the extreme east of the country, in Ilam and parts of the Koshi-Tamur basin. Certain species, for instance *Cryptomeria japonica*, which flourish in Darjeeling show considerably poorer growth in most parts of Nepal. Thus in using information from India attention must be paid to the different conditions which may be found there.

Many species are planted in the subtropics and tropics of a large part of the world, for example, tropical pines, teak, eucalypts and *Gmelina arborea*. Many of the techniques used in raising these species elsewhere are also applicable to Nepal, but in transferring these techniques consideration must be paid not only to possible differences in climate and soil, but also to different socio-economic conditions. Techniques suited to a highly developed country where labour is expensive and there is a well-developed transport network may not be appropriate to a village community in Nepal, approachable only by walking several days from the nearest road and where labour is relatively cheap but capital is scarce.

Organization of the manual

The manual is produced in two volumes. Volume 1 deals with general matters, and Volume 2 with particular species or groups of species.

The early sections of Volume 1 give background information on geography and topography, geology and soils, climate, and vegetation. The chapters on topography, soils and vegetation are very summary, and for more complete information other works must be consulted. More details have been given on climate, emphasis being placed on the occurrence of unusually wet or dry years, rather than mean rainfall figures. In any month the rainfall will be less than average in one year out of two, and techniques which only succeed in years of average or above average rainfall will fail half of the time.

Then follows a chapter on plantation policy and planning. This begins with a general discussion of government policies as they affect forest plantations, and goes on to deal with plantation planning. When devising a plantation programme it is necessary to have first a clear idea of what purpose the plantation is designed to achieve. Secondly, although there may be an excellent theoretical knowledge of the best techniques to use in nurseries and plantation establishment, this will be wasted unless operations are planned so that the work is carried out at the proper time, and labour and materials are available when needed.

The next section of the manual deals with general techniques applicable to several species. It is divided into chapters on seed, nurseries, plantation establishment and plantation protection. It is assumed that the standard technique will be to raise seedlings in polythene bags (polypots) as this is a general and well-understood practice in Nepal, and is also more reliable than other methods under less than optimum conditions. It is also assumed that the best size for planting seedlings of most species is between 20 and 30 cm tall. Alternatives to these techniques are described briefly where appropriate.

Finally a short chapter on the management of natural forests has been added, as the importance of the natural forest in supplying local needs of fodder, fuelwood and timber is being increasingly recognized. Natural forest management is an immense subject, and here it has only been possible to describe a few techniques which might be used by local communities. In Nepal this type of management is relatively new, although it builds on old traditions. As more knowledge and experience is obtained it should eventually be possible to deal with the subject in much more detail.

Volume 2 deals with individual species. More space is given to the most important species, but this is also influenced by the amount of information available. There are some fairly important species about which relatively little has been published.

The metric system is used throughout, as this is the official system in Nepal. The use of units such as acres, cubic feet and gallons should be strongly discouraged. However, it is still customary to express the dimensions of some items, such as plastic pots, in imperial units. In such cases measurements in both systems have been given. Rural people will continue to use traditional measures, such as *mana*, *pathi* and *ropani* for a long time into the future. The equivalents of some of these measures are given in Appendix 1 at the end of both volumes.

While every effort has been made to be accurate, some errors are almost certain to have been included. The manual is not the last word on afforestation in Nepal. More information is continually becoming available, and new and improved techniques are being developed. It is hoped that all new information will be published and disseminated as widely as possible.

Chapter 2

GEOGRAPHY AND TOPOGRAPHY

The Kingdom of Nepal occupies a large part of the central Himalaya and its foothills. It is roughly rectangular in shape, averaging about 870 km in length by 130 km in width, on an axis running from west-northwest to east-southeast. Its total area is about 147,480 km^2. In latitude it ranges from 26°22' to 30°27'N, and in longitude from 80°04' to 88°12'E. In altitude it ranges from about 70 m above sea level in the southeastern Terai, to 8848 m at the summit of Mount Everest (Sagarmatha), the highest point on the surface of the earth.

Topographically Nepal can be divided into six roughly parallel zones, from south to north. These are: (1) the Terai; (2) the Siwalik or Churia Hills; (3) the Mahabharat Range, sometimes known as the Lesser Himalaya; (4) the Middle Hills or Midland; (5) the Main Himalaya Range; and (6) the Trans-Himalaya Valleys and Hills.

The Terai

The term terai is used loosely to refer to the relatively flat area lying between the Siwalik Hills and the southern frontier of Nepal. It forms a continuous belt along the frontier except in two areas, near Koilabas and south of Chitawan, where the frontier runs along the crest of the Siwalik Hills. Its altitude ranges from 70 to 300 m.

The Terai can be divided into three sub-zones. The Bhabar Terai zone lies immediately at the foot of the Siwalik Hills, and consists of bouldery and gravelly areas derived from alluvial fans at the base of the hills. Many of the streams flowing from the hills disappear into the very freely drained soil of this area to reappear again in the Terai proper. Surface water supplies are scanty, and digging wells is difficult because of the bouldery subsoil. The land is not very good for crops, and hence the area is relatively lightly inhabited and still contains a good deal of forest.

The Terai in the strict sense is the area where the water which has drained into the gravels of the Bhabar Terai reappears again at the surface, often in a line of springs. At one time much of this zone was swampy, and it used to be very sparsely inhabited because of the existence of a particularly virulent form of malaria. Since the 1950s mosquito control has allowed settlements to take place, and almost the whole area is now under cultivation. The region to the south of this, the southern Terai, is an extension of the Gangetic Plain of India, and is also nearly all cultivated.

The rivers flowing through the Terai have broad, very flat, bouldery beds, through which in the dry season often only a trickle of water flows. The banks are ill-defined, and especially in the Bhabar Terai zone the rivers tend to erode laterally rather than to deepen their beds. They tend to change course frequently, often with disastrous consequences; the bed of the Koshi River has moved 115 km to the west during the last one hundred years (Hagen, 1980).

The Terai in the broad sense is the most productive agricultural zone of Nepal, and in 1981 it was estimated to have about 44 per cent of the population of the country, or about 6,600,000 people (Pant, 1983).

The Siwaliks or Churia Hills

These hills have been formed from sediments produced by the rising Himalaya during the last 40 million years or so. They rise steeply from the Terai along the whole of its northern flank. Their highest point is about 1800 m. West of about 84°E longitude the peaks average about 1500 m but in the east they are lower, between 500 and 700 m. The hills vary in width, being narrowest in the east, where they are sometimes reduced to a narrow fringe, and broadest in the west. Especially in the east they frequently abut directly on to the Mahabharat range, but further west they are more often separated from it by broad flat-bottomed valleys known as duns or the Inner Terai (*bhitra madesh*); in addition the Siwaliks themselves are in places divided into two ranges with a dun between them.

The duns are generally the valleys of large rivers, such as the Karnali, the Bheri, the Babai, the Western Rapti, and the Chitawan Rapti. These rivers characteristically flow parallel to the hill ranges, either from east to west or vice versa, before suddenly turning south to cross the mountains. This has been attributed to the relatively rapid rise of the Siwaliks which has prevented the rivers cutting a direct course to the south. Apart from these major rivers, the streams rising on the slopes of the Siwaliks themselves flow either north or south, and are very frequently only seasonal.

The Siwaliks are formed from soft, very erodible sediments, so that gullies and areas of bad-land are frequent. For these reasons and lack of water they have not been cultivated in the past and there is little inhabitation. Recently however areas of cultivation have begun to appear in the hills, a very undesirable trend in view of the extremely fragile nature of the soil in this area.

The duns were also previously largely uninhabited, due to malaria, except for the Dang area which was inhabited by an indigenous people, the Tharu, who had developed a considerable natural resistance to this disease. However, now that malaria has been considerably reduced, there has been a good deal of settlement in some of the duns, particularly in the Rapti Valley.

The Mahabharat Range

This range runs from west-northwest to east-southeast across the whole of southern Nepal. It reaches a height of about 2960 m, but most of the peaks are between 2000 and 2500 m. The Mahabharat Range is formed of much older and harder rocks than the Siwaliks, and hence is much less eroded. In places the topography is very rugged, with very steep rocky slopes. As with the Siwalik Hills there are only a few gaps through which the large rivers have cut valleys, often in steep-sided gorges. In eastern and central Nepal the Mahabharat Range is often bounded to the north by valleys running approximately east and west, such as those of the Tamur and Sun Koshi, the Trisuli, and the lower Kali Gandaki. The Kathmandu Valley forms a similar boundary in the centre. In the far west of Nepal, however, the northern boundary is generally less clearly marked.

The Middle Hills and Valleys

These occupy the centre of the country, between the Mahabharat Range and the Himalaya. Unlike these ranges and the Siwaliks, the hills are intersected by both north-south and east-west valleys, and form a rather irregular deeply dissected plateau rising gradually to the north. Within the Middle Hills altitudes can vary considerably within short distances, as the river valleys are often very deep and may be less than 500 m, while nearby ridge tops may be at 2000 m or more. Thus the lands of a single village may span a considerable range of altitude and hence climate.

The valleys themselves are often rather sparsely inhabited, partly because of malaria in the past, partly because the valley floors are often very narrow. In contrast most of the hill slopes, especially between 1000 and 2000 m, are under intensive, terraced cultivation. In such areas there is often little remaining forest apart from 'shrubberies'. In most places they rise gradually to the north to the main Himalayan range, and there is no clear topographic feature separating them. The 3000 m contour has been taken as a conventional boundary between the Middle Hills and the lower slopes of the Himalaya.

Above 2000 m cultivation and settlement become scarcer, and above 2400 m large-scale cultivation almost ceases. The land lying below 2000 m, however, includes some of the most densely inhabited parts of Nepal; in 1981 it was estimated that 52 per cent of the population lived there. Within these hills there are two considerable depressions, both the sites of former lakes, the Kathmandu and Pokhara Valleys. Both consist of a series of flat-topped terraces separated by escarpments. They are both extensively cultivated.

The Main Himalayan Range

In eastern Nepal the northern frontier of the country roughly follows the line of the Himalaya, except in the Kodari area where the boundary lies to the south of the range. Further west, however, the main range runs well south of the frontier and fairly large areas of Nepal lie north of the main range.

The main Himalayan range does not form the watershed between the Ganges and Brahmaputra (Tsangpo) Rivers, but lies considerably to the south of it. Thus many of the great rivers of Nepal rise north of the main Himalayan chain and cross it in deep gorges. That of the Kali Gandaki with an altitude of 1200 m, separating the mountains Annapurna (8091 m) and Dhaulagiri (8167 m), is one of the deepest gorges in the world. Thus even in the heart of the Himalaya there is land of relatively low altitude. These gorges and other valleys mean that the Himalaya is not a single continuous chain, but is divided into a number of separate massifs. The highest point is Mount Everest (Sagarmatha) at 8848 m. There are seven other peaks above 8000 m in Nepal, and many over 7000 m.

Naturally the Himalaya is very sparsely inhabited. About 21,000 km^2 are under permanent ice and snow, and much of the rest is poor grazing land, usable only in the summer. There are a few patches of cultivation in the valleys near villages.

The Trans-Himalayan Valleys and Mountains

The most important areas north of the main Himalayan chain are the upper tributaries of the Kali Gandaki (Mustang), of the Bheri (Dolpo), and of the Karnali (Humla, Mugu). These are areas of high elevation (3000 m and more) lying in the rain shadow of the Himalaya. They have considerably lower rainfall than the rest of Nepal and are often semi-desert. The Mustang area is the most arid, and is virtually treeless; Dolpo has a few scattered trees, while in Humla there are larger areas of forest. Much of this zone can be classified as cold semi-desert; it has greater affinities with Tibet than with the rest of Nepal.

Chapter 3

GEOLOGY

Introduction

The geology of Nepal is governed by the events which resulted in the elevation of the Himalaya, and is very complex. Many hundreds of millions of years ago the continents of South America, Africa, Antarctica and Australia, together with the Indian Peninsula, were joined together in one continent which geologists call Gondwanaland. In the late Palaeozoic Era, about 200 million years ago, this continent began to split up, and part of the continental plate which is now the Indian Peninsula drifted slowly northeastwards towards the main continental mass of Asia. For a time the Indian plate and the Asian continent were separated by a shallow sea, in which sediments were deposited, but eventually the Indian plate collided with the Asian plate, squeezing the sedimentary rocks of the old sea into folded mountains. This happened at the end of the Mesozoic Era or early in the Tertiary Era, about 40 million years ago.

After the collision the Indian plate continued to move northwards, and indeed still does so, compressing and folding the strata to the north. In addition to this folding and contortion of the strata great masses of rock have been forced over younger strata along a series of thrust faults, so that in many places younger rocks now lie beneath older ones. Another result of all this movement was that some rock formations were driven to great depths and subjected to extremes of heat and pressure, which changed many of the original sedimentary rocks such as sandstones and shales into metamorphic rocks such as quartzites and schists; other rocks were converted into gneiss.

This folding, metamorphosis and subsequent erosion has produced a complicated geology often with a number of different types of rock within a very short horizontal distance. For this reason only a very generalized account of the geology of Nepal is attempted here. The oldest rocks are the Precambrian schists, gneisses, and limestones which form much of the Mahabharat Range and also occur at the base of parts of the Himalaya. At Phulchoki in the Mahabharat Range they are overlain by sedimentary sandstones and limestones ranging in age from Cambrian to Devonian, and in the upper Kali Gandaki valley and the Mustang area all geological periods from the Cambrian to the Cretaceous are represented.

The Churia or Siwalik Hills consist of sandstones and conglomerates dating from the Miocene to Pleistocene periods; they were formed from debris eroded from the Himalaya as it rose. At a few places in western Nepal there are rocks of Cretaceous and Eocene age but in general sedimentary rocks are rare throughout the country, and metamorphic rocks prevail; most of the midlands have schists, quartzites and phyllites.

To the forester, however, the age and origin of different rocks is less important than their mineral composition and hardness, and the ease with which they can be weathered. These factors influence topography and soil, and hence the vegetation which can grow at different sites. The most common types of rock in Nepal are listed below, and a very generalized map of their occurrence is given in Figure 1, page 13.

Common rocks in Nepal

Granite and gneiss

These are massive coarse-grained igneous rocks containing a high proportion of quartz, with orthoclase feldspar, and muscovite or biotite micas. They occur over most of the Himalaya zone of northern Nepal and form a great deal of the high Himalaya, though the extreme summit of Sagarmatha (Mount Everest) and much of the Annapurna and Dhaulagiri massifs are of limestone, and other types of rock are found in the upper Kali Gandaki valley. Granite and gneiss are also found in the Mahabharat Range where they form some of the higher peaks, in the Shivapuri Lekh (north of Kathmandu), and in many other localities. They are hard rocks and weather slowly. Under temperate conditions they tend to produce shallow and droughty soils, but under conditions of high temperature and rainfall may weather deeply to produce a deep layer of kaolinite (white clay). This has not been recorded in Nepal. The soils produced from them tend to be strongly acid.

Limestones

These are originally sedimentary rocks consisting mainly of calcium carbonate, but some have been metamorphosed by heat and pressure to form crystalline limestone or marble; this has happened to many limestones in Nepal. In addition many Nepal limestones contain large quantities of magnesium carbonate; such rocks are called dolomites. The main occurrences of limestone in Nepal are in the northwest, particularly in the Annapurna and Dhaulagiri massifs, and in the Mahabharat Range, where they are quarried for building stone and cement. However, there are many other areas of limestone sometimes interbedded with schists and phyllites. Limestone slowly dissolves in water containing carbon dioxide. However, most of the limestones in Nepal, especially the dolomites, are hard, and weather slowly. Hence the typical 'karst' forms of limestone country, with underground streams, caverns, and very little surface water, are rare in this country. Limestones weather to form soils with a low sand content, and usually a high pH associated with a high calcium carbonate content. However weak to moderately acid soils can develop on limestone in some circumstances.

Shales, schists, quartzites and phyllites

Large parts of the Middle Hills are composed of alternating strata of these rocks, together with beds of limestone and other types of rock. The different strata range in thickness from a few centimetres upwards, and so in a short distance a series of rocks of very different mineral composition may be found. Some of these are easily weathered and eroded while others are hard and resistant. These strata are strongly folded and in most places slope down or 'dip' steeply either to the north or to the south. The slope parallel to the surface of the strata is known as the dip slope and is usually of fairly even and gentle gradient. Scarp slopes are roughly at right angles to the surface of the strata, and are relatively steep. The different strata often differ in their rate of weathering, when the alternation of dip and scarp slopes may produce a stepped effect. Frequently the dip slope will be mainly under agricultural crops while the steeper scarp slope remains under forest.

Of the different rock types shales are fine-grained sedimentary rocks which split into thin sheets. They are metamorphosed into slates which are rather harder. Slate-like rocks with much flaky mica on the cleavage plains are called phyllites. Phyllites vary in composition. A common type in Nepal is chloritic phyllite which is greenish in colour. Others contain much calcium carbonate and are called calcareous phyllites, while if they contain a lot of sand they are sandy or quartzose phyllites. With the exception of the quartzose phyllites all these rocks weather easily and tend to form soils with a high percentage of silt and clay. Except for those derived from calcareous material they tend to be weakly acid. Schists are similar in composition to granites and gneisses, but they are foliated, that is the minerals are arranged in thin layers which are often wavy or contorted. Schists vary in their ease of weathering, and also in their mineral composition. Hard schists form stony coarse-textured soils; more easily weathered schists are similar to phyllites. Quartzites are metamorphosed sandstones in which the grains are strongly cemented together by silica. They are composed of almost pure silica, and are very resistant to weathering, often remaining behind after softer rocks have been eroded away. They produce sandy, strongly acid, infertile soils.

Sandstones and conglomerates of the Siwalik Hills

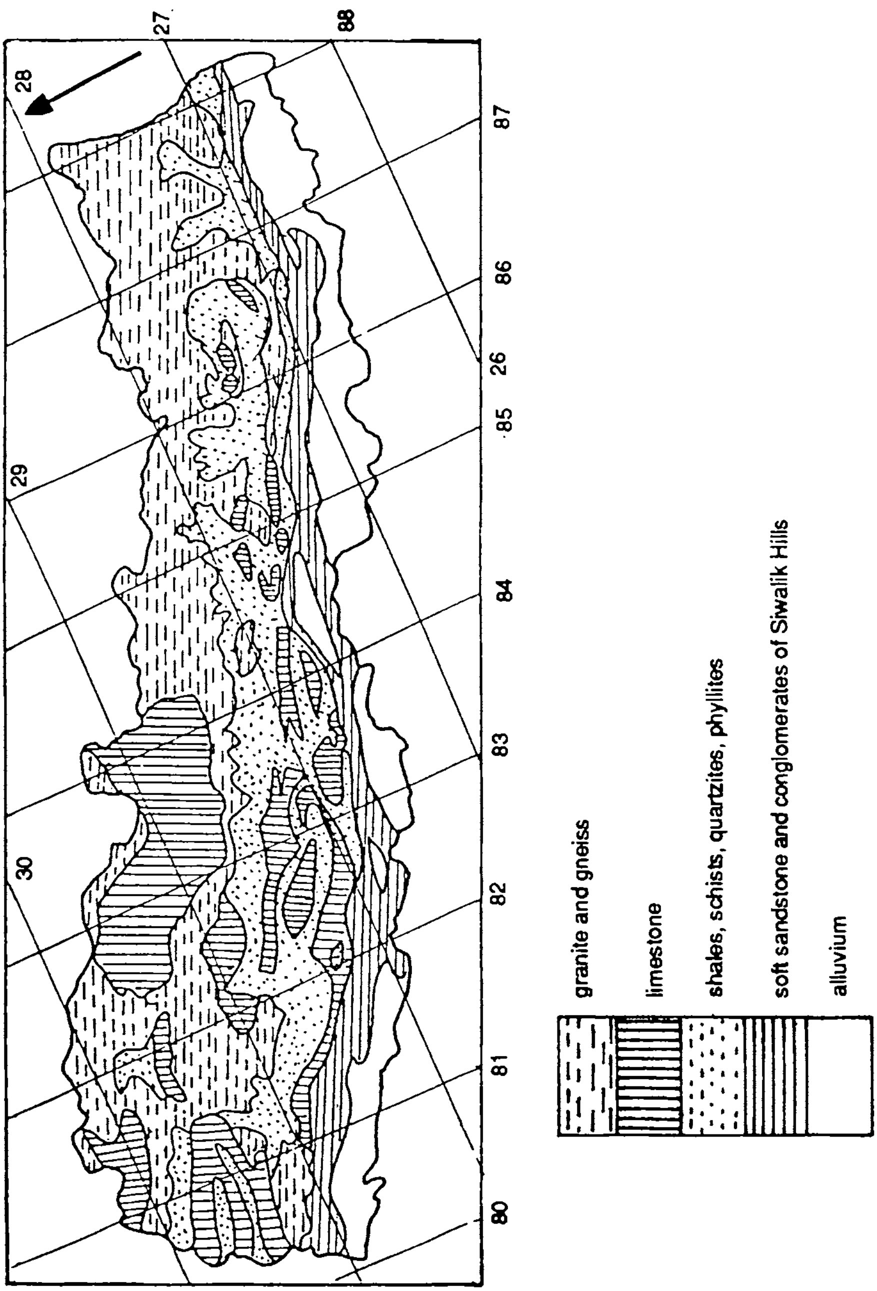
These form an almost continuous belt in the south of Nepal, immediately north of the Gangetic Plain. They are divided into two formations, the Lower Siwalik group consisting of sandstones (some calcareous), thin limestones, claystones, clays and phyllites, and the Upper Siwalik group consisting of friable sandstones, conglomerates, pebble and boulder beds, and clays. These rocks are soft and very susceptible to erosion, the rate of which is so high that many of the soils are skeletal (consisting mostly of rock fragments). The texture of the soil varies according to the parent material.

Alluvium and glacial deposits

Alluvium is unconsolidated material deposited by rivers. The most extensive area is in the Terai which is part of the great Indo-Gangetic Plain. In parts of India the depth of alluvium reaches 6000 m and in Nepal it is believed to reach over 1500 m. Other areas of alluvium are found in the duns, the Kathmandu and Pokhara Valleys, and along most rivers and streams except where they have cut deep gorges. The nature of the alluvium depends on the parent materials from which it has been derived, and so it may vary in texture from sand to clay, and in pH from acid to basic, though many alluvial soils in Nepal are rather basic. In the Indo-Gangetic Plain the zone nearest the Siwalik Hills contains many boulders and much gravel, while further out the texture becomes finer. The very gravelly area is distinguished as the Bhabar zone; in it the rivers erode laterally at a very fast rate, so that they have very wide stony beds which are dry for most of the year. Rivers have been known to erode from streams over which a man could jump to two hundred metres wide within a human life-span (Bulmer, 1984). Another type of deposit is the material left behind by glaciers, such as moraines. Soils in the Himalaya are often formed on such deposits.

References: Hagen (1960; 1963; 1980); Kenting Earth Sciences Ltd (1982)(far west of Nepal); Khan and Tater (1969); Remy (1975) includes map at 1 inch to 8 miles of all Nepal west of longitude 86°E; C.K. Sharma (1977). For further details see references in these works.

Figure 1—Sketch map of the distribution of the more important rock types (after Hagen (1963); scale 1: 6 million)



Chapter 4

SOILS

Soil classification

Soil classification is a highly technical subject and not one in which the ordinary forest officer can be expected to become an expert. Nevertheless in order to make use of the literature and especially the Land Systems maps produced by the Land Resources Mapping Project, which now cover the whole of Nepal at the scale of 1:125,000, it is desirable to have some understanding of the meaning of terms used in soil classification. For more information about the maps see Maharjan (1982).

There are many systems of soil classification, but the one which it has been agreed should be used in Nepal is *Soil taxonomy* produced by the United States Department of Agriculture (Soil Survey Staff, USDA, 1975). This system involves the use of a large number of newly coined and unfamiliar terms, and some of the distinctions between different categories of soil are highly technical, so that the classification is not easily understood by the non-specialist. In addition, for accurate classification both field and laboratory data are needed, and this is not always available. Howell (1986c) has prepared simplified keys to *Soil taxonomy*, but it is doubtful whether many laymen would actually find them simple to use. Here an attempt is made to describe in fairly general terms the most common types of soil in Nepal, as classified under the USDA system. The descriptions are necessarily imprecise; greater precision would involve many technical details which are inappropriate here. In preparing the descriptions considerable use has been made of Carson (1992a).

Soil taxonomy distinguishes a hierarchy of six categories of soil: Orders, Suborders, Great Groups, Subgroups, Families and Series. Only the first three will be described here. Ten orders are recognized in the system; those which are most common in Nepal are Entisols, Inceptisols, Mollisols and Alfisols. For the suborders the formative elements in these names—'ent', 'ept', 'oll' and 'alf'—are given a prefix, and an additional prefix is added to give the name of the great groups. Thus in the order of Entisols, the suborder found in the flood plain of rivers is called Fluvents, while the great group of Fluvents that is developed under an ustic moisture regime (during which the soil is dry for at least 90 days in the year) is called Ustifluvents.

Soils of Nepal

1. Order Entisols

Very young soils with little profile[1] development, formed on fresh alluvial deposits or on actively eroding rocks. The bulk of the soil is of relatively unchanged parent materials, such as sand or rock fragments. In some classifications these would be described as skeletal soils.

(a) Suborder Fluvents
These Entisols are recently deposited river sediments. They are generally coarse sandy soils, with a considerable admixture of gravel especially in the mountains. Many are liable to flooding. In Nepal most are classified as Ustifluvents, in that they are dry for at least 90 days in the year.

(b) Suborder Orthents
These are typically found on steep hill slopes (over 30°), or where soil has been deposited by landslides. In the older soils profile development is prevented by rapid erosion. They are usually very shallow, and contain much gravel and many stones and rock fragments. The texture is usually sandy to loamy. Most are Ustorthents, dry at least 90 days in the year, but at higher altitudes when the soil is frozen for considerable periods Cryorthents may be found.

2. Order Inceptisols

These are young soils in which profile development is more advanced than in Entisols; there has been some leaching of the topsoil and weathering of the subsoil, but no marked accumulation of clay or oxides in any horizon.

(a) Suborder Aquepts
These are Inceptisols formed under conditions of impeded drainage, in which there is a high water table, at least during the monsoon, and with the subsoils under anaerobic conditions for long periods. Most are in the Great Group Haplaquepts, characterized by bluish-grey or mottled soil in the lower horizons. They are dominant on the lower piedmont of the Terai, and also common in the duns. Elsewhere they occur sporadically in areas of impeded drainage.

(b) Suborder Ochrepts
Ochrepts include all light-coloured Inceptisols found on well-drained deeper parent materials on the Terai, and in the mountains up to about 1500 m (higher

1 As soils develop a profile is formed consisting of a series of horizontal layers or horizons. The A horizon is near the surface and contains the highest accumulation of organic matter. The B horizon lies below it, and may contain material leached down from the A horizon. The C horizon is the soil parent material, usually partly decomposed rock. Horizons may be clearly demarcated, or may gradually merge into each other.

on south-facing slopes). The Great Group Ustochrepts are found in areas of drier climate (at least 90 days dry each year) and are most common in the Far Western and Mid-Western Development Regions; they have a high base saturation and a relatively high pH. Eutrochrepts are found under wetter climates; they also have a high base saturation (pH 6.5) in the surface horizon. Dystrochrepts have a pH less than 5.5 and are among the commonest soils of the mountainous regions, especially in central and eastern Nepal. Cryochrepts are common over 3500 m, where the soil is frozen for part of the year.

(c) Suborder Umbrepts

These are Inceptisols in which the surface soil is dark coloured, with a high organic matter content and relatively low pH. Haplumbrepts are soils found in the cool temperate climatic zones of the Middle Hills and High Mountains, on neutral to acid bedrock, usually on steep slopes. Cryumbrepts are found over 3500 m.

3. Order Mollisols

These have a dark base-rich topsoil, containing much organic matter, and with a high pH (>6.5). They are found sporadically in *Shorea robusta* forests on the Terai, and under grassland on calcareous rocks at higher elevations. Most Nepalese soils in this order fall into the Great Group Haplustolls of the Suborder Ustolls. Rendolls may occasionally be found. They are formed on limestones and calcareous rocks, with a deep, friable, very dark, often almost black A horizon lying directly over weathered rock.

4. Order Alfisols

These are soils which usually have a light-coloured surface horizon and an accumulation of more clay in the subsoil. They are usually weakly acid and more strongly weathered than Inceptisols. The only important suborder is Ustalfs, which are Alfisols formed when they are dry for 90 days or more in the year. There are two great groups, Rhodustalfs and Haplustalfs. Rhodustalfs are very deep red soils found on ancient river terraces in the Siwalik Hills and Middle Mountains, and occasionally on quartzitic phyllites in the latter. They may be more than 5 m deep. They are very erodible, and often heavily gullied, with the upper horizons completely removed. They are known as *rato mato* in Nepali. Haplustalfs are not so deep red in colour. The surface horizon is often sandy loam to loam, and the subsoil is silt loam to clay. There may be iron mottlings in the subsoil. These soils are found from the Terai to the Middle Hills, on a variety of parent materials.

5. Order Spodosols

These are soils in which iron and organic matter are leached from the surface soil layers and deposited in the subsoil to form strong reddish or blackish layers. They are found in stable landscapes at altitudes above 3000 m where conifers are dominant. They include the podsols of some other classifications.

Note: The Mustang area, which is both very cold in winter and has a very low rainfall, has quite different soils from those in the rest of Nepal. They often have a pH of eight or more, and in places salt efflorescence occurs at the surface. They do not fall into the categories listed above.

Soil properties which affect tree growth

At any given locality the type of tree which can be grown successfully depends on the soil and the climate. Within a small area the general climate is for all practical purposes uniform, though the microclimate may be affected by such factors as aspect, slope and exposure. There may, however, be quite considerable variations in soil even within an area as small as one hectare. Regrettably little is known in Nepal about the species that grow best on different soil types. Some species such as *Pinus roxburghii* will grow reasonably well on almost any type of soil, except the very poorest, and nearly all species of trees will grow well on deep, well-drained, fertile loams, though such soils are rarely available for forestry. We need to know more, however, about which species other than *Pinus roxburghii* and one or two other very tolerant species are best suited to the different types of less fertile soil. To study how different species grow on different soil types it is necessary to define the soil characteristics which affect tree growth, and to recognize them in the field. Some of the more important characteristics are described below.

Soil depth

Trees need a certain depth of soil in which to develop their roots and anchor themselves in place, but in addition the soil depth governs the volume of soil available to the tree for the supply of water and nutrients. Some trees once established can send their roots down into cracks in rock, and may obtain some nutrients in this way. Shallow soils, however, hold very low reserves of water and will dry out soon after the rains have ended. The depth of soil which can be utilized by trees is the depth to consolidated rock or some other layer through which roots cannot penetrate, provided that this is within the depth to which the roots can grow. Alluvial sands, although in a geological sense they may be rocks, can be considered as soils for this purpose. In the Middle Hills soil depths can vary from a few centimetres to several metres.

Soil texture

The main classes of soils according to their texture are sands, clays and loams, with intermediate classes such as sandy clay loams and so on. The texture depends on the relative proportions of particles of different sizes, which are distinguished as sand, silt and clay particles. Different systems of classification differ slightly in the size range allotted to the different sizes of particles. In the US System they are as follows.

- Sand: 2.0 to 0.05 mm
- Silt: 0.05 to 0.002 mm
- Clay: Less than 0.002 mm

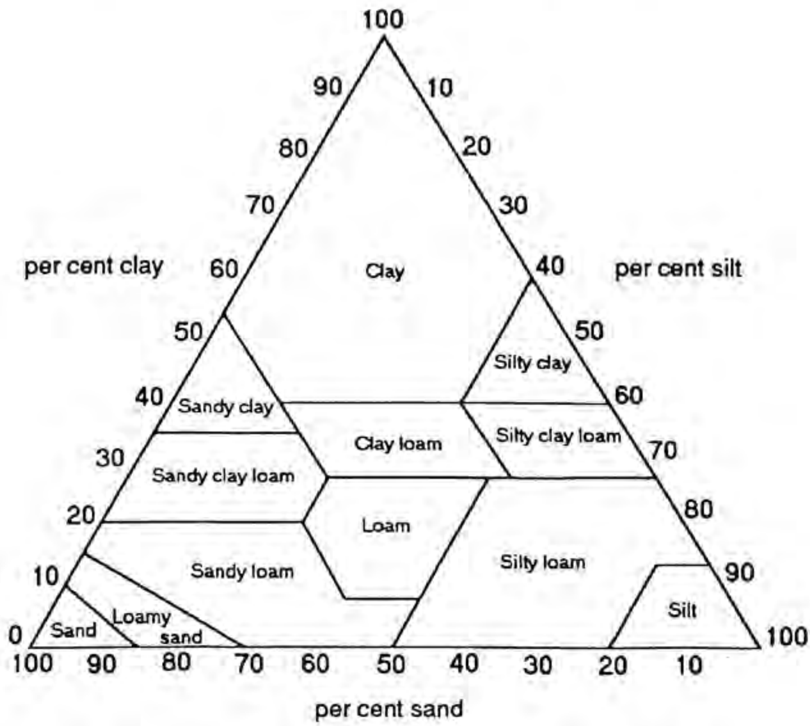
Particles more than 2.0 mm in diameter are classified as gravel and are disregarded in textural classification. The International System differs from the US System in putting the division between sand and silt at 0.02 mm and not 0.05 mm. For some purposes the sand fraction in the US System is further subdivided as follows.

- Very coarse sand: 2.0–1.0 mm
- Coarse sand: 1.0–0.5 mm
- Medium sand: 0.5–0.25 mm
- Fine sand: 0.25–0.10 mm
- Very fine sand: 0.10–0.05 mm

Figure 2 shows the division of soil into different textural classes using the US System. The classification is based on laboratory analysis, but it is also possible, with practice, to distinguish textural classes in the field with a fair degree of accuracy. A scheme for doing this is given in Appendix A of this chapter, page 28.

After soil depth, soil texture is considered to be the most important and permanent soil characteristic. It is the most important factor governing soil-water relationships, as it affects water-holding capacity, infiltration rates and the rate at which water moves through the soil. It also affects the ability of the soil to hold and release nutrients, the ease with which it can be cultivated and its penetration by plant roots. The structure of the soil is also affected by its texture. Sandy soils often hold less water than clays, but a higher proportion of the water contained in them is available for plant growth. Infiltration rates are high and drainage rapid. They are generally low in nutrients, partly because these are rapidly leached out, but mainly because nutrients tend to be associated with clay particles. Clay soils have the opposite characteristics. They store more water than sands, but a higher proportion of the stored water is bound tightly to the clay particles and is not available for plant growth. Infiltration rates are rather slow, and drainage is slow and may be impeded. These soils

Figure 2—Soil texture triangle (after Soil Survey Staff, 1975)



tend to have higher concentrations of nutrients than sands. Loams are in some respects intermediate between clays and sands. In general the best growth of plants is found on loams. Most of the soils in the Middle Hills are of loamy texture. They range from sandy loam to clay loams and very often have a high silt content. Sandy soils are rare except on alluvial deposits. Clays also are rather rare. The effects of soil texture on water relationships are described on page 25.

Soil acidity

The acidity or alkalinity of soils is expressed in the pH value, which is the logarithm of the reciprocal of the hydrogen ion concentration. A pH value of 7 is neutral, so that soils with a pH of less than 7 are acid, and those with a pH higher than 7 are alkaline. With few exceptions the pH values of soils range from 3 to 10.

Soil pH is affected by the parent material, the climate and the biological activity within the soil. Soils derived from calcareous rocks such as limestone will tend to have a higher pH, though acid soils may sometimes be found over limestone. Increased rainfall and, within the same rainfall regime, increased altitude (i.e. lower temperatures) tend to decrease pH and produce more acid soils. In very general terms low altitude soils of the Terai and Bhabar Terai zones have pHs varying around the neutral point of pH 7, often with higher levels in the subsoil than in the topsoil. In the Middle Hills, between 1000 and 2000 m, most soils have pH values between 5 and 6; the average is about 5.4 (Carson, 1992b). At higher elevations still pH values of between 4 and 5 are found. These are generalizations and locally soils may differ considerably from these values. The soils in the Mustang area, where the altitude is over 3000 m but rainfall is 350 mm or less, mostly have pH values of 8 or more (Agricultural Projects Services Centre, 1979). This is an example of the effects of drought cancelling out the effects of cooler climates. One group of soils with particularly high pH values are the usar soils found in parts of the Terai, for instance in some areas near Nepalganj. These have pH values up to 9, and abundant calcium carbonate concretions which are often scattered over the surface. These soils may be waterlogged during the rains, and are often severely eroded, with a typical landscape of hillocks and depressions. They are of little agricultural value and hence are often assigned to be used in forestry, but there are considerable difficulties in planting trees on such sites.

Tree species differ in the pH at which they thrive best. Many pines grow best on somewhat acid soils, though the two native Nepal species, *Pinus roxburghii* and *P. wallichiana*, tolerate a wide range of soil pH values. However some of the poor results obtained from certain species of exotic pines planted in the Terai may be due to soils with high pH values. Alkaline soils should be avoided in potting mixtures for pines in nurseries. *Leucaena* does not thrive on very acid soils. Some species such as *Camellia sinensis* (tea), *Magnolia campbellii* (lal champ) and many species of *Rhododendron* (but not *R. arboreum*) do not thrive on soils with high pH values but none of these are important forest trees. However, very little is known about the range of tolerance in pH values for many Nepal trees and much more work is needed.

Drainage

Most trees grow best on well-drained, but not excessively drained, soils. In general very sandy soils have excessive drainage, in which the water in the upper layers is rapidly removed by gravitation. The upper layers of such soils thus tend to be dry. However if the growth of tree roots can keep pace with the receding water good growth can be obtained on sandy soils, especially if there is a water table a few metres below the surface. Clay soils, or soils with a high clay content in the lower horizons, tend to be badly drained. Impeded drainage may also be due to topographical position if, for instance, the soil is at the bottom of a valley from which water can only drain away slowly.

The main effect of poor drainage is to reduce the oxygen supply to the roots of plants, which are often killed as a result. Poor drainage also reduces the activity of soil micro-organisms which fix nitrogen and make it available to plants. Poorly drained soils can be recognized by the lower horizons being gleyed, that is grey or bluish grey in colour, or by having reddish or yellowish mottles. (Mottles are more characteristic of soils which are waterlogged for only part of the year.) Probably no trees prefer to grow on badly drained soils, but some species are more resistant to bad drainage than others. These include *Salix* spp., *Albizia procera, A. stipulata* and to some extent *Alnus nepalensis.* Not all of these will grow well on stiff clays however. A distinction should be made between badly drained soils and soils which are liable to seasonal flooding. Soils which are flooded for relatively short periods are not necessarily poorly aerated, especially if the water is flowing. It is where water is stagnant that oxygen deficiency is likely to occur.

Soil structure

In most soils the sand, silt and clay particles are aggregated together to form larger bodies. The smaller structural units are termed granules, which are up to 0.5 mm in size, and crumbs usually up to about 5 mm in size. In turn these units may form larger aggregates (clods or peds) which may be blocky, columnar or prismatic, and may reach a size of 100 mm or more. Of these different types of structural units the crumbs are the most important to the properties of the soil. Soils with a good crumb structure have greater permeability to water, better drainage and better aeration than those where the crumb structure is poor. A good crumb structure also helps root development.

Addition of organic matter to the soil will usually improve crumb structure, as organic matter is one of the materials which bind soil particles together to form crumbs. Maintenance of the soil under natural vegetation also improves structure. The soil structure may be damaged by repeated cultivation, trampling, repeated wetting and drying such as is caused by certain irrigation practices, and the impact of fast-falling large raindrops during heavy showers, especially at rainfall rates of 50 mm an hour or more. Thus a good vegetation cover will help to preserve the soil structure. Certain types of soil tend to form a more or less impervious crust at the surface after frequent watering. This can be harmful in nursery seed beds, as seedling roots find it difficult to penetrate such crusts. Soil mixtures with a high proportion of very fine sand are particularly liable to crusting.

Cation exchange capacity

Cation exchange capacity (CEC) is the sum total of exchangeable cations that a soil can absorb, expressed in milli-equivalents (meq) per 100 g of soil. Soil cations that can be absorbed by clay are calcium, magnesium, potassium and sodium which are the basic cations, together with ammonium and hydrogen. Cation exchange capacity depends on the amount and nature of the clay in the soil, and on the organic matter content. The proportion of CEC occupied by basic cations, expressed as a percentage of the total, is termed the base saturation. This is used as a criterion for distinguishing certain types of soil, for instance eutrochrepts and dystrochrepts. In general low base saturation corresponds to low pH values, and vice versa.

Organic matter content

The organic matter content of the soil has very important effects on its properties. Organic matter is capable of absorbing large quantities of water and thus increases the water-holding capacity of the soil. It acts as a binding substance, and helps to form structures such as soil crumbs. It is also a source of plant nutrients, especially nitrogen and phosphorus. Thus, added to either sands or clays, organic matter will improve the water relations of the soil. In sandy soils it will increase the water-holding capacity, while in clays, by improving crumb structure, it will increase infiltration rates and improve drainage. Organic matter is also important in increasing the activities of the numerous living organisms in the soil, from bacteria and fungi to insects and earthworms, which are essential to many processes going on in the soil. Many of the soils available for forestry plantations have lost much of their organic matter through prolonged cultivation or erosion of the topsoil, so that it is often possible to grow only very hardy pioneer species. As the plantation develops and the soil is given protection against misuse the organic matter is restored, and it becomes possible for less hardy species to grow on the site.

Soil nutrients

Nutrients are the elements needed by plants in addition to carbon, hydrogen and oxygen which form the bulk of plant tissues. They are conventionally divided into macronutrients, those needed in large quantities, and micronutrients or trace elements, needed in much smaller quantities, but there are intermediates between these two classes. The three macronutrients needed in the largest quantities are nitrogen, phosphorus and potassium. Sulphur is also sometimes classified as a macronutrient but is needed in smaller quantities than the first three.

Nitrogen in the soil is ultimately derived from the atmosphere through the activities of various organisms, especially bacteria, which can fix nitrogen, that is they can convert nitrogen gas into ammonia and eventually nitrates which can be used by plants. Electric discharges during thunderstorms also may convert nitrogen into its oxides, which eventually produce nitrates. The total amount of nitrogen in any soil is variable and depends on the history of the soil. It is the result of the balance between additions to soil nitrogen through fixation from the atmosphere and the use of manures and fertilizers, and losses due to removal of nitrogen in plants when they are harvested, change of nitrogen compounds to gases which are lost to the atmosphere, leaching of nitrogen compounds to below the rooting depths of plants, and soil erosion. In many tropical soils the amount of nitrate, the form in which nitrogen is most readily used by plants, fluctuates considerably during the course of the year. Frequently there is a slow build-up of nitrate in the topsoil during the dry season, followed by a very rapid increase at the beginning of the rains (the nitrate flush). As the rains progress there is at first a rather sharp decline in nitrate content, followed by a further gradual decline as the rainy season progresses, until nitrates again begin to build up during the next dry season. During the flush the amount of nitrate in the topsoil may be increased by up to five times. This is important to the timing of planting. If seedlings are planted very early in the rains they may benefit from this flush of nitrates whereas a few weeks later the increased amount of nitrate will have disappeared.

Some sulphur is present in rain water, but it is also found in some rocks. The other plant nutrients are derived from the rocks from which the soil has been formed, and the amounts in the soil depend partly on the composition of the parent rock, and partly on the extent to which nutrients have been removed in weathering. In general rocks which have a high silica content, such as sandstone, quartzites and granites, will produce soils low in nutrients. Those with less silica are more fertile.

The total phosphorus content of a soil depends to a large extent on the age of the soil and the amount of weathering it has been subject to. Thus young soils such as Inceptisols and Mollisols will tend to have a higher phosphorus content than older soils such as Alfisols. However the total phosphate content of the soil is relatively unimportant, as much of this is not readily available to plants. In particular, in soils with a pH of less than about 5.5 much of the phosphorus forms compounds with aluminium and iron which are relatively insoluble and thus unavailable to plants.

Potassium is a main constituent of certain very common rock-forming minerals such as orthoclase feldspar and some micas. Perhaps because rocks containing these minerals are common in Nepal, serious deficiency of potassium appears to be rather rare. Elements needed in moderate quantities include calcium and magnesium, and perhaps sodium and silicon. No records have been made of deficiency of these elements in Nepal. Some other elements, the so-called trace elements or micronutrients, are needed in very small quantities. These include iron, manganese, zinc, copper, boron and molybdenum. In Nepal there is a possibility that some abnormalities of growth in *Pinus patula* and some eucalypts may be due to boron deficiency, but no other instances of trace element deficiencies affecting trees are on record. Boron deficiencies are commoner in acid light-textured soils with low organic matter content.

Soil and water relationships

Unless they are near to rivers, lakes or springs, soils receive their water from rain or snow. They lose it by evaporation from the soil surface, by transpiration by plants, and by downward movement to depths beyond the reach of plant roots. In addition in some sites there is an underground water table within the reach of tree roots. Such a water table may be the result either of local rainfall or the lateral movement of water from other areas.

Infiltration capacity

The maximum rate at which a soil in a given condition can absorb rain is the soil infiltration capacity. This varies with the soil type, condition, and water content. Infiltration capacities of sandy soils are very much higher than those of clay soils; published figures vary a good deal (Rodda *et al.*, 1976) but the infiltration capacity of a coarse sand may be as much as 25 times that of a clay, and possibly much more. A high content of organic matter in the soil, particularly in clay and clay loam soils, increases the infiltration capacity. Vegetation cover increases infiltration capacity while compaction of the surface soil such as is produced by heavy grazing reduces it considerably, sometimes to zero. Compaction of the surface soil by very heavy rainfall has the same effect. The infiltration capacity also depends on the moisture content of the surface layers of the soil. When these are dry it will be high, and when they are saturated infiltration ceases. But the water content of the surface soil also depends on how fast water moves from this layer down to deeper layers, and hence on the percolation rate of water in the soil. During the rainy season in Nepal there are frequently periods when rainfall exceeds the infiltration rate (see Chapter 5, page 41), causing run-off and very probably erosion.

Water storage in the soil

When soil has been saturated with water and has been allowed to drain for about 24 hours it is said to be at field capacity. If plants are growing on such a soil they will gradually use up this water until no more is available and they begin to wilt. The percentage of water remaining in the soil when plants wilt permanently is known as the permanent wilting point. Soils with a water content below the permanent wilting point may still contain quite large amounts of water, but this is so tightly bound to the soil particles that plants are unable to use it. Thus the water in the soil available to plants is that which is held between the field capacity and the permanent wilting point. This can be expressed in a number of ways, but the most generally useful is as millimetres of water per metre of soil, as this is directly comparable with rainfall and evapotranspiration. It is known as available water capacity, or available water. The most important factor governing available water capacity is the soil texture. It is generally held that sandy soils have less available water capacity than silt and clay soils, but a great deal depends on whether the sand is coarse or fine, as coarse sands have very low capacity, while that of fine sands is very high. This is shown in Table 1, page 26. Soils with a high content of organic matter have a higher available water capacity.

Losses of soil water

Apart from losses due to run-off and percolation to depths beyond the reach of plant roots, soil looses water by evaporation from the surface and by transpiration by plants. The combined effect of these two factors is termed evapotranspiration (see Chapter 5, page 43). Evaporation from a wet soil surface depends largely on the potential evapotranspiration rate, but as the surface dries out the rate of evaporation is considerably reduced. This is because when the surface soil is wet, water vapour diffuses directly into the atmosphere, but when it is dry the water vapour must in addition diffuse and ascend through a layer of soil before it can reach the atmosphere and be removed by air currents, which is a much slower process. Thus if vegetation is removed from the soil, water losses are greatly reduced; this is the basis for the use of bare fallows to conserve water in semi-arid regions.

In dry periods losses due to transpiration by plants will be more important than evaporation from the surface soil. How the gradual drying out of the soil affects actual evapotranspiration is a matter about which there is not complete agreement. Formerly it was assumed that evapotranspiration continued at the potential rate (ET) until all water reserves were used up, after which it was limited to the precipitation, if any (Veihmeyer, 1927). Then Thornthwaite and Mather (1956) assumed that the rate of water loss was proportional to the

Table 1—Available water capacity (mm m^{-1})

Textural class	Composition		Available water capacity
	Coarse sand	Fine sand	
Sand			
Coarse sand	55–100	0–50	40–120
Sand	45–55	35–75	110–180
Fine sand	8–25	65–92	150–210
Very fine sand	0–8	75–100	210–230
Loamy sand			
Loamy coarse sand	45–80	10–40	70–130
Loamy sand	25–45	35–65	130–170
Loamy fine sand	8–25	55–80	170–210
Loamy very fine sand	0–8	72–87	200–220
Sandy loam			
Coarse sandy loam	35–70	10–45	80–150
Sandy loam	15–35	32–65	140–190
Fine sandy loam	8–15	45–72	180–200
Very fine sandy loam	0–8	72–87	190–220
Sandy clay loam	55–35	22–32	140–160
Loam	15–25	22–40	150–175
Clay loam	8–5	27–45	170–190
Silt loam	0–8	27–40	180–200
Silty clay loam	0–5	15–27	180–190
Silty clay	0–5	0–15	170–180
Sandy clay	15–35	5–20	130–160
Clay	5–15	0–25	150–180

Notes: Derived from Salter and Williams (1967), quoted in Rodda *et al.* (1976). The percentages of coarse sand and fine sand are the percentages of the total soil weight: the remainder consists of the silt and clay fractions. In this table coarse sand particles are 0.2 to 2.0 mm in diameter, and fine sand 0.02 to 0.2 mm.

remaining water in the soil; thus if half the available water in the soil had been used, evapotranspiration would drop to half its potential value, and so on. Penman (1949) took a somewhat intermediate position. He developed the concept of a root constant, the quantity of readily available water held within the depth of rooting; this (in Europe) ranges from about 50 mm for grass to 200 mm for woodland. Transpiration proceeds at the potential rate until the root reservoir (holding water equal to the root constant) has been depleted, after which about 25 mm more water can be withdrawn at close to the potential rate. Then there is a change after which actual evapotranspiration falls to about a twelfth of the potential rate. According to Zahner (1967) losses from a clay soil approximate to the Thornthwaite and Mather model, while those from a sandy soil more closely resemble Penman's model.

These discrepancies are probably less important than they might appear, in view of other possible errors. It is certainly correct that as a soil dries out there will eventually arrive a time when plants begin to suffer water stress to which they will react by dying if they are annuals, or reducing transpiration by other means, such as shedding their leaves or stomatal closure if they are perennials. From data on precipitation, evapotranspiration, and soil moisture storage it is possible to calculate water balances (see Chapter 5, page 45).

Soil surveys and analysis

Soil survey and analysis are highly technical subjects requiring trained staff, and will not be considered in detail here. At the Forest Research and Survey Centre, Kathmandu, the Soil Section undertakes soil survey of forest areas and carries out soil analysis, though the amount of work is limited by the facilities available. People wishing to collect their own soil samples should follow the methods described in Appendix B of this chapter.

References: There is no comprehensive published account of the soils of Nepal. For soil surveys of limited areas made before 1985 see Agricultural Projects Services Centre (1979); Forest Resources Survey (1968b; 1969; 1970; 1971a; 1971b; 1972; 1973); Impat (1980); Mulder (1978); M.L. Pradhan *et al.* (1964; 1965; 1969a; 1969b). For surveys of forest areas made since 1985 see the various papers by Howell; Juwa; and Teare.

Appendix A

Estimation of soil texture in the field

A quantity of soil is taken and moistened. The first step is to try to form it into a cube; if this is possible an attempt is made to roll out the soil between the fingers and form a thread 7–8 mm thick. The thread is then bent round to form a ring. The different textural classes are defined in Table 2.

Table 2—Guide chart for hand-texturing of soil

Textural class	Description
Sand	Gritty, non-coherent; does not form cube even when moist; leaves fingers clean.
Loamy sand	Gritty; forms a weak cube when moist; slightly coherent.
Sandy loam	Gritty; markedly coherent; forms a firm cube and will roll into weak thread; sand grains can be seen and make a faint grating noise when the soil is moulded; soil does not polish.
Sandy silt loam	Silky and somewhat gritty; coherent; forms a cube and may roll a weak thread; leaves a silty film on the fingers; does not polish.
Sandy clay loam	Gritty and somewhat sticky; resists deformation; will form a firm thread; sand grains can often be seen and heard when the soil is moulded; may polish.
Clay loam	Sticky; will polish quite readily; will form thread but will not form a firm ring.
Silty clay loam	Silky and somewhat sticky; will form a thread but will not form a firm ring; leaves a silty residue on the fingers.
Silty clay	Sticky and somewhat silky; resists deformation; will form a thread and may form a weak ring; leaves a silty residue on the fingers; polishes readily.
Sandy clay	Sticky and somewhat gritty; sand can often be seen but is not audible when the soil is moulded; will polish, but sand grains may scar the smooth surface; will form a thread but will not form a firm ring.
Clay	Sticky; resists deformation; polishes readily; forms a thread and this can easily be bent into a firm ring.

Appendix B

Forest soil sampling for laboratory analysis (by staff of the Soil Section)

Soil sampling for laboratory analysis is only necessary when field observations alone are insufficient to make a satisfactory assessment of the site. Usually soil problems are self-evident, e.g. shallowness, stoniness or, if the site is badly degraded, low fertility, in which case laboratory analysis will only confirm the field observations. However, if laboratory analysis is required correct soil sampling is essential.

The aim of soil sampling is to collect soil which is representative of all the soil in the study area. As the soil property values for these samples will be taken as averages for the whole area it is important that the samples are truly representative and that the selection of sample sites is unbiased. The value of laboratory results and their interpretation will depend on an appropriate method of sampling being adopted. Below are some guidelines for soil sampling in forest related sites. Although the area of interest can be a whole hillside or just a few square metres, depending on the proposed land use, the general method used is the same.

(1) Identify your area of study and its boundaries. Only if the area is relatively uniform in soils and topography can it be treated as a single sampling unit. For larger areas, like plantation sites, it is unlikely that the area is uniform. In this case divide it into smaller areas which are more uniform. This can usually be done on landscape features, e.g. valleys, ridges or slopes, either by eye in the field or by using a contour map. Each of these units can now be treated as a single sampling unit. Areas under different management practices at present, or that will be in the future, should also be treated as different sampling units.

(2) Locate a sampling unit in the field. Starting near an edge proceed to walk in a W-shape, stopping at the five points of the W (see Figure 3, page 31). At each point of the W take a core sample as follows.

(3) Firstly clear the litter and any grass from the surface. Then take a sample from the top 15 cm with either: (a) a sampling tube about 5 cm in diameter; or (b) a spade (*kudalo*) or trowel (*khurpi*). From the freshly exposed side of a small hole take a slice about 2.5 cm thick and 10 cm wide, from the surface down to about 20 cm deep. Trim this slice to leave a core sample 5 cm across and 15 cm long, measured from the surface. Place all the core samples in a clean dry bucket or bag as you take them, so that they can mix.

(4) When the five core samples have been taken pour the soil out of the bucket/bag on to a clean piece of cloth/paper/polythene and mix it thoroughly. Discard any stones bigger than 2 cm across.

(5) Take about 1 kg of this mixed soil as the sample for sending to the laboratory. This is called a composite sample.

(6) Put the composite sample preferably in a clear plastic bag, expel the air and turn over the top a few times, and seal the bag with rubber bands preferably, or string. Knotting should be avoided. Put this bag inside another similar bag and place the label between the two so that it can be read through the outer bag. Seal the second bag as before. (Suitable bags and rubber are available from the Soil Section on request. State the number required.)

Labelling: Labels should be clear, legible, standardized and written with a waterproof pen or a pencil. They should record the following.

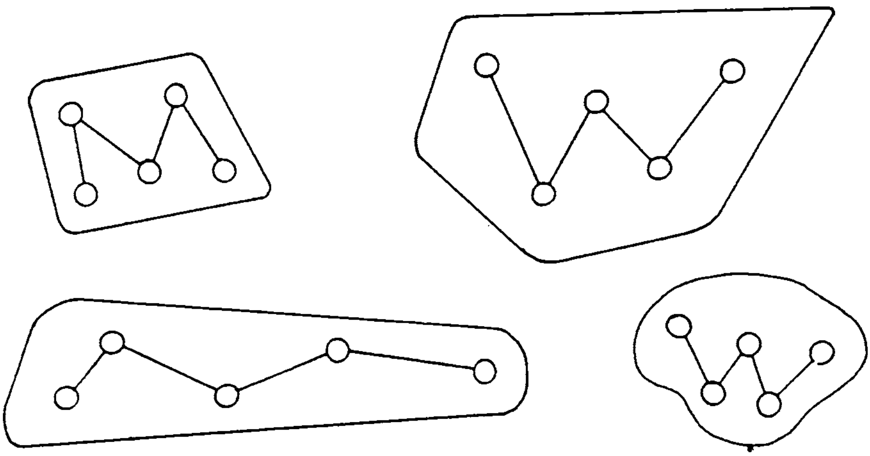
- Project name
- Date sampled
- Site/Sampling unit
- Sample number
- Analysis required

The samples sent to the laboratory should be accompanied by a covering letter containing a few details including the following.

- Sampler's name
- Organization name and address
- Proposed site use
- Brief site description (aspect, altitude, slope)
- Recommendations/information sought

The sampler should retain a record sheet and sketch map of the area sampled showing locations of sampling units and core sample sites.

Figure 3—Examples of walking Ws for various shaped sampling units



Notes: When walking the W it is important to avoid sampling areas such as marshy sites or old compost heap sites. Never sample from exposed road cuts or gully sides. As the soils of Nepal are so variable you may find that the five core samples are very different. In this case you may need to start again, dividing the area into smaller sampling units.

Chapter 5

CLIMATE

Introduction

The information in this section has been obtained from the Nepal Meteorological Service's *Climatological records of Nepal* (Department of Hydrology and Meteorology, 1968; 1971; 1972; Department of Irrigation, Hydrology and Meteorology, 1973; 1977; 1982). These include some rainfall data going back to 1948, and records for only Kathmandu going back to 1921. The latest volume published covers the period up to 1980. There is a substantial amount of information available, but it is more scarce from stations above 2000 m.

In addition Dr Janak L. Nayava, formerly Chief Meteorologist, has very kindly made available the climatic tables covering 168 stations from his doctoral thesis (Nayava, 1980). These tables contain a great deal of information not available elsewhere, particularly on evapotranspiration. Other sources of information include Dobremez (1976) who discusses the climate of Nepal in considerable detail, but is now unfortunately rather out of date, as he only used records going up to 1969. Kenting Earth Sciences Ltd (n.d. about 1980) has considerable detail about the climate of the Far Western Development Region. See also D.P. Joshi (1984); Shankar and Shrestha (1984); Singha (1984). Climatic data from a number of stations in Nepal are summarized in Appendix C, Tables 5 and 6, pages 50–103 and 112–116, at the end of this chapter.

Temperature

Temperatures are affected by several factors. Nepal is situated far enough north to have marked summer and winter seasons; monsoon cloud and rain reduce average temperatures. Temperatures are affected by altitude. The highest mean monthly temperatures generally occur in April or May before the monsoon breaks, and during this period mean monthly maximum temperatures are at their highest, ranging from 35°C to 40°C in the Terai to about 16°C at 3000 m. In parts of the Terai extreme maximum temperatures of more than 40°C occur annually, and temperatures as high as 46°C have been recorded. During this period there is also a large difference between mean daily maximum and minimum temperatures, this difference ranging from about 15°C in the Terai to

8°C at higher altitudes. After the onset of the monsoon mean monthly temperatures remain much the same, or decline slightly, but the maximum temperatures are lower and the difference between mean monthly maximum and minimum temperatures decreases to between 7°C and 8°C in most localities. During the monsoon mean temperatures remain fairly steady until September, when there is a slight fall. In October the rate of fall increases and this fairly rapid fall continues until January, the coldest month. During January mean monthly temperatures are between 14°C and 16°C in the Terai, 6°C and 8°C at 2000 m, and about 2°C at 3000 m. Above 3300 m they fall below zero. Winter temperatures in the Kathmandu Valley are lower than would be expected for the altitude, as the valley is a depression surrounded by hills, and cold night air accumulates. The mean monthly January temperature at Kathmandu (1300 m) is 9.5°C.

Effect of topography on temperatures

Temperatures as recorded at a climatological station can be assumed to be representative of the locality on a fairly broad scale. However on a smaller scale temperatures may differ considerably from those recorded, as a result of local topography.

One of the most important topographical features affecting temperature is aspect. It is well known that south-facing slopes are considerably warmer than north-facing slopes, and often carry a different type of natural vegetation. Similarly, in the morning, an east-facing slope will be warmer than a west-facing slope. The magnitude of this effect depends on the slope of the ground, and on the altitude of the sun above the horizon, and thus on the angle at which the sun's rays strike the soil surface. At midday on the winter solstice, 21 December, at a latitude of 28°N, the soil on a south-facing slope with a gradient of 30° will receive about 1.5 times as much direct solar radiation as level ground, while a north-facing slope of the same gradient will receive less than 0.25 as much as level ground. Thus the south-facing slope will receive six times as much direct radiation as the north-facing slope. This is, of course, an over-simplification, as not all the heat received by the soil is in the form of direct solar radiation, but it gives some idea of the magnitude of the effect. In mountainous country the situation may be complicated further by shadows cast by other ranges of hills. The higher temperatures on south-facing slopes will also increase evapotranspiration, and hence such slopes are drier than those facing north.

Another effect of topography on temperature is seen in enclosed valleys, where on still nights cold air flows down the hillsides and collects in the valleys causing lower night temperatures. The case of the Kathmandu Valley has already been mentioned.

Frost

The Climatological Records list the number of days each month and each year in which the minimum temperature fell below 0°C. This is not, however, the same as the number of days of frost, as the night temperature of the surface of the soil is usually lower than the temperature recorded in a meteorological screen, and so ground frosts can occur when the air temperature is a little above zero. Unfortunately there are very few records available in Nepal of soil-surface or grass temperatures. Some records of mean monthly grass minimum temperatures for the years 1976 to 1981 are available from Pakhribas in eastern Nepal (P.C. Pradhan, 1983). These indicate that grass minimum temperatures average about 3.5°C lower than screen minima when the latter are between 3.5 and 5°C. If this relationship is applicable to other parts of Nepal some frosts may be expected when minimum screen temperatures of less than 3–4°C are recorded.

According to the Climatological Records, below-zero temperatures occur every year at altitudes over 1800 m, but they may also occur rarely at much lower altitudes. For instance they have been recorded at Nepalganj in the Terai. Frosts also occur at lower altitudes in enclosed valleys, from the effects of cold night air collecting in them, as already mentioned. Thus regular night frosts occur at Kathmandu in the months of December to February. Kathmandu, at 1300 m, has an average of 12 days with below-zero temperatures each year, whereas Nagarkot on the rim of the valley, and only 16 km away, but 700 m higher, has an average of only 4.2 days. Above 2700 m severe winters occur, with an average of 98 days per year with below-zero minimum temperatures at Jomsom (2744 m), increasing regularly with altitude to 225 days at Tengboche (3867 m). Jumla, at 2300 m, has more severe winters than would be expected, with an average of 128 days with minimum temperatures below zero. Jiri also has cold winters although its altitude is only 2003 m; it has an average of 44 days each year with minimum temperatures below zero. Above about 5000 m there is permanent frost and snow. The injurious effects of frost are discussed in Chapter 11, page 242.

Wind

The Climatological Records include mean monthly wind speeds for 17 stations, and also daily average speeds, maximum average hourly speeds and extreme speed in gusts for Kathmandu Airport. Nayava (1980) gives estimates of mean, highest and lowest wind speeds in kilometres per day, for each month for the stations included in his list. Local topography will obviously affect exposure to wind, and the strength of winds blowing from different compass directions.

In mountainous regions winds may also be produced as the result of differing rates of heating and cooling between the surrounding mountains and the valleys. During the day the air over the mountains heats up and in a narrow valley this may cause an up-valley wind to arise; at night the reverse occurs, producing down-valley winds. In some valleys, such as that of the Kali Gandaki, these winds may be very strong, reaching gale force at times. Such winds are also generally strongly desiccating.

Apart from this sort of wind, wind speeds, especially of gusts, are usually highest in the pre-monsoon months of April and May, and it is during this period that the strongest gusts have been recorded at Kathmandu Airport. In the period 1971–1975 the strongest gust recorded at Kathmandu was 118 km hr^{-1}, just short of hurricane force, and gusts over 60 km hr^{-1} were recorded each year, all in the months of April and May.

Relative humidity

Relative humidities are recorded for most climatic stations, but unfortunately the times of record are at 0840 and 1740 hours whereas the minimum relative humidity usually occurs in the early afternoon. Published data for relative humidity at other times of day are available from Kathmandu Airport only, and are shown in Table 3, page 36. As is to be expected relative humidity is high during the monsoon, and then gradually decreases to a low point in March to April, after which it increases again. In many parts of the Terai considerably lower humidities than those at Kathmandu occur during the months of February to May, and relative humidities at 1740 hours of 30 per cent or less are not uncommon, indicating a relative humidity probably below 20 per cent at the hottest part of the day. At high altitudes, above 3000 m, in the months of December to March, the 0840 relative humidity is below that at 1740. This is presumably because temperatures are below freezing point in the early parts of the day.

Table 3 — Mean relative humidity at Kathmandu Airport 1968–1975 (%)

Local time	0540	0840	1140	1440	1740
January	96	94	60	37	61
February	93	87	52	37	51
March	91	78	41	30	43
April	86	68	38	35	41
May	89	70	51	49	55
June	93	79	66	66	72
July	94	84	74	72	80
August	96	86	72	73	81
September	95	87	72	70	80
October	97	89	63	56	75
November	97	92	57	47	70
December	96	94	58	42	66

Precipitation

Precipitation includes both rain and snow, but except at very high altitudes the proportion of the annual precipitation occurring as snow is relatively small in Nepal. By far the most important factor governing rainfall is the summer monsoon. In much of southern Asia this is accompanied by south-west winds, and it is termed the south-west monsoon; however in Nepal and the central and eastern Himalaya the monsoon winds are deflected to the south-east. Hence the monsoon begins earlier in the east of the country than further west, and rainfall tends to be heavier in the east, though the effect of topography modifies this considerably. The main range of the Himalaya is a considerable barrier to the monsoon, and north of the range, such as in Dolpo and Mustang, precipitation is strongly reduced so that semi-desert conditions prevail. Even in these areas, however, the greater part of the very low precipitation occurs during the monsoon season.

In addition to the summer monsoon rains, a certain amount of precipitation occurs in winter, as the result of atmospheric disturbances originating in the Mediterranean area. These depressions bring fairly heavy rainfall and snowfall to the western Himalaya such as in Kashmir and Himachal Pradesh, but in Nepal the proportion of the precipitation occurring in winter is low compared with the summer rainfall. Winter rainfall and snowfall are most abundant in the hills of the far west of Nepal, but even there precipitation falling between December and March is usually only about 15 per cent of the annual total.

Seasonal course of precipitation

The monsoon

In Nepal south of the Himalaya the rainfall is usually very reliable between the onset of the monsoon and its end. The average date of the onset of the monsoon in Kathmandu is 12 June; the earliest date in the years from 1947 to 1975 was 2 June and the latest 22 June. Its average duration is 102 days, the extremes being 85 and 118 days, and it ends on average on 21 September (earliest 11 September, latest 30 September). In the Far Western Development Region the monsoon begins one or two weeks later, and in the far east of Nepal it begins up to two weeks earlier, though these periods are quite variable and sometimes the onset of the monsoon in the west and in Kathmandu is almost simultaneous. The monsoon also tends to end earlier in the west and later in the east. During the monsoon rainfall almost always exceeds evapotranspiration, often very considerably, and much of the rainfall is lost in run-off. Thus the total monsoon rainfall is relatively unimportant in its effect on plant growth; the duration of the monsoon is much more important.

Post-monsoon rains

The date of the end of the monsoon, in September, is variable, and the monsoon itself is often followed by quite heavy rain which may continue almost to the end of October. Sometimes, however, the rains end abruptly with the departure of the monsoon. The date of the last measurable post-monsoon rain in Kathmandu, between 1947 and 1975, ranged from 15 September (the end of the monsoon) to 26 October (35 days after the end). Thus October rainfall is extremely variable; sometimes it is very heavy, and sometimes there may be a complete drought. The months of November and December are usually dry and November in most stations is the driest month of the year. Very rarely, however, there are rainstorms in November and December with heavy rain spread over three or four days only. Thus in November 1972, in Chainpur (E) 140 mm fell in three days, with a maximum daily fall of 70 mm, and in Taplethok 262 mm fell in seven days, with a maximum daily fall of 130 mm. Such heavy rain in November and December has only been recorded from a few stations in the east of the country, and does not occur more than about one year in ten. These unseasonal storms may be connected with depressions coming from the east.

Winter rains

These are caused by depressions moving in from the west, and are heaviest in the hills of the Far Western and Mid-Western Development Regions. Even there however they rarely produce more than 20 per cent of the total annual rainfall, and in addition they vary considerably both in the total amount of rainfall and in the months in which the heaviest rainfall occurs. This can be seen in Table 4 which shows the January to March rainfall for Silghadi Doti and Jumla, two stations with relatively high winter rainfalls. The occurrence of these winter rains has the effect of prolonging the growing season, and may affect the species of trees which can be grown satisfactorily. However as can be seen from Table 4 their occurrence is very irregular and in general they are not reliable enough for routine planting. In addition their value is reduced as they are frequently followed by a dry spell in April and May. East of about longitude 82°30' and south of the Himalaya light rain often occurs in winter, but the amount of rain is very small when compared with the total annual rainfall, and also varies considerably from year to year. These rains are known as *magejhari* and are of some importance to farmers growing winter crops, such as wheat and barley, in the hills. They are of little importance in afforestation practice apart from ameliorating the severities of the dry season to some extent.

Table 4—Winter rainfall at two stations (mm)

	Silghadi Doti					Jumla				
Year	Jan	Feb	Mar	Total	Year total	Jan	Feb	Mar	Total	Year total
1971	15	54	77	146	2104	5	5	81	91	879
1972	108	0	32	140	1195	11	55	66	132	755
1973	51	45	68	215	1572	47	66	64	167	1051
1974	32	38	9	79	858	85	20	0	105	579
1975	61	80	62	203	1797	34	78	40	152	933
1976	0	84	8	92	1121	2	132	34	168	1160
1977	41	15	4	62	1128	42	17	30	89	956
1978	21	77	174	272	1395	1	73	160	234	1035
1979	42	88	38	168	962	18	64	28	110	674
1980	14	32	111	157	1249	10	33	132	175	1045

Pre-monsoon rains

As the weather begins to warm up after the winter the humidity also increases and thunderstorms begin to occur which gradually increase in frequency and intensity until the monsoon itself arrives. In the hills of central Nepal these pre-monsoon rains usually begin in late March or early April, in the west up to four weeks later, and in the east two or three weeks earlier. They are less intense in the Terai than in the hills. In April the average amount of rain is usually rather low, less than 60 mm, but in May heavy rains frequently occur; east of about 86° longitude the average May rainfall is over 100 mm in most places. The very wet area south of the Annapurna range also has fairly heavy rainfall in April and May. These pre-monsoon rains often merge with the true monsoon, and it may be difficult to assess when one ends and the other begins. The pre-monsoon rains, however, are generally accompanied by south-west winds, while during the monsoon south-east winds prevail. The pre-monsoon rains could be important in afforestation, as they are usually followed by a reliable June rainfall. For further discussion see Season of planting in Chapter 10, page 216.

Effect of topography on precipitation

As moisture-laden air approaches a mountain range it rises and becomes cooler, and sheds much of its moisture as rain. The windward side of a mountain range is usually much wetter than the leeward side. This effect is clearly seen in many parts of Nepal. The most striking example is the main Himalaya range, which acts as an almost complete barrier to the monsoon, with the result that the region north of the Himalaya, the Mustang–Dolpo region, has a cold semi-desert climate, compared with the tropical monsoon climate of the rest of the country. The transition is in many places very abrupt, as can be seen by comparison of the precipitation at Lete, Thakmarpha and Jomsom. All three stations are in the Kali Gandaki valley, where it cuts through the Himalaya between the Dhaulagiri and the Annapurna massifs. Lete is about 15 km south of Thakmarpha, which in turn is about 5 km south of Jomsom. The mean annual precipitation at the three stations is 1051, 340 and 249 mm respectively. Lumle, 55 km south-east of Jomsom, to the south of the Annapurna range, has over 5000 mm of rainfall a year.

Less dramatic effects are produced by other mountain ranges. Stations at the foot of the Siwalik and Mahabharat ranges have considerably higher rainfall than that of stations in the Terai to the south of them. Thus Bhairawa in the Terai has a mean annual rainfall of 1525 mm, compared with Butwal at the foot of the Siwalik range with 2452 mm; Simra (Terai) has 1622 mm, while Hetauda at the foot of the Mahabharat range has 2211 mm; and Tarahara (Terai) has 1628 mm, compared with Dharan with 2401 mm at the foot of the Mahabharat range. Some stations in valleys to the north of the main mountain ranges, apart from the Himalaya, have comparatively low rainfalls. Such stations include Dhankuta, in the Tamur valley, with only 1006 mm rainfall, and Salyan, north of the Sarda Khola, with 1078 mm. The mountains to the north of these two stations have more normal rainfall.

A peculiar effect of topography on rainfall is seen in some of the deep valleys which cut through the mountain ranges in parts of Nepal. As described earlier these valleys are often subject to very strong winds. These winds are not only desiccating in themselves, but they reduce the rainfall over the valley centres, so that in the rainy season there are often long sinuous gaps in the cloud above the centre of the river valleys (Hagen, 1980). The valley floors may carry a xerophytic type of vegetation, while the slopes a thousand metres higher have a much more mesophytic type.

Reliability of precipitation

Published data on precipitation usually give the mean values each month. For many purposes it is desirable to know not only the mean values, but to have some idea of the variability of the rainfall, in particular the lowest value which may be expected in a given period. In normally distributed data half the values will be less than the mean (in a skew distribution more than half may be less), which means that a planting technique which is successful under mean conditions may fail nearly half the time. For example the mean October rainfall at Silghadi Doti is 62 mm. However in 7 years out of 25 there was no rainfall at all, and in a further 2 years less than 10 mm. Thus anyone relying on an October rainfall of 60 mm or more in this area would be disappointed for much of the time.

Thus a knowledge of how much rainfall can be expected in poor years is very desirable. It is not possible to plan for the worst possible case, such as an event which might occur one year in a hundred. It is suggested that failure caused by climatic factors might be risked in one year out of five while in some circumstances one year out of ten might be preferred. For this reason the figures given in Table 5 in addition to mean, maximum, and minimum rainfalls include the median, which is the middle value, exceeded by half the figures recorded; the five-year low, exceeded by 80 per cent of the figures; and the ten-year low exceeded by 90 per cent of the figures. Thus in four years out of five rainfall has equalled or exceeded the five-year low, and in nine years out of ten it has equalled or exceeded the ten-year low.

This method of expressing variability is used rather than the standard deviation of the mean, or the coefficient of variation, because these measures are not appropriate for use with skew distributions, and in most of the months with very variable rainfall in Nepal the distribution is markedly skew. To evaluate the rainfall figures further they should be compared with those for potential evapotranspiration (see page 43). It should be noted that the mean values for monthly rainfall and temperature may differ from other published figures, as different spans of time may have been used in calculating them.

Effectiveness of precipitation

It has already been pointed out that the total amount of rainfall during the monsoon is of little importance in its effects on plant growth, as during most of the monsoon season the rainfall is much heavier than can be used by plants or stored in the soil. At Lumle, for instance, with a mean average rainfall of 5164 mm, it is likely that at least 80 per cent is surplus to the needs of plants. Such surpluses have other effects, of course; they may be used to fill reservoirs, but more often cause flooding and increase soil erosion. However, in most parts of Nepal it is of very little importance to plant growth whether for instance the August rainfall is 150 mm or 1000 mm.

Another factor which affects utilization of rainfall is its intensity, the quantity of rainfall which falls per hour or per day. Even if the soil is not saturated there is a maximum rate at which water can infiltrate into it. If the rate of rainfall exceeds this rate the surplus will be lost as run-off and will very likely cause soil erosion. Storms with very high rates of precipitation per hour are quite common; each year there are many stations recording at least one day with more than 100 mm rainfall, and daily rainfalls of over 400 mm have been recorded (Tansen, 7 September 1959). With rainfalls of such intensity a high proportion will be lost as run-off.

Rainfall occurring in very light showers of up to 5 mm may also be relatively ineffective because such light rainfall is often evaporated immediately from the soil surface, or is intercepted by vegetation before it reaches the ground. I.J. Jackson (1977), however, points out that even such light showers may be of some advantage in increasing humidity and reducing plant transpiration demands. The most important factor governing the effectiveness of rainfall is the rate at which water is lost through evapotranspiration, and this is discussed later.

Snow

In Nepal most of the precipitation falls in summer, so the proportion occurring as snow is rather low, except at very high altitudes. The permanent snow line in most of Nepal is at about 5000 m. There are very few reliable records on snowfall; in a few scattered places in the Climatological Records it is recorded that the precipitation was in the form of snow, but there are obviously many other occasions when snowfall is not distinguished from rainfall. As a broad generalization it may be assumed that any precipitation in the period from December to early March, above 2100 m, is likely to be in the form of snow. However, snow sometimes falls at much lower altitudes, and in late December 1983 there was a fall at Tistung (1800 m) which melted after two or three days, but did considerable damage to trial plots. Snow has even been recorded in the Kathmandu Valley, but this is extremely rare. The last occasion was in January 1945 when an appreciable fall of snow occurred, lasting three quarters of an hour (Shankar and Shrestha, 1984).

There is very little information on the date that winter snowfall melts, though this is of considerable importance to the growth of plants, as they can only obtain water from snow after it has melted. From what information is available, it appears that the snow disappears fairly soon after it falls except at very high altitudes, and on the north faces of mountains and other shady places such as under forest. According to Stainton (1972), in Dolpo, where snow falls occasionally throughout the winter, most of it disappears during the intervening periods of fine weather. Dolpo lies above 3600 m. However, the Seti valley at 3500 m is still covered in snow in May (T.B. Shrestha, 1982). More knowledge about snow in Nepal would be desirable. However, it is much less important in forestry here than it is further west in the Himalaya; this needs to be taken into account when considering the applicability of some Indian techniques to Nepalese conditions.

Hail

In many localities violent hailstorms occur, which can do considerable damage to crops and trees, especially to small seedlings. Hail can be very severe, and in exceptional storms the hailstones may reach a diameter of 6 cm. Hail is always associated with thunderstorms but there is little precise information about its occurrence in Nepal. It is generally most severe just before the monsoon, but can occur at other times of the year. Kenting Earth Sciences Ltd (n.d. about 1980) gives the following dates of occurrence in the Far Western Development Region (as it was at the time of the report; it has since been divided into the Mid-Western and Far Western Regions).

- Terai—mostly winter.
- Dang Valley—both winter and summer; severe storms in October–November.
- Surkhet— winter, and start of the monsoon.
- Pusma Camp and Salyan—main season February–March; also sometimes in April–May.
- Dailekh—small hailstones in winter, larger in summer.
- Dandelhura—small hail in winter, large in May.
- Jumla—March and April main season, but hail damage also recorded August–September.

Evapotranspiration

The water available to plant growth does not depend on rainfall alone, but also on the rate at which water received from rain, and that stored in the soil, is used in transpiration by plants and evaporated from the soil surface. Some water may also be evaporated from rain intercepted by plant leaves and stems. The term used for the combination of transpiration by plants and evaporation is evapotranspiration. In general terms if evapotranspiration greatly exceeds rainfall over a period, that period will be dry; if rainfall exceeds evapotranspiration, the period will be wet. This generalization, however, is affected by changes in the water content of the soil; during a dry period plants will draw water from reserves in the soil, as long as this is available, while during wet periods water will be added to soil reserves until field capacity is reached. This will be discussed in more detail later. Because of the importance of evapotranspiration, an amount of rainfall which would be more than enough for satisfactory plant growth in January could be seriously below requirements in April or May. Also the same amount of water which would be enough for plant growth in the High Mountains could be very inadequate in the Terai.

Direct measurement of evapotranspiration from vegetation and soil is difficult, involving the use of lysimeters—large tanks containing soil and vegetation, in which changes in soil water content are usually estimated by weighing. They are very expensive to construct and thus cannot be replicated on a wide scale. For this reason a number of indirect methods for defining wet and dry periods have been devised. Because evapotranspiration is correlated with temperature (among other factors), temperature in relation to rainfall has often been used to discriminate between 'dry' and 'wet' periods. Gaussen (1954) classified climates by plotting monthly rainfall in millimetres against twice the temperature in degrees Celsius for each month. Any month in which the rainfall was less than twice the temperature was considered to be a dry month. This method has been used by Dobremez (1976) and D.P. Joshi (1984) for the preparation of ombrothermic diagrams for a number of stations in Nepal. However there are objections to the method. At Butwal the mean temperature for May is 31.4°C, indicating that if the rainfall were over 63 mm the month would be wet. Actually the evapotranspiration for May is estimated at 220 mm, which in conjunction with a rainfall of 63 mm would cause considerable stress to growing plants.

Evapotranspiration from a free water surface may be estimated from evaporation pans. Results from these vary considerably with the size of the pan, its material, depth, colour, exposure and the water level, and thus must be taken with some caution. Pan evaporation data from a number of stations in Nepal have been published in Climatological Records 1971–75. Correction factors exist for converting pan evaporation values into actual evapotranspiration by crops and natural vegetation, but these vary with the pan type and the climate of the locality, and need to be confirmed by local studies. Because of the difficulties in measuring evapotranspiration directly, a number of formulae have been devised to estimate it from meteorological factors. One of the simplest of these is that of Thornthwaite (1948), which is based essentially on temperature, with a factor for day length included. It has been used widely, but tends to seriously underestimate evapotranspiration in the tropics, especially in the warm months. For a discussion on this and other estimates of evapotranspiration see I.J. Jackson (1977). Nowadays the most generally accepted method of estimating evapotranspiration is that devised by H.L. Penman. This was first developed in 1948 but has been modified since; a more accessible account of the method may be found in Penman (1963). Calculation of potential evapotranspiration by the Penman formula requires knowledge of incoming solar radiation (which can be estimated from hours of bright sunshine and day length), air temperature, vapour pressure (which can be calculated from relative humidity measurements) and wind speed. An example of the calculations for a station in Nepal is given by T.J. Wormald (1984).

Fortunately estimates of Penman evapotranspiration have been calculated for many stations in Nepal by Dr J.L. Nayava (Nayava, 1980) and these have been included in the tables. These figures are Penman's E_o, and are estimates of the evaporation from a free water surface. To estimate the evapotranspiration from vegetation they must be multiplied by a factor ranging from about 0.75 for certain pastures to 0.93 for evergreen tropical montane forest; these factors assume that the ground cover is complete, and that plant growth is not restricted by shortage of water. This value is known as E_T. Where the ground cover is incomplete, or low water supplies restrict growth, the actual evapotranspiration will be less than E_T. Lower values will also be found when plants are relatively inactive or dormant, as when deciduous species lose their leaves.

In Nepal potential evapotranspiration is usually lowest in December, a month of relatively low temperature and short days. From then it gradually increases to February, and then rises much more steeply to reach a peak in May. There is a drop with the onset of the monsoon, and thereafter evapotranspiration gradually declines until September and October, and more steeply in November, until the low December values are reached. Naturally evapotranspiration is highest at low altitudes in the Terai, and lowest at high altitudes in the mountains. At Nepalganj it ranges from 226 mm in May to 50 mm in December; at Kathmandu the May figure is 167 mm, while December figures are about the same as at Nepalganj; and at Chialsa the May figure is 115 mm and that of January (the lowest) 40 mm.

Water balance

After a dry period, if rainfall exceeds evapotranspiration the excess water will at first be stored in the soil. When the soil can store no more water any further rainfall will be lost to the immediate locality either by run-off or by percolation to depths beyond the reach of plant roots. After the rainy season, when evapotranspiration exceeds rainfall, plants will draw on the reserves of water stored in the soil. How this water is used is a matter of some discussion (see Chapter 4, Soil and water relationships, page 24), but whether evapotranspiration continues at the potential rate until all reserves are exhausted, or is proportional to the reserves left in the soil, or is intermediate between the two, a time will come when the water available to plants is considerably less than the potential evapotranspiration rate, and they will be subject to water stress which will continue until the rainfall once again exceeds evapotranspiration.

For accurate calculation of the water balance considerably more information is needed on soil-water relationships and their effect on plant growth than is currently available in Nepal. However, from the data available it has been possible to calculate crude water balances for a number of stations. Great accuracy is not claimed for these calculations but it is hoped that they may be of value in giving a general picture of water use in Nepal, and in making comparisons between different stations. In drawing up these water balances the following assumptions have been made.

- During periods when evapotranspiration exceeds rainfall, soil moisture reserves are used at the potential evapotranspiration rate until they are exhausted, after which the monthly evapotranspiration rate equals the monthly rainfall.

- As long as water is freely available, the evapotranspiration rate (E_T) is equal to 0.85 of the Penman rate for evaporation from a free water surface (E_o).
- The soil is capable of storing 150 mm of water. This is the amount which will be stored in the top metre of an average soil, and is likely to be available to tree seedlings. Older trees with well-developed roots will be able to extract water from greater depths than this.
- All rainfall is equally effective.

From these calculations the water balance diagrams for 27 stations, given in Figure 4, pages 104–111, have been prepared. These are based on the mean monthly figures for rainfall and evapotranspiration given in Table 5 with the E_o multiplied by 0.85. They begin with the month of September as this is convenient for calculations; with rare exceptions the soil water is fully replenished by the beginning of this month. These diagrams show the following features.

- The period when rainfall exceeds evapotranspiration, and soil water reserves are being recharged.
- The period after which recharge is completed, and excess water is lost by run-off or deep percolation.
- The period during which soil water reserves are being used.
- The period after exhaustion of the reserves during which there is a water deficiency and plants may be expected to suffer water stress.

Use of these mean figures however conceals the effects of years which differ from the average. For instance if the mean rainfall is 100 mm and the mean evapotranspiration 80 m, a surplus will be shown for that month. However, the mean value of 100 mm may be derived from data which include values of 50 mm or less. Thus in some years there will be a deficiency which is not shown on the diagram. For this reason the water balances for some stations for a ten-year period have been calculated, carrying forward any water deficit or stored surplus from one year to the next (occasionally shorter periods have been used, where ten-year data were not available). Table 6, pages 112–116, is derived from these calculations. In addition to giving mean values for water deficiency they give the maximum and minimum values for the ten-year period both in millimetres and as a percentage of potential evapotranspiration (E_T). From these figures and tables the following conclusions can be drawn.

- North of the Himalaya, except on very rare occasions, potential evapotranspiration considerably exceeds rainfall throughout the year. At Jomsom during a seventeen-year period there were only five months during which rainfall exceeded evapotranspiration (not included in Table 6).

- In the rest of Nepal no water deficiency occurs during the months of July and August, and deficiencies in September and October are very rare.
- In the western Terai there may occasionally be a slight water deficiency in November and December, and by January some water deficiency is to be expected in most years. This deficiency becomes severe in February and March, and continues to May and occasionally into June.
- In the eastern Terai slight deficiencies may begin in January (very rarely December). In some years February is deficient, in others it is not. Severe deficiency is usual between March and May, but there is virtually no deficiency in June.
- In the Middle Hills of the Far Western and Mid-Western Development Regions there may be slight deficiencies in January. February is very variable, depending on the amount of winter rainfall received, but despite this winter rainfall there is more likely than not to be a water deficiency in March. Severe deficiencies continue in April and May.
- Elsewhere in the hills slight deficiencies may occur in January and February, but severe deficiencies are not usually experienced until March. East of Kathmandu deficiencies in May are rare, and in June they are virtually unknown.
- In some very wet stations, such as Pokhara, Lumle and Jiri severe deficiencies are rare and in some years no deficiency at all has been calculated. This is also true of some high altitude stations such as Chialsa, and, rather suprisingly, of Lete in the Kali Gandaki valley.
- In contrast there are some stations with low rainfall such as Salyan and Dhankuta, in which water deficiency is more severe and lasts longer than in other stations nearby.
- Throughout Nepal, March and April are the months during which there is the greatest deficiency between available water and potential evapotranspiration.

Water deficiencies will be less severe on north-facing slopes, on soils with a high capacity for storing water, and in places where competition for water has been reduced by thorough weeding. They will be more severe on south-facing slopes, on soils which are shallow, stony or with a low water-storing capacity, and where there is heavy competition for water from weeds and other plants.

Day length

Day length is not strictly a climatic factor but may be mentioned here briefly. At the equator day and night are of about equal length, twelve hours each, throughout the year, but with increasing distance from the equator summer days become longer and winter days shorter, until at the poles the daylight in midsummer lasts 24 hours and there is no night at all. At Kathmandu the longest day (June 21) has about 13.6 hours of daylight, and the shortest (December 21) about 10.4 hours. In the extreme north of Nepal the longest day is about ten minutes longer, and in the extreme south about five minutes shorter.

The importance of day length is that certain species of plants will only flower when days are short (short-day plants) and others when days are long (long-day plants), while a great number (day neutral) of plants are not affected in their flowering by day length. The length of daylight may also influence the time when other stages in the life history of certain plants occur, such as putting out new leaves. Indigenous plants are obviously adapted to local day lengths (or are day neutral), but some exotic plants from regions with long summer days may fail to do well in regions where the contrast between summer and winter day length is less. Certain vegetable cultivars are well known to behave in this way. The only known case in which trees of potential importance in Nepal are affected by day length is that of certain clones of poplars, some of which only thrive when there are long summer days. (There are exotic poplar clones which grow very well in Nepal however.) Day length may be a factor which has helped to cause the failure of some other exotics tried here.

Appendix C

Climatic data for various stations

Notes to Table 5: (a) The statistics are arranged according to the five Development Regions, beginning in the Far Western Development Region; within the region they are arranged in order of altitude. (b) The number in brackets after the station name is the serial number in the Climatological Records. These records have also been used to obtain the data on latitude, longitude and altitude. (c) Mean precipitation and mean temperatures are the means of all data published in the Climatological Records and may differ from other published data derived from records covering a different period. The yearly means of precipitation and temperature are derived from the monthly means. Where no temperature data are available the estimates given by Nayava (1980) have been used; these are indicated by (est.). Evapotranspiration data ('estimated pE') are Penman's E_o, and are also taken from Nayava. (d) The median is the figure exceeded for half the time. The five-year low rainfall was exceeded for four years out of five, i.e. only one year in five has had a lower rainfall. The ten-year low rainfall is analogous.

Table 5—Climatic data for various meteorological stations in Nepal

Far Western Development Region

1. Dhanghadi (0209) — Latitude 23°41', Longitude 80°36', Altitude 167 m.
Years of record: Precipitation 25, Temperature 6.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	26	22	20	14	42	253	576	409	277	75	3	8	1725
Mean temperature (°C)	13.8	15.8	21.5	26.4	29.7	30.2	29.3	29.0	28.2	25.6	20.0	15.0	23.7
Estimated pE (mm)	65	90	152	213	203	180	174	149	123	105	78	50	1582
Precipitation variability (mm)													
Maximum	80	83	72	?11	299	527	1042	619	686	237	16	38	2579
Median	22	17	14	2	29	251	521	403	243	33	0	0	1641
Five-year low	0	1	1	0	0	102	411	255	142	4	0	0	1310
Ten-year low	0	0	0	0	0	82	291	209	119	0	0	0	1279
Minimum	0	0	0	0	0	81	261	70	100	0	0	0	937

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 43.5°C. Absolute minimum temperature 2.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

2. Mahendranagar (0104) Latitude 29°02', Longitude 80°13', Altitude 176 .m
Years of record: Precipitation 10, Temperature 4.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	19	29	15	17	44	216	439	446	247	57	5	13	1547
Mean temperature (°C)	13.4	15.8	20.4	26.2	29.8	29.9	28.9	29.0	27.9	25.4	20.8	16.0	23.6
Estimated pE (mm)	69	92	155	213	242	186	161	152	129	124	78	52	1653
Precipitation variability (mm)													
Maximum	50	57	82	94	157	338	713	522	346	169	34	53	—
Median	14	27	8	3	37	255	425	440	243	21	0	12	—
Five-year low	0	8	0	0	4	83	188	339	180	6	0	0	—
Ten-year low	0	0	0	0	—	—	—	—	—	0	0	0	—
Minimum	0	0	0	0	3	12	180	285	33	0	0	0	—

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 43.0°C. Absolute minimum temperature 2.6°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

3. Kakerpakha (0101) — Latitude 29°39', Longitude 80°30', Altitude 842 m.
Years of record: Precipitation 25, Temperature —.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	39	40	53	40	57	279	442	392	216	57	8	14	1637
Mean temperature (°C (est.))	14.2	15.8	21.0	25.7	27.8	27.8	26.0	25.2	25.1	23.4	17.2	14.3	22.0
Estimated pE (mm)	65	87	143	198	229	180	152	143	126	115	75	59	1572
Precipitation variability (mm)													
Maximum	109	121	209	149	217	672	628	586	354	232	50	50	2373
Median	36	32	38	31	46	239	429	410	241	35	0	10	1563
Five-year low	2	12	17	10	6	140	363	299	137	4	0	0	1417
Ten-year low	0	0	5	1	2	104	322	222	100	0	0	0	1374
Minimum	0	0	0	0	0	78	263	167	79	0	0	0	1286

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

4. Chainpur (W) (0202) — Latitude 29°33', Longitude 81°43', Altitude 1304 m.
Years of record: Precipitation 24, Temperature 1.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precepitation (mm)	56	55	60	41	54	188	351	353	203	64	5	22	1542
Mean temperature (°C)	11.2	12.8	15.6	21.4	24.0	24.4	24.0	23.5	22.2	18.7	15.4	11.8	18.8
Estimated pE (mm)	59	73	130	183	208	162	133	124	108	102	69	56	1407
Precipitation variability (mm)													
Maximum	51	202	205	119	282	455	652	617	465	260	32	26	2077
Median	56	46	51	32	38	168	337	318	178	42	0	10	1415
Five-year low	13	22	20	1	18	86	298	254	109	5	0	0	1166
Ten-year low	2	15	7	0	8	64	231	247	70	0	0	0	1087
Minimum	0	2	5	0	6	54	177	234	30	0	0	0	950

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 35.8°C. Absolute minimum temperature 5.0°C (one year only).

Table 5 cont.—Climatic data for various meteorological stations in Nepal

5. Silghadi Doti (0203) — Latitude 29°16', Longitude 80°59', Altitude 1360 m.
Years of record: Precipitation 25, Temperature 5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	50	42	53	32	59	217	283	252	161	62	6	19	1236
Mean temperature (°C)	12.6	14.1	18.3	23.6	25.9	25.8	25.1	24.7	24.3	22.1	18.5	14.2	20.8
Estimated pE (mm)	56	76	127	162	198	153	129	124	108	99	66	53	1351
Precipitation variability (mm)													
Maximum	150	104	174	122	131	648	470	458	312	283	28	68	2104
Median	42	35	48	16	56	167	269	246	152	36	0	1	1166
Five-year low	16	8	7	1	18	88	230	196	91	0	0	0	946
Ten-year low	2	2	4	0	12	75	188	186	60	0	0	0	858
Minimum	0	0	0	0	3	71	119	92	12	0	0	0	793

Mean number of days per year with minimum temperature 0 °C or less: 0.
Absolute maximum temperature 36.0°C. Absolute minimum temperature 3.6°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

6. Dadeldhura (0104) — Latitude 29°18', Longitude 80°35', Altitude 1837 m.
Years of record: Precipitation 14, Temperature 7.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	56	63	59	42	65	213	368	297	167	54	8	28	1420
Mean temperature (°C (est.))	8.2	9.4	13.1	17.9	20.7	21.4	20.1	20.1	18.9	16.5	12.7	9.8	15.7
Estimated pE (mm)	50	64	112	159	183	138	115	121	99	93	57	50	1241
Precipitation variability (mm)													
Maximum	131	142	133	120	165	556	550	446	349	335	36	92	2088
Median	38	47	52	33	53	178	368	316	162	12	4	3	1454
Five-year low	17	15	21	2	18	55	238	214	64	2	0	0	1224
Ten-year low	5	13	12	0	4	52	196	158	28	1	0	0	1114
Minimum	0	11	9	0	15	48	182	136	25	0	0	0	1076

Mean number of days per year with minimum temperature 0°C or less: 3.1.
Absolute maximum temperature 32.5°C. Absolute minimum temperature -3.4°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

Mid-Western Development Region

7. Khajura (0409) — Latitude 28°06', Longitude 81°34', Altitude 190 m.
Years of record: Precipitation 13, Temperature 12.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	22	16	13	20	36	206	416	286	207	56	3	4	1285
Mean temperature (°C)	14.6	16.7	21.6	27.8	30.6	30.7	29.1	28.9	27.6	25.5	20.5	16.0	24.1
Estimated pE (mm)	59	81	136	198	226	180	158	149	126	115	72	50	1560
Precipitation variability (mm)													
Maximum	60	54	75	124	84	540	691	357	477	230	18	19	—
Median	22	12	6	8	36	186	358	310	214	36	0	0	—
Five-year low	3	1	2	0	3	84	312	213	51	8	0	0	—
Ten-year low	0	0	0	0	0	57	270	172	37	7	0	0	—
Minimum	0	0	0	0	0	50	252	162	37	7	0	0	—

Mean number of days per year with minimum temperature 0°C or less: 0.08.
Absolute maximum temperature 43.5°C. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

8. Koilabas (0510) — Latitude 27°42', Longitude 82°32', Altitude 320 m.
Years of record: Precipitation 10, Temperature 0.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	10	21	8	18	48	250	575	369	276	59	6	4	1644
Mean temperature (°C (est.))	14.0	16.4	21.0	27.0	29.0	28.8	27.6	27.3	26.6	24.8	19.3	14.8	23.0
Estimated pE (mm)	59	90	140	186	210	168	164	144	120	112	75	53	1521
Precipitation variability (mm)													
Maximum	28	66	22	134	127	542	827	494	594	150	30	15	2092
Median	4	12	8	4	42	230	582	380	238	50	0	0	1616
Five-year low	0	3	0	0	2	122	352	172	129	9	0	0	1216
Ten-year low	0	2	0	0	0	57	311	171	39	3	0	0	—
Minimum	0	2	0	0	0	57	311	171	39	3	0	0	1215

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

9. Tulsipur (0508)	Latitude 28°08', Longitude 82°18', Altitude 725 m. Years of record: Precipitation 10, Temperature 5.												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	32	32	10	22	69	322	475	390	266	73	7	8	1706
Mean temperature (°C)	13.6	16.0	20.3	25.9	27.6	27.2	26.3	26.3	25.1	22.5	19.0	15.0	22.0
Estimated pE (mm)	56	81	140	192	217	156	140	127	111	109	69	50	1448
Precipitation variability (mm)													
Maximum	142	96	32	133	136	639	634	598	432	179	32	54	2251
Median	20	24	8	6	69	363	456	376	259	63	1	0	1767
Five-year low	1	5	0	0	13	109	399	309	206	21	0	0	1302
Ten-year low	0	0	0	0	0	102	344	187	55	8	0	0	1141
Minimum	0	0	0	0	0	102	344	187	55	8	0	0	1141

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 39.9°C. Absolute minimum temperature 1.5°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

10. Pusma Camp (0401) — Latitude 28°53', Longitude 81°15', Altitude 950 m.
Years of record: Precipitation 16, Temperature 16.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	34	38	40	25	52	303	489	359	231	41	2	18	1632
Mean temperature (°C)	13.2	15.1	19.5	24.3	26.6	25.8	24.3	24.0	23.7	21.3	17.5	13.8	20.8
Estimated pE (mm)	62	81	133	192	198	152	136	127	108	105	72	56	1422
Precipitation variability (mm)													
Maximum	114	94	115	145	146	707	653	532	422	191	22	69	2342
Median	26	32	23	9	48	187	530	327	209	24	1	7	1566
Five-year low	2	19	3	0	24	133	398	275	119	9	0	0	1200
Ten-year low	1	4	1	0	12	114	321	222	53	4	0	0	1030
Minimum	1	3	0	0	4	104	305	188	10	0	0	0	1019

Mean number of days per year with minimum temperature 0°C or less: 0.2.
Absolute maximum temperature 42.6°C. Absolute minimum temperature 0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

11. Jajarkot (0404) — Latitude 28°42', Longitude 82°12', Altitude 1231 m.
Years of record: Precipitation 24, Temperature 0.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	33	30	29	49	40	295	480	410	212	75	4	16	1673
Mean temperature (°C (est.))	10.9	12.6	17.5	22.0	24.3	24.5	23.4	23.3	21.4	20.0	14.9	11.5	18.9
Estimated pE (mm)	56	76	127	174	195	147	133	121	108	102	66	53	1358
Precipitation variability (mm)													
Maximum	150	256	82	366	132	899	851	815	876	241	27	64	2926
Median	24	14	30	22	33	205	458	399	163	39	0	8	1565
Five-year low	4	0	1	0	16	115	378	324	57	1	0	0	1214
Ten-year low	0	0	0	0	1	101	323	208	4	0	0	0	1191
Minimum	0	0	0	0	0	59	106	132	0	0	0	0	1179

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

12. Dailekh (0402) — Latitude 28°41', Longitude 81°43', Altitude 1402 m.
Years of record: Precipitation 18, Temperature 18.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	38	34	42	40	62	250	466	476	211	58	10	10	1697
Mean temperature (°C)	10.3	12.8	15.9	21.1	23.4	23.7	22.8	22.5	21.6	18.9	14.9	11.4	18.3
Estimated pE (mm)	53	67	118	174	195	141	130	115	99	93	66	53	1304
Precipitation variability (mm)													
Maximum	110	256	82	366	132	899	851	815	876	241	27	64	1463
Median	27	25	40	24	44	232	462	514	192	36	0	6	1689
Five-year low	10	16	15	1	16	131	384	376	131	12	0	0	1292
Ten-year low	2	5	1	0	4	113	336	290	77	0	0	0	1262
Minimum	0	0	0	0	0	59	106	132	0	0	0	0	1222

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 36.0°C. Absolute minimum temperature 0.7°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

13. Salyan (0511) — Latitude 28°23', Longitude 82°10', Altitude 1457 m.
Years of record: Precipitation 19, Temperature 15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	39	34	34	25	55	200	283	231	101	48	11	17	1078
Mean temperature (°C)	10.9	13.0	17.2	21.8	24.1	23.3	22.4	22.1	21.1	18.7	15.0	12.1	18.5
Estimated pE (mm)	56	78	127	186	208	156	133	115	105	99	69	50	1382
Precipitation variability (mm)													
Maximum	174	114	82	107	194	492	440	396	226	276	18	166	1874
Median	22	27	26	15	41	164	264	211	98	18	0	1	1009
Five-year low	3	9	4	0	14	95	203	158	58	3	0	0	849
Ten-year low	2	4	0	0	4	81	172	92	36	0	0	0	781
Minimum	0	0	0	0	4	54	153	84	18	0	0	0	707

Mean number of days per year with minimum temperature 0°C or less: 0.13.
Absolute maximum temperature 36.8°C. Absolute minimum temperature -0.6°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

14. Rumumkhot (0501) — Latitude 28°36', Longitude 82°38', Altitude 1560 m.
Years of record: Precipitation 16, Temperature 0.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	37	61	56	72	165	446	704	720	387	111	22	17	2798
Mean temperature (°C (est.))	8.8	10.2	14.4	19.6	21.4	21.8	21.2	21.2	20.2	17.9	13.1	9.8	16.6
Estimated pE (mm)	50	67	112	162	180	141	124	115	102	96	63	50	1262
Precipitation variability (mm)													
Maximum	97	308	145	274	1139	1220	1366	1117	889	360	142	60	4796
Median	35	35	41	43	70	379	666	718	360	103	2	9	3237
Five-year low	0	5	0	5	13	213	479	406	110	7	0	0	1850
Ten-year low	0	1	0	0	2	112	371	266	73	0	0	0	1683
Minimum	0	0	0	0	0	111	355	196	59	0	0	0	1665

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

15. Shera Gaun (0502) — Latitude 28°35', Longitude 82°49', Altitude 2152 m.
Years of record: Precipitation 20, Temperature 0.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	42	35	46	46	68	211	339	349	166	55	7	11	1375
Mean temperature (°C (est.))	5.8	7.0	11.1	15.8	18.1	19.2	18.6	18.4	17.4	14.6	9.8	6.8	13.6
Estimated pE (mm)	50	59	102	144	167	132	115	109	96	87	57	43	1161
Precipitation variability (mm)													
Maximum	107	89	110	126	144	496	517	538	255	137	30	65	1723
Median	38	33	50	50	69	198	342	327	188	31	0	0	1370
Five-year low	7	13	12	5	34	123	283	285	77	8	0	0	1274
Ten-year low	0	9	4	15	27	66	276	243	61	5	0	0	1104
Minimum	0	1	0	0	10	60	180	219	53	4	0	0	981

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

16. Jumla (0303) — Latitude 29°17', Longitude 82°10', Altitude 2300 m.
Years of record: Precipitation 24, Temperature 7.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	29	42	50	34	41	74	184	187	80	35	4	9	769
Mean temperature (°C)	3.8	4.9	8.4	12.7	15.7	18.9	19.6	19.4	17.4	12.8	8.4	5.2	12.3
Estimated pE (mm)	49	64	109	150	174	153	124	115	102	87	57	43	1227
Precipitation variability (mm)													
Maximum	94	126	160	120	146	223	315	427	161	168	54	10	1160
Median	30	32	40	27	44	64	182	164	86	19	0	1	738
Five-year low	4	11	30	12	11	20	127	128	43	0	0	0	563
Ten-year low	1	1	3	4	6	14	120	101	22	0	0	0	498
Minimum	0	0	0	0	2	10	114	82	7	0	0	0	490

Mean number of days per year with minimum temperature 0°C or less: 127.8.
Absolute maximum temperature 30.4°C. Absolute minimum temperature -13.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

Western Development Region

17. Bhairawa (705) — Latitude 27°31', Longitude 83°28', Altitude 110 m.
Years of record: Precipitation 11, Temperature 11.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	13	11	14	7	53	244	543	342	231	59	2	6	1525
Mean temperature (°C)	15.1	17.5	22.6	28.2	30.2	29.7	28.9	29.0	28.1	25.9	21.4	16.5	24.4
Estimated pE (mm)	59	84	146	201	220	171	161	149	123	118	81	53	1566
Precipitation variability (mm)													
Maximum	60	39	46	33	110	512	828	566	625	242	10	51	1922
Median	6	10	9	4	38	285	574	306	153	35	0	0	1588
Five-year low	2	2	0	0	9	74	353	209	73	10	0	0	1238
Ten-year low	0	1	0	0	1	54	171	59	55	6	0	0	751
Minimum	0	1	0	0	0	52	153	44	54	5	0	0	701

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 44.1°C. Absolute minimum temperature 2.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

18. Butwal (703) — Latitude 27°42', Longitude 83°28', Altitude 263 m.
Years of record: Precipitation 20, Temperature 15.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	13	14	29	70	433	695	665	390	110	10	7	2452
Mean temperature (°C)	17.8	17.7	24.8	29.6	31.4	30.3	28.8	28.7	28.0	26.2	22.6	18.7	25.6
Estimated pE (mm)	71	95	161	216	226	168	155	146	123	121	87	65	1634
Precipitation variability (mm)													
Maximum	76	46	58	117	167	971	1193	1661	985	392	100	36	3963
Median	7	10	8	22	55	405	627	575	332	90	0	0	2276
Five-year low	0	0	0	1	25	214	481	398	208	38	0	0	1906
Ten-year low	0	0	0	0	16	153	364	313	181	12	0	0	1851
Minimum	0	0	0	0	10	127	124	248	174	0	0	0	1556

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 44.9°C. Absolute minimum temperature 4.3°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

19. Chapkot (810) — Latitude 27°53', Longitude 83°49', Altitude 400 m.
Years of record: Precipitation 24, Temperature 3.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	21	24	36	61	130	304	469	360	224	88	3	10	1780
Mean temperature (°C)	12.6	15.5	20.4	25.5	26.1	27.1	26.4	26.5	25.4	23.0	18.4	14.0	21.7
Estimated pE (mm)	66	87	140	192	205	165	158	149	120	115	78	59	1534
Precipitation variability (mm)													
Maximum	105	184	139	272	364	674	845	846	652	334	24	73	3273
Median	11	9	26	31	99	308	495	287	203	38	0	1	1580
Five-year low	0	0	9	4	59	167	319	248	83	11	0	0	1240
Ten-year low	0	0	2	1	26	147	259	225	59	4	0	0	1186
Minimum	0	0	0	0	19	116	210	136	48	0	0	0	1159

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 40.4°C. Absolute minimum temperature 3.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

20. Khairani Tar (0815) — Latitude 28°02', Longitude 84°06', Altitude 500 m.
Years of record: Precipitation 9, Temperature 6.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	12	28	33	91	306	418	534	393	277	78	25	19	2214
Mean temperature (°C)	14.8	17.0	21.1	25.2	26.2	27.5	27.8	27.9	27.0	24.0	20.2	16.2	22.9
Estimated pE (mm)	65	90	143	189	192	162	149	136	123	115	75	56	1495
Precipitation variability (mm)													
Maximum	25	46	67	241	556	547	1022	673	446	166	60	69	2623
Median	12	32	38	83	288	420	511	312	274	58	7	3	2202
Five-year low	4	11	11	10	163	315	292	200	209	28	2	0	1865
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	3	4	7	7	101	308	262	133	66	13	0	0	1865

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 40°C. Absolute minimum temperature 4.2°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

21. Tansen (0702) — Latitude 27°52', Longitude 83°32', Altitude 1067 m.
Years of record: Precipitation 20, Temperature 6.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	23	18	26	45	61	235	432	391	189	60	2	12	1494
Mean temperature (°C)	13.2	15.0	18.6	21.6	23.3	23.8	23.9	23.7	22.5	20.8	16.9	13.8	19.8
Estimated pE (mm)	53	73	121	168	183	141	133	121	105	99	66	50	1313
Precipitation variability (mm)													
Maximum	127	85	101	173	126	439	682	719	666	189	8	73	2220
Median	8	0	13	36	52	238	440	360	149	20	0	0	1524
Five-year low	0	0	0	4	28	148	300	249	56	1	0	0	1194
Ten-year low	0	0	0	0	18	106	219	188	46	0	0	0	1031
Minimum	0	0	0	0	3	100	149	165	37	0	0	0	972

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 36.0°C. Absolute minimum temperature 1.2°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

22. Gorkha (0809) — Latitude 28°00', Longitude 84°37', Altitude 1097 m.
Years of record: Precipitation 20, Temperature 19.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	22	16	32	66	157	358	432	398	203	65	15	12	1776
Mean temperature (°C)	12.6	14.8	19.5	23.2	24.1	24.5	23.9	23.8	23.0	20.7	17.2	13.7	20.1
Estimated pE (mm)	56	78	136	174	164	138	127	118	102	99	66	47	1305
Precipitation variability (mm)													
Maximum	117	45	112	217	298	812	703	635	359	133	126	113	2312
Median	10	12	20	60	136	332	437	389	202	53	4	1	1731
Five-year low	2	2	6	21	86	222	335	265	106	16	0	0	1471
Ten-year low	0	1	0	2	77	209	271	217	79	11	0	0	1353
Minimum	0	0	0	2	67	190	203	208	76	10	0	0	1280

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 35.6°C. Absolute minimum temperature 0.9°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

23. Pokhara (0803+0804) — Latitude 28°13', Longitude 84°0', Altitude 850 m.
Years of record: Precipitation 24, Temperature 24.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	26	31	56	102	285	658	886	841	580	215	17	13	3710
Mean temperature (°C)	13.2	15.1	19.5	23.4	24.5	25.3	25.5	25.5	24.5	21.5	17.1	14.1	20.8
Estimated pE (mm)	59	78	130	165	171	146	136	127	111	99	69	53	1344
Precipitation variability (mm)													
Maximum	100	74	109	273	527	1022	1385	1400	1096	454	101	68	4667
Median	18	23	58	75	277	677	918	818	570	218	4	1	3844
Five-year low	3	8	21	42	155	449	689	577	400	89	0	0	3241
Ten-year low	1	4	6	31	142	416	624	487	341	58	0	0	3157
Minimum	0	0	0	24	97	206	553	430	298	40	0	0	2753

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 37.4°C. Absolute minimum temperature 2.4°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

24. Baglung (0605)

Latitude 28°16', Longitude 83°36', Altitude 984 m.
Years of record: Precipitation 10, Temperature 2.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	19	16	53	134	251	494	430	218	96	10	11	1748
Mean temperature (°C)	13.8	15.6	19.8	24.8	25.1	26.6	26.2	26.4	25.0	21.9	19.1	14.8	21.6
Estimated pE (mm)	69	84	130	171	192	153	133	124	111	102	69	53	1391
Precipitation variability (mm)													
Maximum	63	55	54	119	244	353	730	702	415	214	37	36	2332
Median	12	16	12	52	127	238	472	393	207	82	6	8	1695
Five-year low	0	0	0	0	80	204	331	236	110	62	0	0	1505
Ten-year low	0	0	0	0	49	160	233	200	73	48	0	0	1076
Minimum	0	0	0	0	49	160	233	200	73	48	0	0	1033

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 37.2°C. Absolute minimum temperature 4.4°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal.

25. Lumle (0814) — Latitude 28°18', Longitude 83°48', Altitude 1642 m.
Years of record: Precipitation 11, Temperature 11.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	24	43	46	112	305	848	1417	1291	797	242	30	12	5167
Mean temperature (°C)	8.7	10.2	14.4	17.6	18.4	19.5	19.9	19.9	18.9	16.6	13.3	9.9	15.6
Estimated pE (mm)	53	70	118	144	146	117	112	105	93	96	66	53	1173
Precipitation variability (mm)													
Maximum	51	74	69	288	466	1208	1719	1659	1278	533	122	58	5964
Median	22	44	45	90	310	910	1378	1210	836	211	11	0	5308
Five-year low	4	13	20	33	177	579	1195	1104	546	115	1	0	4743
Ten-year low	2	8	4	11	171	536	1068	994	370	100	0	0	4021
Minimum	2	8	2	9	170	532	1054	982	352	98	0	0	3944

Mean number of days per year with minimum temperature 0°C or less: 0.1.
Absolute maximum temperature 28.2°C. Absolute minimum temperature -0.4°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

26. Khanchikot (0715) — Latitude 27°56', Longitude 83°09', Altitude 1760 m.
Years of record: Precipitation 10, Temperature 4.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	21	30	23	34	91	294	468	365	246	85	6	18	1681
Mean temperature (°C)	9.2	10.7	14.9	19.0	19.6	20.1	20.0	20.2	19.3	16.9	14.2	10.5	16.2
Estimated pE (mm)	43	62	105	153	171	132	121	112	96	62	60	43	1160
Precipitation variability (mm)													
Maximum	87	79	52	143	156	520	736	640	729	539	21	98	2452
Median	11	26	26	20	97	258	476	324	185	26	2	0	1885
Five-year low	2	6	2	3	37	146	281	261	73	6	0	0	1200
Ten-year low	0	5	0	1	9	55	162	94	52	4	0	0	739
Minimum	0	5	0	1	9	55	162	94	52	4	0	0	688

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 29.7°C. Absolute minimum temperature 0.5°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

27. Lete (0607)

Latitude 28°38', Longitude 83°36', Altitude 2384 m.
Years of record: Precipitation 11, Temperature 0.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	27	60	73	86	97	146	178	186	113	63	13	9	1051
Mean temperature (°C (est.))	5.2	6.5	10.6	14.5	16.6	16.8	17.7	17.4	16.2	13.6	8.9	6.2	12.5
Estimated pE (mm)	48	53	102	141	158	135	121	112	96	84	48	43	1141
Precipitation variability (mm)													
Maximum	62	100	128	173	144	285	257	266	134	162	61	44	1203
Median	24	62	67	102	84	164	167	196	118	74	7	0	1054
Five-year low	5	28	39	32	56	86	110	115	92	17	0	0	970
Ten-year low	1	16	25	9	46	18	107	79	56	9	0	0	836
Minimum	0	15	24	6	45	2	106	78	48	8	0	0	822

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

28. Thakmarpha (0604) — Latitude 28°45', Longitude 83°42', Altitude 2566 m.
Years of record: Precipitation 13, Temperature 10.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	11	14	26	24	23	41	51	52	45	43	7	3	340
Mean temperature (°C)	4.3	5.5	8.4	11.3	13.3	15.5	16.4	16.0	14.9	11.6	8.0	5.6	10.9
Estimated pE (mm)	68	87	136	168	192	162	136	124	108	109	78	68	1436
Precipitation variability (mm)													
Maximum	37	47	59	50	57	107	94	98	107	140	24	16	499
Median	10	8	23	21	22	31	54	49	46	25	6	0	367
Five-year low	0	2	9	3	4	18	22	25	6	6	0	0	265
Ten-year low	0	0	6	0	3	12	13	15	9	1	0	0	171
Minimum	0	0	5	0	3	11	12	11	6	0	0	0	171

Mean number of days per year with minimum temperature 0°C or less: 68.7.
Absolute maximum temperature 24.6°C. Absolute minimum temperature -10°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

29. Jomsom (0601) — Latitude 28°47', Longitude 83°43', Altitude 2744 m.
Years of record: Precipitation 17, Temperature 9.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	16	22	14	6	25	39	43	32	31	3	2	249
Mean temperature (°C)	4.4	5.9	8.8	12.0	15.1	18.6	19.4	18.9	17.1	11.9	8.2	5.5	12.2
Estimated pE (mm)	40	65	102	123	143	138	124	115	99	78	51	37	1115
Precipitation variability (mm)													
Maximum	97	92	84	60	11	114	83	85	61	200	18	13	451
Median	6	8	16	9	2	13	42	43	38	4	1	0	223
Five-year low	1	2	2	2	1	1	17	8	2	0	0	0	159
Ten-year low	0	0	0	0	0	0	11	5	1	0	0	0	120
Minimum	0	0	0	0	0	0	4	4	0	0	0	0	100

Mean number of days per year with minimum temperature 0°C or less: 98.
Absolute maximum temperature 30.5°C. Absolute minimum temperature -10°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

30. Mustang (Lomantang) (0612) Latitude 29°11', Longitude 83°58', Altitude 3705 m.
Years of record: Precipitation 7, Temperature 7.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	11	13	6	2	1	14	56	62	9	0	3	7	184
Mean temperature (°C)	-4.0	-3.2	1.0	6.1	9.2	12.8	14.0	13.7	11.7	7.6	2.4	-1.5	5.8
Estimated pE (mm)	—	—	—	—	—	—	—	—	—	—	—	—	—
Precipitation variability (mm)													
Maximum	18	42	18	7	8	49	118	119	39	1	11	18	296
Median	11	6	1	1	0	5	49	52	4	0	0	5	185
Five-year low	2	1	0	0	0	0	22	25	2	0	0	0	—
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	0	0	0	12	23	2	0	0	0	155

Mean number of days per year with minimum temperature 0°C or less: 187.
Absolute maximum temperature 25.4°C. Absolute minimum temperature -26.1°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

Central Development Region

31. Hardinath (1114) — Latitude 26°48', Longitude 85°59', Altitude 93 m.
Years of record: Precipitation 10, Temperature 10.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	11	10	12	47	84	229	389	294	165	80	6	5	1332
Mean temperature (°C)	16.3	18.2	22.8	27.4	28.7	29.1	28.8	28.5	28.2	26.3	22.2	17.2	24.5
Estimated pE (mm)	68	90	146	201	217	177	167	152	133	121	81	56	1609
Precipitation variability (mm)													
Maximum	52	27	44	129	172	407	722	532	361	217	45	27	1588
Median	10	8	4	47	81	220	342	308	146	45	0	0	1336
Five-year low	0	1	0	2	25	130	204	155	62	25	0	0	1121
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	1	20	25	201	130	26	1	0	0	869

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 41.8°C. Absolute minimum temperature 5.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

32. Simra (909) — Latitude 27°10', Longitude 84°59', Altitude 137 m.
Years of record: Precipitation 10, Temperature 10.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	8	16	14	42	114	253	508	324	230	110	5	8	1632
Mean temperature (°C)	15.2	17.1	22.1	27.3	29.0	29.4	28.6	27.8	27.8	25.2	21.2	15.9	23.9
Estimated pE (mm)	62	81	140	186	202	165	164	149	120	115	75	53	1512
Precipitation variability (mm)													
Maximum	48	38	31	137	228	502	997	628	418	215	22	43	2312
Median	7	14	17	24	115	253	397	296	210	87	3	1	1771
Five-year low	0	3	0	14	23	116	169	172	105	58	0	0	1177
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	1	0	0	11	85	164	124	94	56	0	0	913

Mean number of days per year with minimum temperature 0°C or less: 0.1.
Absolute maximum temperature 42.8°C. Absolute minimum temperature -0.6°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

33. Jhawani (903) — Latitude 27°35', Longitude 84°32', Altitude 270 m.
Years of record: Precipitation 23, Temperature —.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	18	17	18	39	93	331	459	462	279	82	12	7	1817
Mean temperature (°C (est.))	15.7	17.7	22.9	27.4	29.0	29.0	28.2	27.8	27.1	25.4	20.3	16.3	23.9
Estimated pE (mm)	65	90	149	195	208	165	158	149	120	115	78	59	1551
Precipitation variability (mm)													
Maximum	129	82	76	274	246	767	734	978	687	199	112	48	2772
Median	5	6	8	19	83	273	443	407	228	67	0	1	1855
Five-year low	0	0	0	3	36	191	347	296	156	35	0	0	1541
Ten-year low	0	0	0	0	12	164	323	260	143	5	0	0	1455
Minimum	0	0	0	0	0	123	266	252	121	0	0	0	1283

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

34. Hetauda (906) — Latitude 27°25', Longitude 85°03', Altitude 303 m.
Years of record: Precipitation 13, Temperature 12.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	15	16	29	55	130	403	646	469	330	91	19	8	2211
Mean temperature (°C)	14.2	16.1	20.8	25.3	27.2	27.0	26.9	26.8	26.0	22.8	18.7	15.1	22.2
Estimated pE (mm)	62	87	140	183	198	159	146	136	117	112	75	56	1471
Precipitation variability (mm)													
Maximum	48	56	240	202	231	798	1171	874	572	218	122	35	2709
Median	5	12	10	46	165	388	626	388	319	78	6	1	2290
Five-year low	0	1	1	14	28	226	429	339	192	55	0	0	1747
Ten-year low	0	0	0	2	1	162	407	316	147	34	0	0	—
Minimum	0	0	0	0	0	148	402	307	138	30	0	0	1602

Mean number of days per year with minimum temperature 0°C or less: 0.8.
Absolute maximum temperature 40.0°C. Absolute minimum temperature -2.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

35. Trisuli (1003)	Latitude 27°55', Longitude 85°09', Altitude 595 m. Years of record: Precipitation 8, Temperature 8.												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	13	17	25	27	97	348	453	427	232	114	7	7	1767
Mean temperature (°C)	14.6	16.6	20.3	25.1	26.8	27.2	26.4	26.4	25.2	22.8	20.2	15.6	22.3
Estimated pE (mm)	68	90	143	189	208	171	153	138	126	118	78	62	1544
Precipitation variability (mm)													
Maximum	40	39	62	76	163	671	780	743	394	338	21	51	2546
Median	8	15	16	20	104	288	376	424	208	91	6	2	1653
Five-year low	1	2	5	11	38	191	305	252	75	33	0	0	1504
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	6	11	121	280	93	47	20	0	0	1453

Mean number of days per year with minimum temperature 0°C or less: 1.0.
Absolute maximum temperature 41.0°C. Absolute minimum temperature 0.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

36. Nuwakot (1004) — Latitude 27°55', Longitude 85°10', Altitude 1003 m.
Years of record: Precipitation 23, Temperature 18.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	20	28	42	91	343	461	487	246	71	8	6	1819
Mean temperature (°C)	13.4	15.1	20.0	23.8	24.1	24.3	24.0	23.8	23.3	21.5	17.8	14.3	20.4
Estimated pE (mm)	65	84	140	180	189	141	130	124	105	109	75	59	1401
Precipitation variability (mm)													
Maximum	70	106	95	142	225	687	716	782	447	238	49	54	2542
Median	11	12	18	24	91	301	458	478	238	70	0	0	1824
Five-year low	0	0	4	11	46	204	363	384	172	18	0	0	1612
Ten-year low	0	0	0	8	28	177	267	276	114	14	0	0	1437
Minimum	0	0	0	6	16	157	244	217	65	11	0	0	1190

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 36.0°C. Absolute minimum temperature 2.9°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

37. Kathmandu (1014 + 1030) Latitude 27°44', Longitude 85°20', Altitude 1324 m.
Years of record: Precipitation 60, Temperature 12.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	18	24	26	52	96	227	369	335	159	46	8	4	1364
Mean temperature (°C)	9.5	11.9	15.6	19.3	22.0	23.6	23.8	23.6	22.5	19.5	14.6	10.8	18.1
Estimated pE (mm)	59	73	115	153	167	144	133	127	111	102	66	50	1300
Precipitation variability (mm)													
Maximum	100	89	90	176	241	698	626	526	374	191	107	38	1969
Median	12	16	17	42	86	234	341	334	168	30	2	0	1369
Five-year low	1	3	4	21	51	143	275	238	94	8	0	0	1195
Ten-year low	0	1	1	10	37	122	252	205	78	2	0	0	1112
Minimum	0	0	0	0	12	80	179	180	31	0	0	0	872

Mean number of days per year with minimum temperature 0°C or less: 12.
Absolute maximum temperature 36°C. Absolute minimum temperature -3.9°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

38. Chautara (1009) Latitude 27°47', Longitude 85°43', Altitude 1676 m.
Years of record: Precipitation 15, Temperature 6.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	12	21	37	62	92	332	544	578	302	62	10	4	2056
Mean temperature (°C)	11.8	14.1	17.2	20.8	22.1	23.2	22.6	22.2	21.9	19.7	15.9	13.4	18.7
Estimated pE (mm)	53	62	112	153	152	126	121	115	90	87	54	40	1165
Precipitation variability (mm)													
Maximum	55	90	103	161	239	715	808	1249	525	159	34	33	3151
Median	4	11	37	46	77	297	519	579	324	59	0	6	2060
Five-year low	0	0	1	11	50	190	449	391	233	29	0	0	1642
Ten-year low	0	0	0	4	20	170	401	360	187	8	0	0	1520
Minimum	0	0	0	2	16	164	388	340	174	2	0	0	1492

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 34.1°C. Absolute minimum temperature 1.3°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

39. Jiri (1103) — Latitude 27°38', Longitude 86°14', Altitude 2003 m.
Years of record: Precipitation 13, Temperature 13.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	18	45	74	146	376	581	584	305	87	15	8	2255
Mean temperature (°C)	6.1	8.0	11.4	15.1	17.0	19.3	19.8	19.6	18.5	14.8	10.7	8.4	14.1
Estimated pE (mm)	42	62	102	132	136	120	115	105	90	87	54	40	1085
Precipitation variability (mm)													
Maximum	57	62	92	132	219	541	797	971	661	191	44	69	2629
Median	9	17	46	78	155	394	568	559	267	75	12	0	2200
Five-year low	2	3	15	42	84	285	510	487	214	51	0	0	2014
Ten-year low	0	0	0	25	76	231	483	464	194	21	0	0	1988
Minimum	0	0	0	17	60	230	360	397	134	9	0	0	1975

Mean number of days per year with minimum temperature 0°C or less: 43.7.
Absolute maximum temperature 28.5°C. Absolute minimum temperature -7.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

40. Kakani (1007) — Latitude 27°48', Longitude 85°15', Altitude 2064 m.
Years of record: Precipitation 13, Temperature 13.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	14	23	48	58	138	450	682	742	465	103	10	8	2741
Mean temperature (°C)	7.9	9.5	13.5	16.2	17.9	18.4	18.6	18.1	17.7	15.9	12.7	10.1	14.7
Estimated pE (mm)	47	62	102	135	143	114	109	102	87	87	60	47	1095
Precipitation variability (mm)													
Maximum	48	55	115	112	238	831	1194	1110	974	219	38	78	3501
Median	8	25	33	54	161	466	642	727	415	110	2	2	2958
Five-year low	0	4	2	24	66	254	505	533	323	27	0	0	2031
Ten-year low	0	1	1	8	14	214	397	449	198	20	0	0	1745
Minimum	0	0	0	6	11	211	354	399	47	19	0	0	1734

Mean number of days per year with minimum temperature 0°C or less: 12.7.
Absolute maximum temperature 29.5°C. Absolute minimum temperature -4.9°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

41. Nagarkot (1043)

Latitude 27°42', Longitude 85°31', Altitude 2150 m.
Years of record: Precipitation 10, Temperature 5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	11	25	42	50	138	378	542	492	309	94	8	10	2099
Mean temperature (°C)	7.2	8.9	12.6	16.6	17.6	18.6	19.0	18.7	17.8	15.0	12.2	8.7	14.4
Estimated pE (mm)	43	59	99	132	143	117	109	99	87	84	54	43	1069
Precipitation variability (mm)													
Maximum	35	46	94	72	221	633	812	1032	828	161	29	64	3743
Median	6	24	40	60	142	358	492	438	243	103	2	2	1856
Five-year low	2	8	0	8	65	183	409	329	74	45	0	0	1726
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	6	0	6	58	126	331	282	58	38	0	0	1641

Mean number of days per year with minimum temperature 0°C or less: 4.2.
Absolute maximum temperature 30.1°C. Absolute minimum temperature -2.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

Eastern Development Region

42. Tarahara (1320) — Latitude 26°42', Longitude 87°16', Altitude 200 m.
Years of record: Precipitation 10, Temperature 10.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	12	10	12	55	124	319	465	275	232	110	5	9	1628
Mean temperature (°C)	15.8	17.8	22.0	26.6	27.7	28.4	28.4	28.5	27.8	25.5	21.2	15.9	23.8
Estimated pE (mm)	62	78	140	189	198	174	169	140	123	105	69	50	1497
Precipitation variability (mm)													
Maximum	42	29	56	116	299	584	719	473	504	215	22	110	2039
Median	6	6	6	54	98	279	443	300	190	86	2	0	1566
Five-year low	0	1	1	14	70	194	302	117	91	20	0	0	1291
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	10	36	128	200	98	89	18	0	0	1286

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 41.8°C. Absolute minimum temperature 6.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

43. Dharan (1322 + 1311) Latitude 26°49', Longitude 87°17', Altitude 400 m.
Years of record: Precipitation 10, Temperature 5.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	11	21	24	76	147	486	595	462	367	188	17	7	2401
Mean temperature (°C)	17.1	19.2	24.2	27.6	27.9	28.2	28.1	28.2	27.4	25.3	22.5	19.3	24.6
Estimated pE (mm)	65	87	140	177	180	153	146	133	114	109	78	56	1438
Precipitation variability (mm)													
Maximum	45	86	81	212	405	1036	1075	730	679	421	79	43	3316
Median	5	10	14	68	110	422	621	504	348	181	4	0	2565
Five-year low	0	0	0	18	61	275	349	199	262	42	0	0	1562
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	16	27	264	279	159	233	16	0	0	1505

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 41.0°C. Absolute minimum temperature 5.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

44. Ilam (1407) — Latitude 26°55', Longitude 87°54', Altitude 1300 m.
Years of record: Precipitation 25, Temperature 11.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	10	9	20	61	138	279	416	281	208	84	8	6	1520
Mean temperature (°C)	12.3	14.0	18.5	21.2	21.3	22.4	22.2	22.3	21.9	20.4	16.7	13.5	18.9
Estimated pE (mm)	43	62	105	129	130	123	121	115	99	87	57	37	1108
Precipitation variability (mm)													
Maximum	42	48	104	223	231	527	998	530	478	398	37	77	2447
Median	6	2	10	59	146	276	325	270	197	47	1	0	1493
Five-year low	0	0	0	19	83	171	281	144	131	14	0	0	1392
Ten-year low	0	0	0	5	54	150	179	121	84	7	0	0	1336
Minimum	0	0	0	1	31	146	138	116	56	3	0	0	909

Mean number of days per year with minimum temperature 0°C or less: 0.1.
Absolute maximum temperature 35.0°C. Absolute minimum temperature 0.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

45. Chainpur (E) (1303) — Latitude 27°17', Longitude 87°20', Altitude 1329 m.
Years of record: Precipitation 19, Temperature 18.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	19	13	25	85	176	239	309	237	192	74	25	5	1399
Mean temperature (°C)	13.2	15.0	18.9	22.0	22.9	23.8	23.7	23.7	22.7	20.7	17.7	14.5	19.9
Estimated pE (mm)	62	84	129	153	152	146	136	133	114	105	78	59	1351
Precipitation variability (mm)													
Maximum	46	46	67	217	348	443	487	540	345	248	141	34	1887
Median	6	11	22	59	160	228	307	248	204	52	6	1	1355
Five-year low	0	0	2	29	115	138	235	163	120	26	0	0	1208
Ten-year low	0	0	0	20	68	94	148	128	83	12	0	0	1122
Minimum	0	0	0	12	66	54	86	66	71	8	0	0	949

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 36.4°C. Absolute minimum temperature 3.0°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

46. Taplethok (1404) — Latitude 27°29', Longitude 87°47', Altitude 1383 m.
Years of record: Precipitation 19, Temperature 14.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	18	25	65	122	195	433	575	542	385	133	39	12	2544
Mean temperature (°C)	12.4	14.1	17.5	20.2	21.4	22.8	22.8	22.6	21.8	20.1	16.6	13.7	18.8
Estimated pE (mm)	65	81	127	153	164	141	133	124	111	105	75	59	1338
Precipitation variability (mm)													
Maximum	85	68	135	282	289	682	817	805	568	278	262	86	3433
Median	6	19	63	104	216	458	578	568	382	120	20	1	2594
Five-year low	0	5	21	77	141	290	496	399	320	56	1	0	2346
Ten-year low	0	4	10	54	95	275	451	344	312	32	0	0	2187
Minimum	0	2	6	34	70	270	447	293	306	4	0	0	2070

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 32.8°C. Absolute minimum temperature 2.9°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

47. Dhankuta (1307) — Latitude 26°59', Longitude 87°21', Altitude 1445 m.
Years of record: Precipitation 10, Temperature 8.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	14	13	20	66	114	199	256	131	105	70	8	10	1006
Mean temperature (°C)	11.1	13.4	17.8	21.0	20.9	22.1	22.3	22.4	21.1	19.0	16.1	12.7	18.3
Estimated pE (mm)	53	76	127	153	167	144	140	136	117	102	72	50	1337
Precipitation variability (mm)													
Maximum	37	38	61	176	182	294	463	214	324	225	45	56	1275
Median	15	12	11	53	120	187	252	122	85	54	0	1	994
Five-year low	0	0	1	23	48	142	105	85	63	4	0	0	771
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	20	23	115	88	48	28	2	0	0	639

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 32.0°C. Absolute minimum temperature 3.3°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

48. Bhojpur (1595) — Latitude 27°11', Longitude 87°03', Altitude 1595 m.
Years of record: Precipitation 19, Temperature 18.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	26	11	32	65	143	232	286	193	166	91	18	5	1268
Mean temperature (°C)	9.7	11.6	15.6	18.7	19.5	20.8	20.9	21.0	20.0	17.8	14.5	11.3	16.8
Estimated pE (mm)	53	70	121	144	140	126	124	115	99	93	63	47	1195
Precipitation variability (mm)													
Maximum	266	47	78	119	250	395	417	343	396	267	144	47	1708
Median	6	6	34	70	138	222	325	200	165	44	4	0	1258
Five-year low	0	0	0	39	90	117	202	124	72	17	0	0	1050
Ten-year low	0	0	0	23	79	105	138	72	50	13	0	0	946
Minimum	0	0	0	14	64	101	110	63	41	2	0	0	396

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 29.8°C. Absolute minimum temperature 0.4°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

49. Taplejung (1405) — Latitude 27°21', Longitude 87°40', Altitude 1768 m.
Years of record: Precipitation 19, Temperature 18.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	15	26	51	115	239	348	443	387	265	84	15	7	1995
Mean temperature (°C)	8.8	10.4	14.0	17.5	19.0	20.4	20.9	20.8	19.8	17.0	13.2	10.5	16.0
Estimated pE (mm)	53	67	109	138	143	123	121	115	99	96	60	47	1171
Precipitation variability (mm)													
Maximum	54	146	135	282	385	551	626	551	508	268	62	72	2321
Median	13	14	52	103	245	344	424	392	271	60	8	2	1990
Five-year low	2	4	8	52	178	276	361	282	168	22	0	0	1756
Ten-year low	1	4	3	41	139	213	323	244	129	12	0	0	1586
Minimum	0	3	0	39	119	212	316	221	100	4	0	0	1573

Mean number of days per year with minimum temperature 0°C or less: 0.
Absolute maximum temperature 28.6°C. Absolute minimum temperature 0.5°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

50. Okhaldunga (1206)   Latitude 27°19', Longitude 86°30', Altitude 1810 m.
Years of record: Precipitation 17, Temperature 16.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	10	13	30	66	139	339	474	383	353	90	8	6	1811
Mean temperature (°C)	9.3	11.1	15.0	18.3	19.3	20.4	20.3	20.4	19.3	17.4	14.0	11.0	16.3
Estimated pE (mm)	62	87	140	174	155	126	124	112	99	99	78	53	1309
Precipitation variability (mm)													
Maximum	30	56	76	127	272	634	682	606	468	204	22	52	2241
Median	10	3	31	66	132	326	456	401	217	75	10	0	1893
Five-year low	0	2	2	30	103	192	360	289	176	36	0	0	1512
Ten-year low	0	1	1	21	78	186	316	216	142	26	0	0	1420
Minimum	0	0	0	13	49	185	254	161	96	25	0	0	1178

Mean number of days per year with minimum temperature 0°C or less: 0.13.
Absolute maximum temperature 29.5°C. Absolute minimum temperature -0.5°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

51. Aisealukharkh (1204) — Latitude 27°21', Longitude 86°45', Altitude 2143 m.
Years of record: Precipitation 32, Temperature —.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	16	10	24	77	196	463	579	543	314	110	21	20	2373
Mean temperature (°C (est.))	6.1	7.6	11.6	14.4	15.7	17.3	18.0	18.0	16.8	14.7	10.6	7.4	13.2
Estimated pE (mm)	43	59	99	123	124	105	105	99	87	81	54	40	1019
Precipitation variability (mm)													
Maximum	87	40	92	336	601	925	1189	935	641	356	113	77	3864
Median	3	2	16	48	181	481	560	508	284	95	1	0	2380
Five-year low	0	0	0	18	62	322	419	396	189	29	0	0	1833
Ten-year low	0	0	0	16	38	229	343	304	81	7	0	0	1573
Minimum	0	0	0	12	19	103	260	262	40	2	0	0	1443

Mean number of days per year with minimum temperature 0°C or less: —.
Absolute maximum temperature —. Absolute minimum temperature —.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

52. Chialsa (1220) — Latitude 27°31', Longitude 86°37', Altitude 2750 m.
Years of record: Precipitation 13, Temperature 11.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	12	6	43	53	88	297	511	481	266	84	10	6	1857
Mean temperature (°C)	2.3	4.0	7.7	10.8	12.0	14.2	14.7	14.7	13.7	10.5	6.1	3.6	9.5
Estimated pE (mm)	40	56	87	111	115	96	96	93	75	68	45	50	932
Precipitation variability (mm)													
Maximum	33	14	99	149	145	486	652	670	367	334	37	62	2354
Median	9	4	40	50	79	318	522	475	264	63	2	0	1831
Five-year low	0	1	7	15	70	176	380	397	181	21	0	0	1569
Ten-year low	0	0	2	13	45	146	335	391	148	4	0	0	1427
Minimum	0	0	0	12	36	135	334	389	138	3	0	0	1391

Mean number of days per year with minimum temperature 0°C or less: 83.1.
Absolute maximum temperature 22.2°C. Absolute minimum temperature -9.8°C.

Table 5 cont.—Climatic data for various meteorological stations in Nepal

53. Olangchung Gola (1401) Latitude 27°41', Longitude 87°47', Altitude 3048 m.
Years of record: Precipitation 9, Temperature 6.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	21	39	87	49	105	252	322	326	254	78	21	4	1558
Mean temperature (°C)	1.0	0.7	4.0	7.1	9.6	12.4	13.0	12.8	11.8	8.5	5.1	3.2	7.4
Estimated pE (mm)	37	50	84	108	115	102	99	93	75	74	51	40	928
Precipitation variability (mm)													
Maximum	41	97	291	117	142	370	449	424	385	317	82	13	2285
Median	25	29	66	42	103	242	382	366	248	52	8	0	1615
Five-year low	0	6	5	25	80	145	146	243	202	21	0	0	1408
Ten-year low	—	—	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	0	0	14	72	110	64	74	201	4	0	0	1121

Mean number of days per year with minimum temperature 0°C or less: 121.9.
Absolute maximum temperature 21.0°C. Absolute minimum temperature -9.5°C.

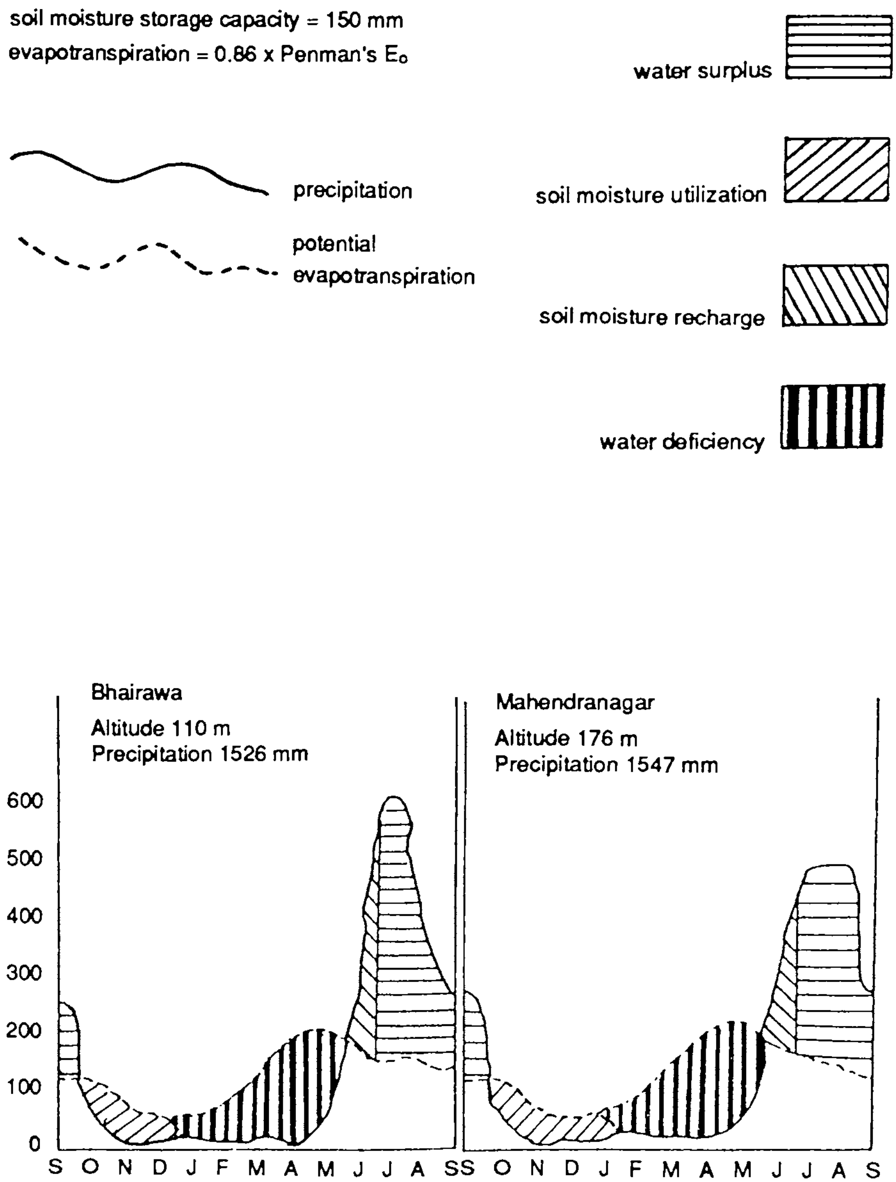
Table 5 cont.—Climatic data for various meteorological stations in Nepal

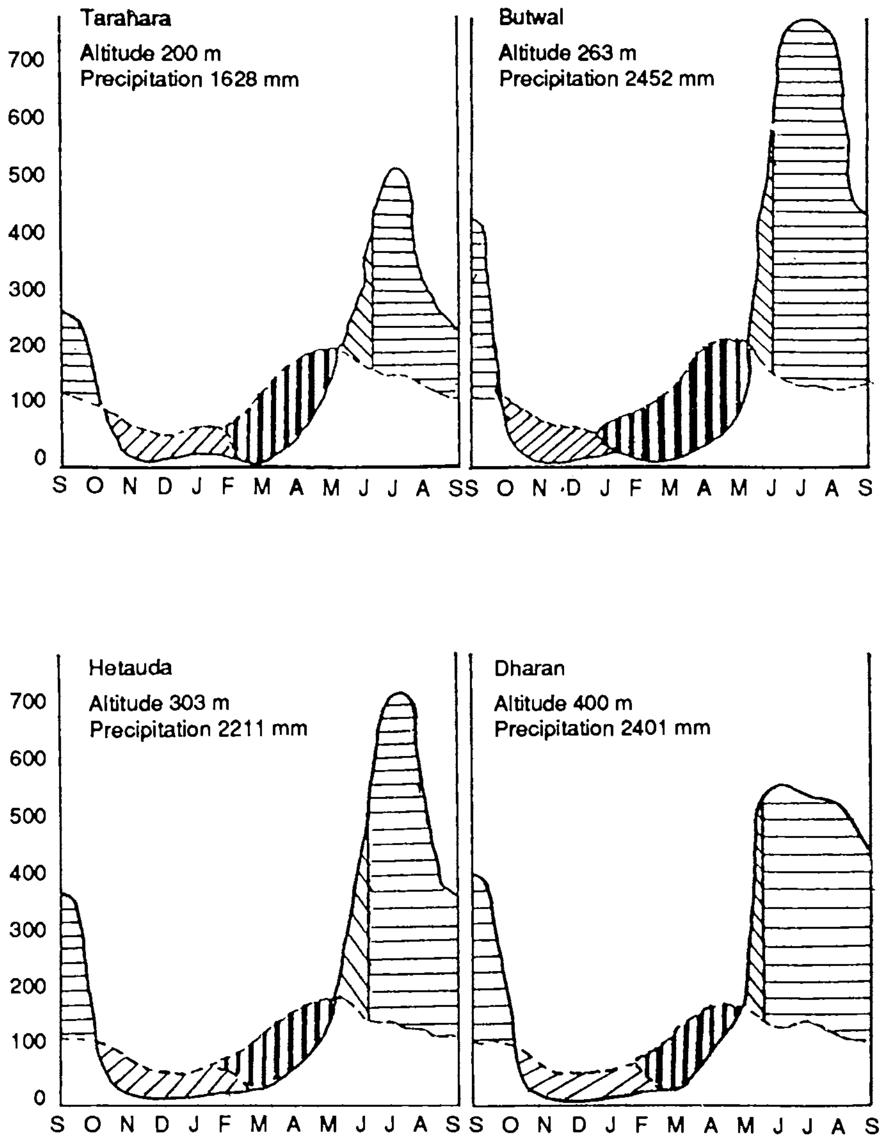
54. Namche Bazaar (1201) — Latitude 27°49', Longitude 86°43', Altitude 3450 m.
Years of record: Precipitation 31, Temperature 15.

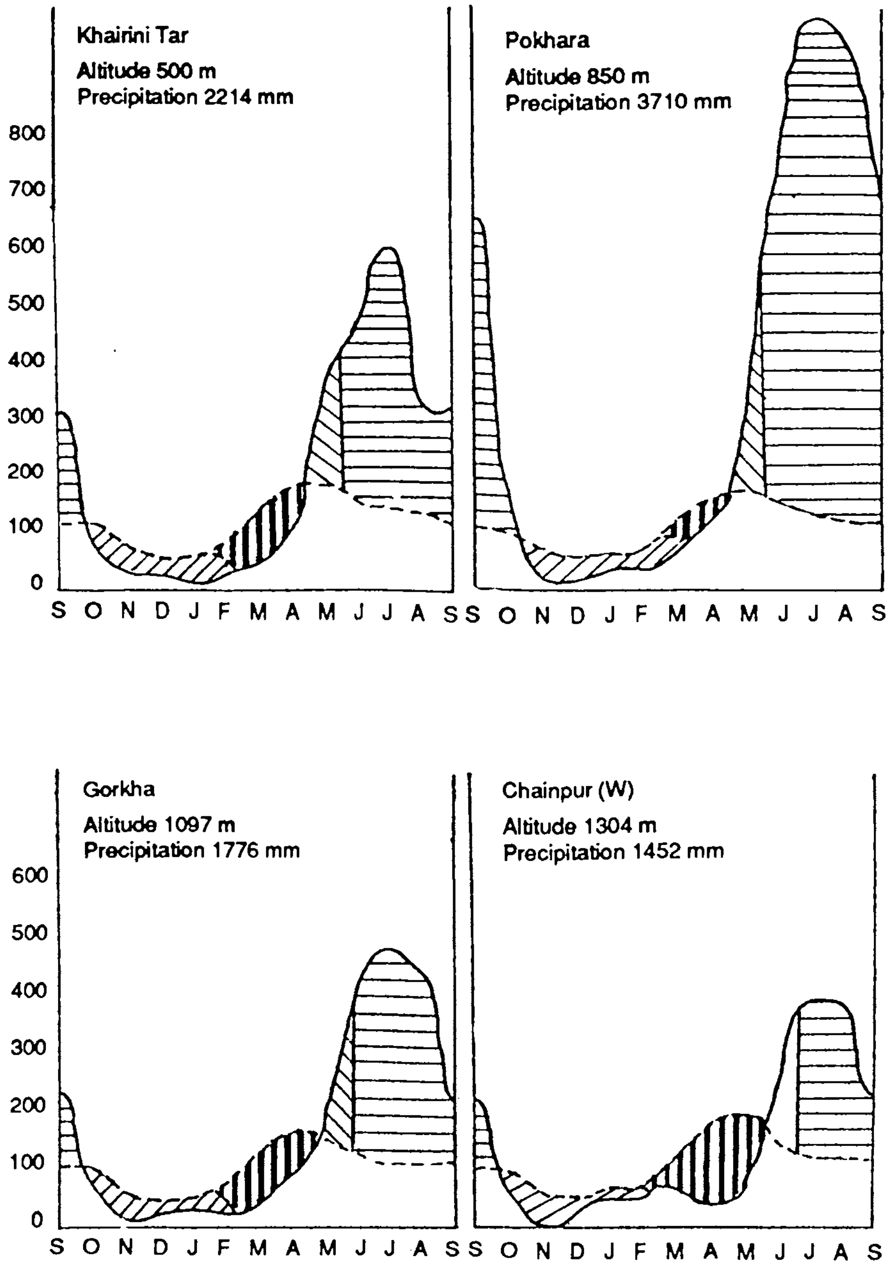
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean precipitation (mm)	34	18	31	27	39	144	234	227	147	71	10	28	1010
Mean temperature (°C)	-0.5	0.6	3.3	6.9	9.5	11.5	11.8	11.8	10.9	7.6	3.4	1.1	6.5
Estimated pE (mm)	25	42	74	93	105	93	83	87	72	56	36	22	788
Precipitation variability (mm)													
Maximum	273	119	120	110	164	309	412	394	311	229	68	255	1710
Median	14	12	26	22	25	134	250	240	144	54	0	0	1017
Five-year low	4	2	8	9	8	94	175	195	98	9	0	0	897
Ten-year low	0	0	4	2	3	82	135	158	79	5	0	0	778
Minimum	0	0	0	0	2	38	114	72	49	0	0	0	722

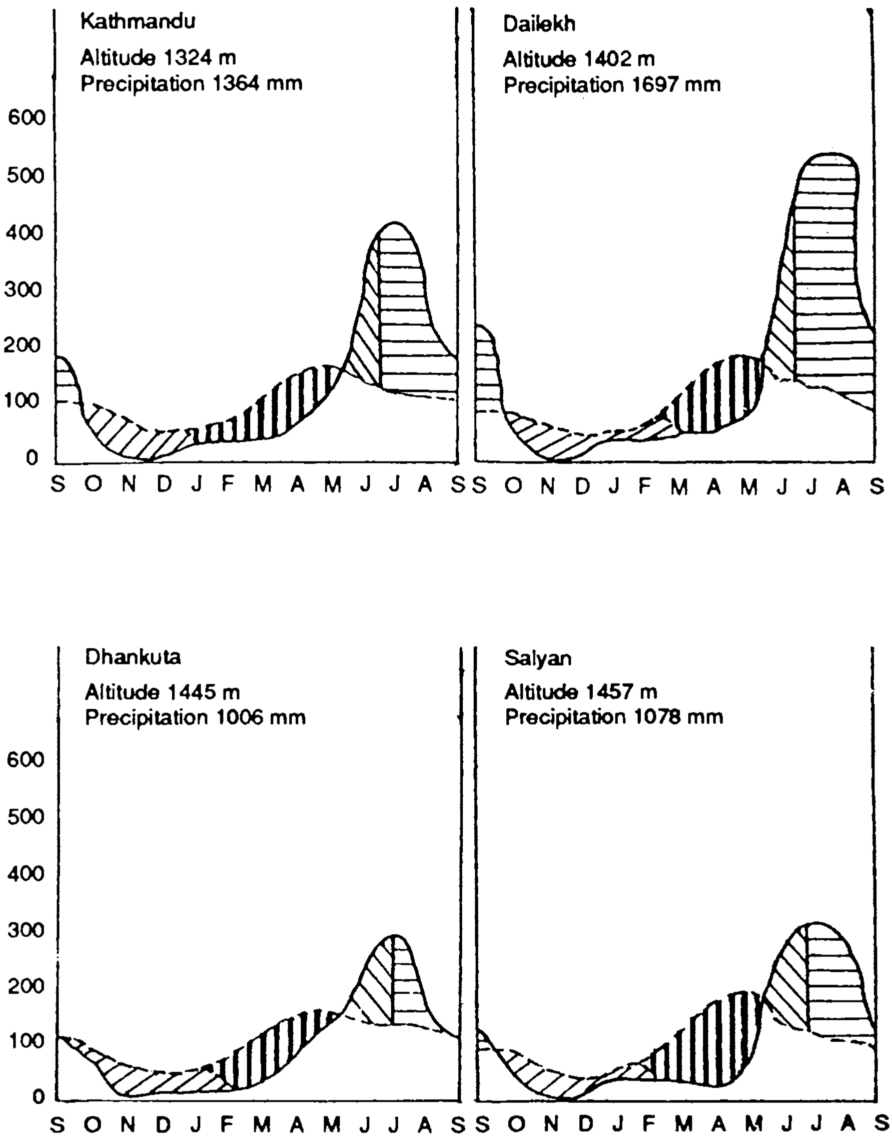
Mean number of days per year with minimum temperature 0°C or less: 172.9.
Absolute maximum temperature 20.6°C. Absolute minimum temperature -15.6°C.

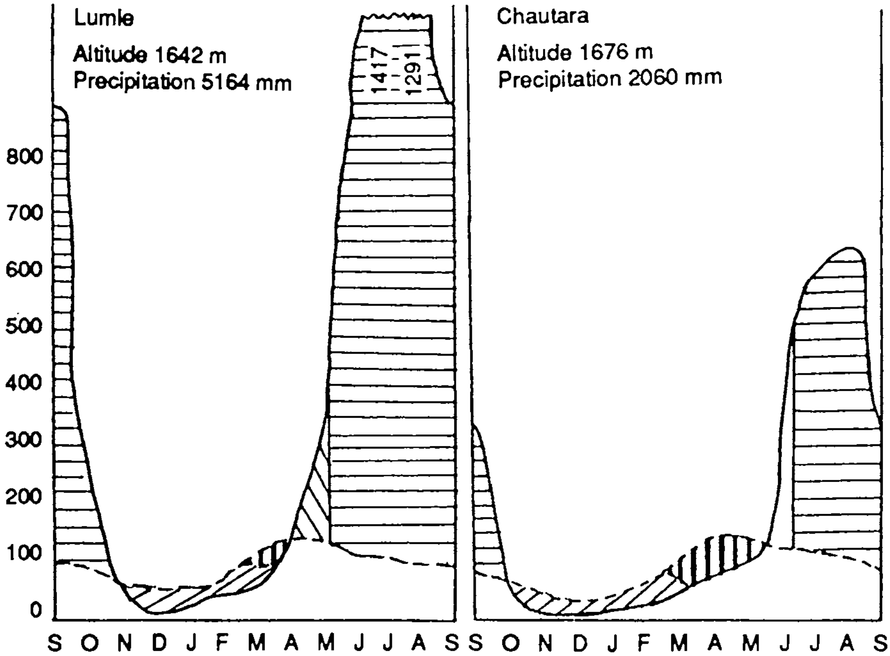
Figure 4—Average water balance throughout the year at various meterological stations in Nepal

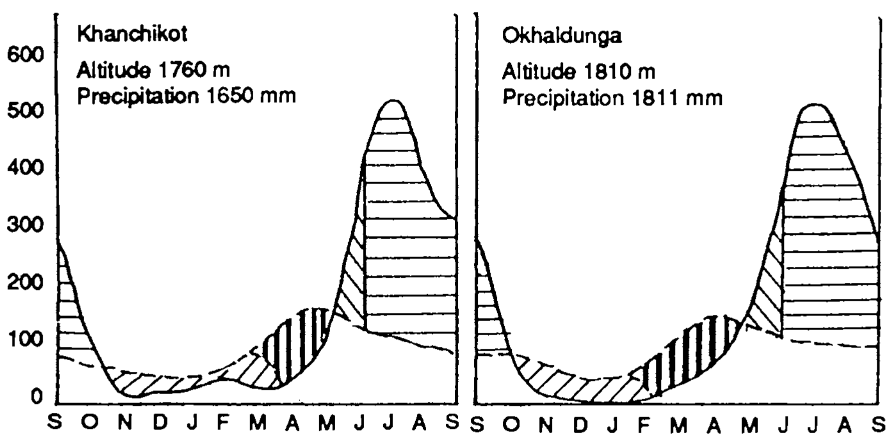


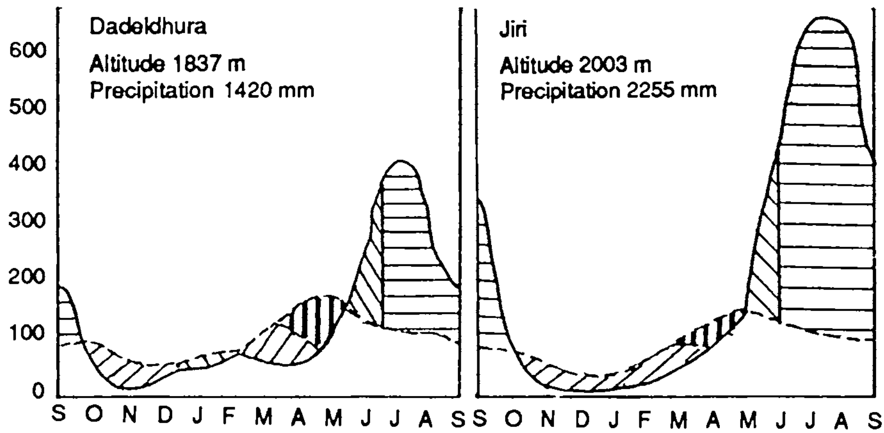

Tarahara
Altitude 200 m
Precipitation 1628 mm
Butwal
Altitude 263 m
Precipitation 2452 mm
Hetauda
Altitude 303 m
Precipitation 2211 mm
Dharan
Altitude 400 m
Precipitation 2401 mm
700
600
500
400
300
200
100
0
S O N D J F M A M J J A S

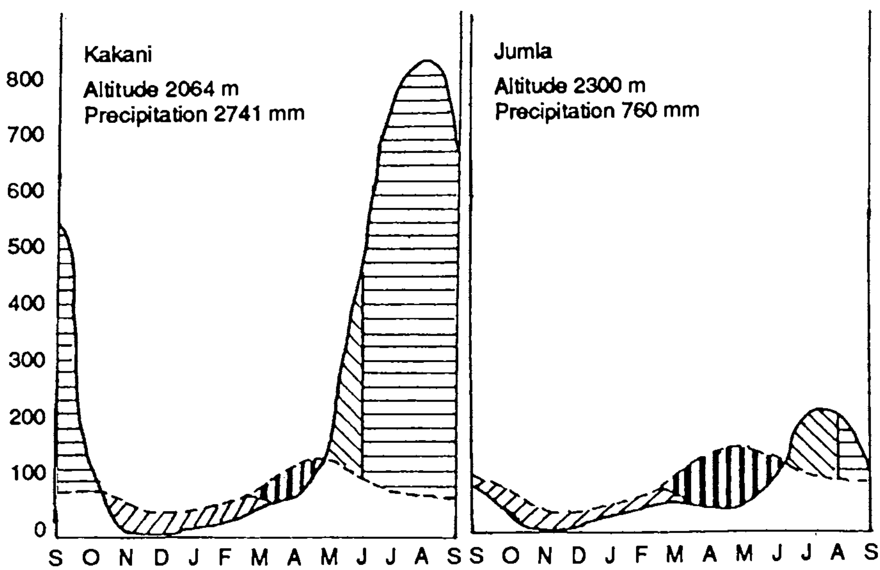

Khairini Tar
Altitude 500 m
Precipitation 2214 mm
Pokhara
Altitude 850 m
Precipitation 3710 mm
800
700
600
500
400
300
200
100
0
S O N D J F M A M J J A S S O N D J F M A M J J A S
Gorkha
Altitude 1097 m
Precipitation 1776 mm
Chainpur (W)
Altitude 1304 m
Precipitation 1452 mm
600
500
400
300
200
100
0
S O N D J F M A M J J A S S O N D J F M A M J J A S

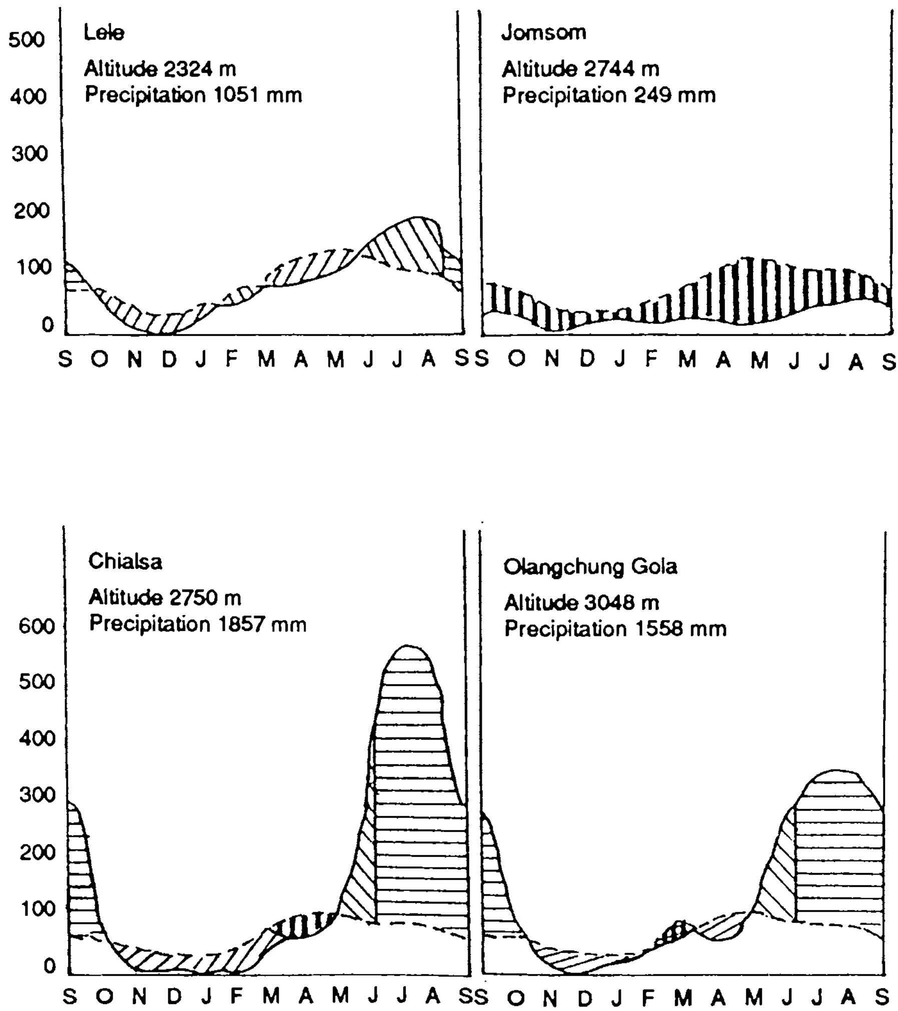

Kathmandu
Altitude 1324 m
Precipitation 1364 mm
Dailekh
Altitude 1402 m
Precipitation 1697 mm
600
500
400
300
200
100
0
S O N D J F M A M J J A S
S O N D J F M A M J J A S
Dhankuta
Altitude 1445 m
Precipitation 1006 mm
Salyan
Altitude 1457 m
Precipitation 1078 mm
600
500
400
300
200
100
0
S O N D J F M A M J J A S
S O N D J F M A M J J A S


Lumle
Altitude 1642 m
Precipitation 5164 mm
1417
1291
Chautara
Altitude 1676 m
Precipitation 2060 mm
800
700
600
500
400
300
200
100
0
S O N D J F M A M J J A S S O N D J F M A M J J A S


Khanchikot
Altitude 1760 m
Precipitation 1650 mm
Okhaldunga
Altitude 1810 m
Precipitation 1811 mm
600
500
400
300
200
100
0
S O N D J F M A M J J A S S O N D J F M A M J J A S


Dadeldhura
Altitude 1837 m
Precipitation 1420 mm
Jiri
Altitude 2003 m
Precipitation 2255 mm
600
500
400
300
200
100
0
S O N D J F M A M J J A S
S O N D J F M A M J J A S


Kakani
Altitude 2064 m
Precipitation 2741 mm
Jumla
Altitude 2300 m
Precipitation 760 mm
800
700
600
500
400
300
200
100
0
S O N D J F M A M J J A S
S O N D J F M A M J J A S


Lele
Altitude 2324 m
Precipitation 1051 mm
Jomsom
Altitude 2744 m
Precipitation 249 mm
Chialsa
Altitude 2750 m
Precipitation 1857 mm
Olangchung Gola
Altitude 3048 m
Precipitation 1558 mm
0
100
200
300
400
500
600
S O N D J F M A M J J A S

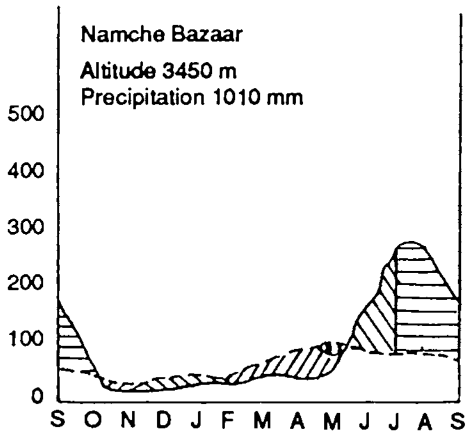

Namche Bazaar
Altitude 3450 m
Precipitation 1010 mm
500
400
300
200
100
0
S O N D J F M A M J J A S

Table 6 —Monthly and annual water deficiency

Reg.	Station	Alt. (m)		Oct Def (mm)	Oct % ET	Nov Def (mm)	Nov % ET	Dec Def (mm)	Dec % ET	Jan Def (mm)	Jan % ET	Feb Def (mm)	Feb % ET	Mar Def (mm)	Mar % ET	Apr Def (mm)	Apr % ET	May Def (mm)	May % ET	Jun Def (mm)	Jun % ET	Year Def (mm)	Year s.d. (mm)
FW	Dhanghadi (1968–78)	167	Mean	0	0	0.7	1	14.5	34	22.0	40	47.8	63	115.8	90	157.0	87	155.0	76	14.1	9	529	144
			Max	0	0	5	8	42	100	55	100	76	100	129	100	181	100	203	100	72	47	598	
			Min	0	0	0	0	0	0	0	0	0	0	79	44	0	0	0	0	0	0	128	
	Kakerparcha (1970–80)	802	Mean	0	0	0.9	1	5.4	11	13.6	24	17.6	24	70.5	58	122.0	73	116.3	60	10.0	7	356	118
			Max	0	0	0	14	35	70	35	64	45	61	122	100	168	100	180	92	75	49	574	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	19	11	0	0	0	0	208	
	Chainpur (w) (1970–80)	1304	Mean	0	0	0	0	2.7	6	7.0	14	6.7	11	41.0	37	94.8	61	120.1	68	22.4	20	298	92
			Max	0	0	0	0	27	56	25	50	35	56	102	93	155	99	158	89	85	62	420	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	36	0	0	93	
	Silghadi Doti (1970–80)	1360	Mean	0	0	44	8	3.5	8	6.9	14	9.4	14	40.8	30	91.2	66	90.2	54	15.5	12	261	105
			Max	0	0	25	45	35	78	33	69	50	77	104	96	138	100	143	85	56	43	407	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	8	0	0	13	
MW	Pusma Camp (1970–80)	950	Mean	1.2	1	3.9	6	9.1	19	16.2	31	22.3	32	70.7	63	135.3	83	111.4	66	3.1	2	373	85
			Max	12	13	39	64	28	58	51	96	65	94	113	100	163	100	149	89	25	19	491	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	20	12	22	13	0	0	208	
	Dailekh (1970–76; 1977–80)	1402	Mean	0	0	0	0	3.3	7	5.4	12	8.2	14	36.8	37	108.6	73	100.6	61	3.7	3	267	108
			Max	0	0	0	0	30	67	23	51	53	93	98	100	148	100	153	92	33	28	397	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	59	40	0	0	0	0	127	

Table 6 cont. —Monthly and annual water deficiency

Reg.	Station	Alt. (m)		Oct Def (mm)	Oct % ET	Nov Def (mm)	Nov % ET	Dec Def (mm)	Dec % ET	Jan Def (mm)	Jan % ET	Feb Def (mm)	Feb % ET	Mar Def (mm)	Mar % ET	Apr Def (mm)	Apr % ET	May Def (mm)	May % ET	Jun Def (mm)	Jun % ET	Year Def (mm)	Year s.d. (mm)
MW	Salyan	1457	Mean	0	0	3.4	6	10.8	25	18.0	38	19.5	30	66.0	61	112.4	74	108.6	61	17.6	13	356	131
	(1970–80)		Max	0	0	34	58	33	77	46	98	61	92	106	98	151	100	173	98	77	58	549	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	44	29	0	0	0	0	162	
	Jumla	2300	Mean	9.4	13	13.3	28	8.4	23	15.9	38	10.7	20	16.8	18	71.4	56	83.7	57	45.8	44	277	86
	(1970–80)		Max	55	74	48	100	37	100	40	95	49	91	63	68	125	98	137	93	120	92	369	
	(Note 1)		Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	144	
W	Bhairawa	110	Mean	7.4	7	7.4	11	20.9	46	26.6	53	59.1	83	109.4	88	163.0	95	131.3	70	29.1	20	554	93
	(1970–80)		Max	7.4	74	5.9	86	45	100	50	100	70	99	124	100	171	100	187	100	93	64	713	
			Min	0	0	0	0	0	0	0	0	22	31	78	63	152	89	77	41	0	0	438	
	Butwal	263	Mean	0	0	0	0	3.4	6	20.4	34	58.5	72	125.1	91	155.1	84	106.4	55	1.6	1	470	65
	(1970–80)		Max	0	0	0	0	29	53	53	88	80	99	137	100	184	100	182	95	16	12	581	
			Min	0	0	0	0	0	0	0	0	2	2	107	78	67	36	25	13	0	0	365	
	Pokhara	850	Mean	0	0	0	0	0	0	0.3	1	13.9	21	38.9	35	21.7	16	0	0	0	0	75	43
	(1970–80)		Max	0	0	0	0	0	0	3	6	51	77	110	100	97	69	0	0	0	0	140	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Gorkha	1097	Mean	0	0	0	0	2.0	5	6.3	13	26.0	40	77.2	67	81.5	55	5.6	4	0	0	199	61
	(1970–80)		Max	0	0	0	0	13	33	36	75	63	97	116	100	138	93	30	22	0	0	—	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6 cont. —Monthly and annual water deficiency

Reg.	Station	Alt. (m)		Oct Def (mm)	Oct % ET	Nov Def (mm)	Nov % ET	Dec Def (mm)	Dec % ET	Jan Def (mm)	Jan % ET	Feb Def (mm)	Feb % ET	Mar Def (mm)	Mar % ET	Apr Def (mm)	Apr % ET	May Def (mm)	May % ET	Jun Def (mm)	Jun % ET	Year Def (mm)	Year s.d. (mm)
W	Lumle	1642	Mean	0	0	0	0	0	0	0	0	5.6	9	23.6	24	23.7	19	0	0	0	0	53	36
	(1970–80)		Max	0	0	0	0	0	0	0	0	29	48	76	100	100	82	0	0	0	0	100	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Khanchikot	1760	Mean	0	0	0	0	0	0	1.3	4	6.2	12	38.0	43	101.3	78	60.0	41	6.3	6	214	86
	(1971–80)		Max	0	0	0	0	0	0	12	32	47	89	87	98	129	99	133	92	57	51	336	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	56	43	0	0	0	0	73	
	Lete	2384	Mean	0	0	0	0	2.4	6	3.8	9	2.2	5	8.5	10	4.2	4	25.1	19	8.8	8	55	67
	(1970–80)		Max	0	0	0	0	24	65	38	93	16	36	49	56	24	20	81	60	68	59	213	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C	Hetauda	303	Mean	0	0	0	0	1.1	2	7.0	13	32.4	44	99.2	83	92.1	59	45.9	27	0	0	278	87
	(1971–73;		Max	0	0	0	0	9	19	49	92	61	85	119	100	147	94	168	100	0	0	415	
	1974–80)		Min	0	0	0	0	0	0	0	0	0	0	70	59	0	0	0	0	0	0	132	
	Kathmandu	1324	Mean	0	0	0	0	2.3	5	9.0	38	35.7	58	64.4	66	74.6	57	36.2	25	0	0	232	42
	(1970–80)		Max	0	0	0	0	11	26	45	90	55	89	98	100	120	92	105	74	0	0	303	
			Min	0	0	0	0	0	0	0	0	0	0	15	15	0	0	0	0	0	0	174	
	Chautara	1676	Mean	0	0	0	0	0	0	8.6	19	11.9	22	41.3	43	62.4	48	26.1	20	0	0	150	82
	(1972–73;		Max	0	0	0	0	0	0	31	69	44	83	89	94	124	95	79	61	0	0	227	
	1974–80)		Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6 cont. —Monthly and annual water deficiency

Reg.	Station	Alt. (m)		Oct Def (mm)	Oct % ET	Nov Def (mm)	Nov % ET	Dec Def (mm)	Dec % ET	Jan Def (mm)	Jan % ET	Feb Def (mm)	Feb % ET	Mar Def (mm)	Mar % ET	Apr Def (mm)	Apr % ET	May Def (mm)	May % ET	Jun Def (mm)	Jun % ET	Year Def (mm)	Year s.d. (mm)
C	Jiri	2003	Mean	0	0	0	0	0	0	0	0	0	0	20.8	24	31.2	28	4.3	4	0	0	56	46
	(1970–76;		Max	0	0	0	0	0	0	0	0	0	0	64	74	74	66	39	34	0	0	127	
	1977–80)		Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Kakani	2064	Mean	0	0	0	0	0	0	3.6	9	10.9	21	30.6	35	45.4	39	15.9	13	0	0	106	55
	(1972–80)		Max	0	0	0	0	0	0	29	73	53	100	73	84	91	79	115	91	0	0	216	
			Min	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	43	
E	Tarahara	200	Mean	0	0	0	0	3.3	8	16.2	31	35.7	54	96.8	81	111.4	69	61.7	37	2.2	1	327	97
	(1971–80)		Max	0	0	0	0	22	42	53	100	62	94	119	100	151	94	132	79	20	14	448	
			Min	0	0	0	0	0	0	0	0	0	0	52	44	45	28	0	0	0	0	188	
	Dharan	400	Mean	0	0	0	0	0.6	1	10.6	19	34.2	46	92.0	77	95.5	64	47.9	31	0	0	281	68
	(1971–72;		Max	0	0	0	0	5	10	51	93	74	100	119	100	137	91	126	82	0	0	417	
	1973–80)		Min	0	0	0	0	0	0	0	0	0	0	38	32	73	49	0	0	0	0	181	
	Ilam	1300	Mean	0	0	0	0	0	0	7.6	21	15.9	30	56.4	63	48.5	44	11.0	10	0	0	139	65
	(1970–80)		Max	0	0	0	0	0	0	32	86	53	100	89	100	110	100	78	70	0	0	217	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	Taplethok	1383	Mean	0	0	0	0	0	0	2.4	4	22.3	32	51.2	25	27.0	21	6.9	5	0	0	110	67
	(1970–80)		Max	0	0	0	0	0	0	16	29	64	93	102	94	96	74	69	50	0	0	203	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 6 cont. —Monthly and annual water deficiency

Reg.	Station	Alt. (m)		Oct Def (mm)	Oct % ET	Nov Def (mm)	Nov % ET	Dec Def (mm)	Dec % ET	Jan Def (mm)	Jan % ET	Feb Def (mm)	Feb % ET	Mar Def (mm)	Mar % ET	Apr Def (mm)	Apr % ET	May Def (mm)	May % ET	Jun Def (mm)	Jun % ET	Year Def (mm)	Year s.d. (mm)
E	Dhankuta	1445	Mean	5.2	6	10.3	17	16.4	39	20.0	44	42.9	66	87.8	81	76.6	59	41.1	29	0.8	1	301	95
	(1971–80)		Max	47	54	61	100	42	100	43	96	62	95	108	100	110	85	119	84	7	6	413	
	(Note 2)		Min	0	0	0	0	0	0	0	0	0	0	43	40	34	26	0	0	0	0	150	
	Okhaldunga	1810	Mean	0	0	0	0	0	0	10.9	21	48.3	65	89.9	76	92.0	62	9.3	7	0	0	250	63
	(1970–80)		Max	0	0	0	0	0	0	4.1	77	72	97	119	100	133	90	83	63	0	0	353	
			Min	0	0	0	0	0	0	0	0	2	3	43	36	21	14	0	0	0	0	136	
	Chialsa	2750	Mean	0	0	0	0	0	0	0	0	4.8	10	29.3	39	39.4	42	11.6	12	0	0	85	53
	(1968–78)		Max	0	0	0	0	0	0	0	0	4.7	98	65	73	80	85	25	26	0	0	165	
			Min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Notes: (a) Reg.=Development Region; FW=Far Western; MW=Mid-Western; W=Western; C=Central; E=Eastern; Alt.=altitude (m); Def=water deficiency (mm); % ET=deficiency as percentage of monthly evapotranspiration; ET=0.85 x Penman's E_0; s.d.=standard deviation of annual water deficiency (mm); figures in brackets below station name are years of record. (b) Water year taken from September to August each year. (c) Note 1: at Jumla there was a deficiency of 19 mm in September 1979; Note 2: at Dhankuta there was deficiency of 6 mm in September 1977; otherwise for stations south of the main Himalaya, there were no deficiencies in September, and none in July and August.

Chapter 6

VEGETATION

Introduction

The account of vegetation which follows is necessarily brief. It is based largely on Dobremez (1976) and Stainton (1972). These two authorities do not always agree with each other in the delimitation of vegetation types and so some modifications have been made.

Factors governing the distribution of vegetation

The most important factor governing the distribution of the natural vegetation is climate, in a broad sense. This includes the effect of altitude, mainly a temperature effect; of rainfall and its distribution; and of aspect, which affects temperature and hence evaporation. In addition the influence of man's activities on the vegetation has been very great. The effects of altitude are the most striking; they result in broadly parallel zones of vegetation ranging from tropical forest in the plains, through temperate and alpine vegetation, to permanent snow. There is a fairly marked discontinuity between 1700 and 2000 m, which is also the altitude above which frosts occur annually (except in enclosed valleys, such as that of Kathmandu where annual frosts occur at considerably lower altitudes). The altitudinal limits of various species tend to be higher on south-facing slopes than on north-facing ones.

South of the main Himalaya range the rainfall and the length of the rainy season tend to increase from west to east, but there are local areas of high rainfall such as the area south of the Annapurna Himal, and parts of the Arun-Tamur basin. These very wet areas tend to carry a different type of vegetation than the less wet areas which surround them. There are also interactions between rainfall, aspect and altitude. For instance ***Pinus roxburghii*** at certain altitudes in the far west of Nepal, a relatively dry area, occurs on both south-facing and north-facing slopes; in central Nepal it tends to be confined to south-facing slopes and dry valleys; while in the very wet districts south of the Annapurna range and in parts of the Arun and Tamur valleys it is almost completely absent.

An example of the interaction between altitude and aspect may be seen in hills of the Mahakali Zone of the Far Western Development Region. At low altitudes *Shorea robusta* is commonest on north-facing slopes, while south-facing slopes have other species such as *Terminalia* and *Anogeissus*. At about 1250 m, however, *Shorea robusta* is confined to south-facing slopes, usually as an understorey to *Pinus roxburghii*. A little higher, *Pinus roxburghii* is virtually pure on all aspects. At about 1600 m *Quercus leucotrichophora* begins to appear on north-facing slopes, while the pine continues on other aspects, while at about 1800 m the oak prevails on all aspects. The area north of the main Himalaya range lies in a rain shadow and is much more arid. In Mustang and Dolpo, the rainfall is so low that the region is cold semi-desert with quite a different vegetation from that of the rest of Nepal. The Humla-Jumla area is to some extent intermediate between this and the rest of Nepal. The deep inner valleys of the Himalayas also have a dry climate and a drought-resistant form of vegetation.

Another factor influencing the distribution of trees can be termed phytogeographical. In the Himalaya, Nepal lies at the meeting place between western and eastern floristic elements. Many western species such as *Cedrus deodara*, *Aesculus indica* and *Quercus floribunda* have their eastern limit in western or central Nepal and are not found in the east; similarly a number of eastern species such as *Larix griffithiana*, *Castanopsis hystrix* and *Quercus lamellosa* are absent from western Nepal. To a lesser extent the plains and foothills are the meeting place for an eastern element, of Burma-Malayan affinity, and a more general North Indian element. The eastern element includes *Acrocarpus fraxinifolius*, *Terminalia myriocarpa*, *Eugenia formosa* and *Schima wallichii*, which are rare or absent in western Nepal. Many species occur throughout Nepal, but certain types of vegetation are found only in the west or the east.

Geology and soil appear to have relatively little effect on the distribution of the vegetation on a broad scale. On a smaller scale, stony ridge tops, valley slopes and moist areas near streams will tend to carry different types of vegetation.

Man's influence on the vegetation has been profound. Over large areas of the Middle Hills nearly all the natural forest has been removed and replaced by cultivation. What forest remains is confined to small patches, and often the only woody vegetation left, apart from trees preserved by farmers for their fodder or other useful products, is in the form of shrubberies—the term used by Polunin and Stainton (1984)—dense intricate masses of shrubs and climbers up to about 3 m in height, including species such as *Berberis*, *Pyracantha crenulata*, *Rosa*, *Rubus* and *Rhus*. Many of these are thorny. In the Terai also large areas of natural *Shorea robusta* forest have been cleared for cultivation in the last three or four decades. Above about 2500 m the population is less dense and more forest remains. Where the forest has not been completely removed it has often been severely degraded by cutting for fuelwood or heavy lopping for fodder. It has often been reduced to low coppice 2–3 m in height or less. When this type of degraded forest is protected it often recovers dramatically after a few years. Fires, which are nearly always caused by human beings, are another important influence on the vegetation. They favour the spread of fire-resistant species such as pines, at the expense of more susceptible species. Pines are often pioneer species which would in many places be succeeded at suitable altitudes by some form of broadleaved forest. Frequent fires prevent colonization by these other species and maintain the pines in almost pure stands.

Types of vegetation

The classification of vegetation types is based primarily on altitude following Dobremez (1976). It must not, however, be thought that the altitudinal zones described are rigid. Many tree species occur over a wide range of altitudes, and though they may predominate in a given zone they may also occur in zones above and below it. *Pinus wallichiana*, which occurs from 1800 m to 4000 m, is one example. Also where two vegetation types meet there is usually a transitional zone between them, where elements of both types occur. Certain types of vegetation described by Dobremez and Stainton, which occur only in very restricted areas, have been omitted.

Tropical zone

This has its upper boundary at about 1000 m.

(a) *Shorea robusta* forest

Where natural vegetation remains, this covers by far the greater part of the zone. *Shorea robusta* is generally dominant; common associates are *Terminalia alata*, *Adina cordifolia*, *Anogeissus latifolia*, *Lagerstroemia parviflora*, *Dillenia pentagyna*, *Syzygium cumini* and *Semicarpus anacardium*. A number of different types of *Shorea robusta* forest have been distinguished by various authors, but 'floristic analysis of the groups is insufficient to distinguish one from the other' (Dobremez, 1976). In the eastern Bhabar Terai zone a number of additional species are found, but those listed above continue to occur in the east also. Hillside and plains *Shorea robusta* forests differ in their general appearance: in the plains the trees are larger and the forest is denser but the species composition does not differ very much, at least as far as trees are concerned. Grasses, however, are much more abundant in the ground layer of the hill forest, compared with the plains.

(b) *Acacia catechu-Dalbergia sissoo* forest
Found on newly deposited alluvium, often gravelly, along streams and rivers. If this alluvium is not eroded, this type of forest will eventually be succeeded by *Shorea* or other types.

(c) Other riverain forest
Small strips of forest are to be found in moist localities near streams. Stainton (1972) distinguishes Tropical Evergreen Forest, with an eastern type including *Michelia champaca*, Lauraceae (*Litsea* spp., *Phoebe lanceolata*, *Actinodaphne angustifolia*, *Cinnamomum* spp.), and a western type in which *Syzygium cumini* is usually dominant; and Tropical Deciduous Riverain Forest, usually dominated by *Bombax ceiba* plus *Holoptelea integrifolia* and *Trewia nudiflora* together with other species found in the *Shorea robusta* forest. The area occupied by this type of forest is not large and does not extend far from the stream banks.

(d) Grassland
Usually found on poorly drained clays, but in places may be the result of clearance of the forest for cultivation many years ago. Characteristic grass species are *Saccharum spontaneum*, *Phragmites karka*, *Arundo donax* and *Eulaliopsis binata*. The grasses may reach a height of 4 m. Such grassland is found in the Rapti valley (Royal Chitawan National Park) and the Shuklaphanta wildlife sanctuary. Both places are important wildlife reserves.

(e) *Terminalia-Anogeissus* deciduous hill forest
Occurs in western Nepal in the foothills, where it replaces *Shorea robusta* forest on south-facing slopes. Elsewhere it is confined to dry south-facing slopes in the larger river valleys. It is mixed in composition: *Anogeissus latifolia* and *Terminalia alata* are often dominant, with *Ehretia laevis*, *Flacourtia indica* and *Lannea coromandelica*. *Shorea robusta* is infrequent or absent. It extends in western Nepal up to about 1200 m.

Subtropical forest

Altitude approximately 1000–2000 m in the west; 1000–1700 m in the east.

(a) *Pinus roxburghii* forest
Found in the west of Nepal on all aspects, but in the centre and east it tends to be confined to southern aspects and dry lower slopes of large river valleys. It is absent from very wet areas, such as the district south of the Annapurna Range, and the very wet parts of eastern Nepal. It is characteristically almost pure *P. roxburghii* with few other trees and little undergrowth. This is probably partly due to the effect of annual fires. In the far west at higher altitudes it may be associated with *Olea ferruginea*, *Pistacia* spp. and other species of Mediter-

ranean affinity. In transitional areas with other types of vegetation it may be mixed with *Schima* or *Shorea*.

(b) *Schima-Castanopsis* forest
Replaces *Pinus roxburghii* forest in central and eastern Nepal on moister sites such as north-facing slopes and areas of heavy rainfall. *Schima wallichii* occurs throughout, with *Castanopsis indica* commoner below 1200 m and *C. tribuloides* above this altitude. *Schima-Castanopsis* forest once covered very large areas of the Middle Hills, but much of it has been cleared to make way for cultivation, and in many localities only small patches are left.

(c) *Alnus nepalensis* forest
Found within the two preceding types of forest in wet areas along streams and ravines, and as a colonizer of soil newly exposed by landslips. It is also frequently found on areas of abandoned cultivation. *Alnus nepalensis* is dominant and almost pure, with some *Lyonia ovalifolia* in places.

(d) Riverain forest with *Toona* and *Albizia* species
Found along streams in the subtropical zone, and corresponds to Stainton's Subtropical Semi-Evergreen Forest, and Dobremez' Forest Riveraine à *Cedrela, Toona ciliata* et *Albizia mollis*. It is confined to narrow strips along streams, and is very mixed in composition. *Pandanus nepalensis* is frequently found in the understorey.

Lower temperate forest

Altitude 2000–2700 m in the west, 1700–2400 m in the east. Different types of forest do not always strictly adhere to these limits.

(a) Forest of *Quercus leucotrichophora* and *Quercus lanata*
Found between 1750 and 2400 m. In the west it is found on all aspects, but in the centre and east tends to be confined to south-facing slopes and the sides of the larger river valleys. It is absent from areas of very high rainfall. Of the two species of oak, *Quercus leucotrichophora* is commoner in the west and *Quercus lanata* in the east. This type of forest has often been cleared for cultivation, and elsewhere it is frequently heavily lopped for cattle fodder.

(b) *Quercus floribunda* forest
Confined to western Nepal, between 2100 and 2850 m, where it replaces the previous type of oak forest on wet sites. It is often associated with *Aesculus indica* and *Acer* spp.

(c) *Quercus lamellosa* forest
Replaces *Quercus lanata* forest in areas of high rainfall, such as south of the Annapurna massif, and the wet areas of eastern Nepal. Elsewhere it is confined to north- and west-facing slopes. It is often associated with the Lauraceae of the

temperate mixed broadleaved forest. Its altitudinal range is between 1900 and 2600 m.

(d) Lower temperate mixed broadleaved forest, with abundant Lauraceae
Found between 1500 and 2100 m, on north- or west-facing slopes and in high rainfall areas. It contains a number of species of the Lauraceae family, including *Machilus* spp., *Neolitsea cuipala*, *Cinnamomum tamala* and *Litsea* spp.; *Michelia kisopa* is also frequent. It sometimes also contains *Quercus lamellosa*. Much of this type of forest has been removed for cultivation.

(e) *Pinus wallichiana* forest (lower type)
This species has a large altitudinal range, from 1800 to 4000 m. In the lower temperate forest it is usually found on dry, south-facing slopes. It often colonizes abandoned cultivation, and in this zone its distribution may be much affected by human activities.

Upper temperate forest

Occurs at altitudes from about 2700 to 3100 m in the west and centre, and from 2400 to 2800 m in the east.

(a) *Quercus semecarpifolia* forest
Found in central and eastern Nepal between 2400 and 3000 m, but in the west it extends considerably higher, up to the tree line at 3700 m in the Karnali region. It tends to be more prevalent on south-facing slopes but is not confined to them, and one variant is found in the wet area south of Annapurna. *Rhododendron arboreum* and *Ilex dipyrena* are common understorey species.

(b) Upper temperate mixed broadleaved forest
Found east of the Kali Gandaki River, between 2400 and 3150 m, mainly on north- and west-facing slopes. It is very mixed in composition: *Acer* spp. (*A. campbellii*, *A. sterculiaceum*, *A. pectinatum*) and *Rhododendron arboreum* are common throughout and Lauraceae (*Litsea*, *Lindera*, *Neolitsea*) are common understorey trees. *Tsuga dumosa* often occurs in it, and may form almost pure patches on ridges and drier sites.

(c) *Rhododendron* forest
Species of *Rhododendron*, particularly *R. arboreum*, occur in a number of different types of forest, but in very moist places, particularly in the far east of Nepal, rhododendrons may become dominant to the exclusion of almost all other tree species. *Rhododendron arboreum* var. *cinnamomeum*, *R. barbatum*, *R. grande* and *R. falconeri* are typical of this type of forest.

(d) Upper temperate coniferous forest
In this type *Pinus wallichiana*, which occurs at altitudes of up to 4000 m, is distributed almost throughout. It is often almost pure, especially on south-fac-

ing slopes, but in rather moister areas in western Nepal it is associated with *Abies pindrow*, *Picea smithiana* and very locally with *Cedrus deodara*. This type of forest is common in the Humla-Jumla area. *Pinus wallichiana* also penetrates into the southern fringes of the very dry Mustang region, where it is associated with *Juniperus indica*. In central and eastern Nepal in the higher level *P. wallichiana* forest, *Tsuga dumosa*, *Taxus baccata* and *Acer* spp. are common associate species. In the west both *Picea smithiana* and *Abies pindrow* sometimes form almost pure stands, and have sometimes been distinguished as separate forest types, for example, by Stainton (1972). However, they nearly always have a few *Pinus wallichiana* among them, and here are included in the upper temperate coniferous forest.

Subalpine forest

Found between 3000 and 4200 m in the west, and around 3000 m in the east.

(a) *Abies spectabilis* **forest**
In western Nepal *Abies spectabilis* is associated with *Quercus semecarpifolia* and extends to the tree line at more than 4000 m. In central Nepal it is found in a belt between 3000 and 3500 m, where it forms an almost pure overstorey, with an understorey in which *Rhododendron* spp. and *Acer* spp. are common. *Abies spectabilis* sometimes ascends to the tree line, but above 3500 m it is usually superseded by *Betula utilis* forest. Locally *Larix griffithiana* and *L. himalaica* are common in the *Abies* forest, but rarely form pure stands.

(b) ***Betula utilis*** **forest**
Found between 3300 m and the tree line. It is frequently almost pure, with *Rhododendron* spp. and *Acer* spp. in the understorey. In western Nepal and the Humla-Jumla area it is frequently mixed with *Abies spectabilis* and *Quercus semecarpifolia.*

(c) ***Rhododendron*** **forest**
As in the temperate zone, *Rhododendron* forest often replaces other types of forest in eastern Nepal on very wet sites in the subalpine zone. There are a large number of species, but among the more important are *R. campanulatum*, *R. thomsonii* and *R. campbellianum.*

(d) ***Juniperus indica*** **steppe**
Found north of the Himalaya, in regions having be 350 and 500 mm rainfall. It is the only tree in such areas but has an open shrubby understorey.

(e) ***Caragana*** **steppe**
Caragana spp. are low spiny shrubs rarely exceeding 1.5 m high. They are dominant (where there is any vegetation) in areas having less than about 250

mm rainfall, such as the Mustang area. In this type of vegetation no trees are found.

Alpine zone

This lies between the tree line and the region of perpetual snow. It has no trees, but shrubby rhododendrons and junipers and some other shrubby species (*Hippophae rhamnoides*, *Cotoneaster microphyllus*) are found at lower elevations, up to about 4500 m.

Further references: J.F. Dobremez and his associates have prepared a series of ecological maps at a scale of 1:250,000 which now cover the greater part of Nepal, except the hills and mountains west of 81°12'E, and the Terai west of 84° 45'E (Dobremez and Jest, 1975; Dobremez *et al.*, 1975b; Dobremez and Shakya, 1977; Dobremez and Shrestha, 1980). They have also prepared 1:50,000 maps of two smaller areas (Alirol *et al.*, 1977; Dobremez *et al.*, 1975a). The vegetation of parts of northwest Nepal has been described by T.B. Shrestha (1982). Kanai and Shakya (1973) describe the vegetation of Nagarjun, including details of quadrats, and a similar study of a cross-section of Nepal at the longitude of Kathmandu has been made by the Department of Medicinal Plants (1976). Detailed studies of the Godavari-Phulchoki area have been made by Khadka *et al.* (1981). See also Fleming (1973); Kanai *et al.* (1975); Maire (1973); Numata (1983); Ohsawa *et al.* (1975); P.R. Shakya (1975); Yoda (1967). The vegetation types of India, many of which resemble those found in Nepal, are described by Champion and Seth (1968a).

Chapter 7

PLANTATION POLICY AND PLANNING

Introduction

In many parts of Nepal, forest produce is becoming increasingly difficult to obtain. This is not so much due to the decline in the total forest area, reliably estimated at 64,000 km^2 in 1964, and 62,200 km^2 in 1986, though in 1986 11 per cent of the total forest area was shrubland, and a further 10 per cent had less than 40 per cent crown cover (E.R. Sharma, 1991). There is, however, evidence that the condition of the forest is deteriorating and that stocking, particularly of mature trees, is declining. In addition the population is doubling every thirty years. Thus, there is increasing pressure on the natural forest to provide for the needs of the people.

One of the most important forest products in the rural economy is fuelwood, which provides well over 80 per cent of the energy needs of Nepal. As the forest deteriorates fuelwood becomes more difficult to obtain. Whereas previously villagers could obtain their fuelwood needs from within a short distance of their house, now they may have to walk long distances to obtain them. In parts of Darchula District the time required to bring wood is now four to twelve hours (Chand and Wilson, 1987). When fuelwood is scarce crop residues and manure have to be used instead of being returned to the land or fed to animals. In the Terai and the larger towns, where road transport is possible, wood may be replaced to some extent by fuels such as kerosene, but it should be considered if, in the long run, replacement of the product of a local, self-renewing, natural resource by an imported, exhaustible resource is really desirable. Timber shortage is less obvious at present, but as the forests of the Terai—the main source of timber for the larger towns—disappear, there will inevitably be a shortage of timber unless steps are taken to prevent it. It is estimated that fodder from trees produces about 35 per cent of the feed needed for domestic animals in Nepal (Panday, 1981). This fodder plays an important part in the agricultural system of the hills, as it is the dung from the animals fed on this fodder which is used to fertilize the land for crops. If fodder supplies are reduced so is the amount of dung produced, and hence crop yields are lowered. For more information on the tree fodder problem in Nepal see Wyatt-Smith (1982).

The effects that forest deterioration is having on soil erosion, sedimentation and flooding are also extremely important. A well-stocked forest with good crown cover gives considerable protection to the soil, especially in comparison with broken overgrazed forest, and also delays run-off and reduces flooding. The landscape in Nepal is one of the most rugged in the world and during the monsoon there is rainfall of very high intensity. Thus measures to protect the soil, and stabilize run-off, are extremely important.

His Majesty's Government of Nepal is well aware of the importance of measures to maintain the supply of forest produce and prevent deterioration of the forests. In 1976 it produced the National Forestry Plan (Anon., n.d.), which included provisions both for improved protection and management of natural forest, and for increased afforestation. In 1988 this was followed by the Master Plan for the Forestry Sector (Ministry of Forests and Soil Conservation, 1988), which went into questions of future supply and demand of forest products in considerable detail.

Local people also recognize the importance of forests to their own welfare. Many communities had traditional rules for protection and elementary management of the forest in their areas, although these rules had no legal basis other than custom. In 1957 all forests, including those which local communities regarded as their own, were nationalized. One result was that in some places the local people were no longer interested in protecting what had become government forest, and there was much uncontrolled cutting and forest destruction. In other places however traditional conservation practices continued, albeit unofficially. The position was changed in 1978 when rules were promulgated whereby in the hills panchayats (councils representing groups of villages, usually with an average population of about 2000) could be allocated up to 2500 *ropani* (130 ha) of bare or sparsely forested government land for plantations (Panchayat Forest), and 10,000 *ropani* of natural forest (Panchayat Protected Forest) to be protected and managed to meet the needs of the local population. (In the Terai the areas were 200 *bigha* and 400 *bigha* respectively: 1 *bigha* = 0.68 ha). The Decentralization Act of 1982 and the Decentralization By-laws of 1984 provided that forestry would be one of the components of the district development plan for each district. Since 1990 panchyats have been replaced by village development committees, and it has also been realized that the panchayat or village is often too large and inhomogeneous a body to represent local interests in forest management. Thus the local body responsible for forest management is now the user group, who are responsible, with the guidance of forestry officials, for preparation of management proposals, and for managing the forest after these proposals have been agreed.

The result of these changes has been a great expansion of forestry activities at the local level. Considerable areas of plantations have been established by agencies such as the Community Forestry Development Project, the Nepal–Australia Forestry Project and numerous other bodies. By 1985, about 5000 ha were being planted annually. Not all the plantations were successful, and in some areas there was a lack of people's participation, apart from paying villagers to raise, plant and protect the trees. In at least one case the people did not know who owned the plantations, or realize that they themselves were legally responsible for managing them (Gautam and Roche, 1987); there is no reason to suppose that this was exceptional.

Partly for these reasons, more emphasis has been laid on encouraging of tree planting by individual farmers. Farmers have been planting trees on their own land for many years, often using wild seedlings from the natural forest. However in recent years this activity has increased considerably, in response to the declining supply of forest products from common forest land. In areas of Sindhupalchok and Kabhrepalanchok Districts studied by Carter and Gilmour (1989) this resulted between 1964 and 1988 in an increase in the number of trees on farmers' land from an average of 65 per hectare to 298 per hectare. The best method to stimulate this activity is to ensure that good quality seedlings of the species farmers want are available in local nurseries.

However community, or village-level, forestry is not always the most appropriate solution to supplying needs for forest products, particularly when action on a large scale is needed. This applies to provision of building timber, other than that for rural use, and the supply of fuelwood to the larger towns, not only Kathmandu but the rapidly expanding towns in the Terai, such as Birganj and Biratnagar. The scale of activity needed is far beyond the capacity of local user groups; in fact the term user group itself indicates this. The user group for the town of Biratnagar would be the whole population of the town, and they are basically not interested in rural forestry development. In such cases the state, or some other large organization, must take responsibility. Commercial plantations are also a possibility.

In some cases manufacturers could be expected to establish plantations to meet the needs of their industries. In the future the match industry can be expected to get the bulk of its supplies from poplar plantations, combined with helping farmers to grow poplar at a guaranteed price for sale to them. The cutch extraction industry is threatened by increasing shortages of *Acacia catechu*, and might well organize plantations to meet this need. Large-scale users of fuelwood, such as brick manufactures, might also establish plantations to meet their needs. Other plantations might be established to reduce erosion on slopes around reservoirs.

Plantation objectives

Before any enterprise is undertaken the objectives which it is intended to achieve should be identified and stated. This is as true of forestry plantations as of all other enterprises. In planning plantations the following are some of the questions which should be asked.

- What is the plantation intended to produce, or what other purpose is it intended to serve?
- Whom is it intended to benefit?
- What constraints are likely to prevent the attainment of the objectives?
- Is there any other method of achieving these objectives?

The produce from plantations may be timber, fuelwood, fodder or other products such as cutch from *Acacia catechu* or resin from pines. Other purposes which may be served by plantations are protection of the soil against erosion and the stabilization of water supplies, and the provision of shade and amenity for recreation. Sometimes hardy trees are planted on degraded soils as pioneers, to restore forest conditions, after which more demanding species can be planted or colonize the site naturally.

Many plantations may be intended to serve more than one purpose. For example, plantations in the hills will almost invariably provide some protection against soil erosion, though this may not be specifically indicated as an objective. Other plantations may have one major objective, but yield another product as well. For instance, a timber plantation will inevitably yield some fuelwood from thinnings and branchwood. However, in multipurpose plantations it may not be possible to obtain the maximum production of each desired product simultaneously, and either one product must be given priority, or a balance must be drawn in which there is some production of each of the products required, but none is obtained at the maximum rate possible for the particular site. Thus in a plantation designed to produce both fodder and fuelwood the intensity of lopping which will produce the highest sustained yield of fodder is likely to reduce fuelwood production, and either fodder production must be given priority, or a balance must be struck between the two end uses.

In plantations which are on very steep slopes, and which have as one purpose the prevention of soil erosion, management practices may have to be restricted, for instance, by avoiding clear felling; there may also be some restriction on the choice of species to those which will allow an understorey of shrubs or dense herbs to develop beneath them, and hence protect the soil. Similar considerations will affect both management practices and the choice of species. A good fodder species may produce poor fuelwood and vice versa, and in such cases it might theoretically be better to compromise on one which produces medium quality fodder and medium quality fuelwood. However in practice other factors, particularly the ability of different species to grow well on different sites, are likely to be of greater importance than this.

Plantations range from those designed to meet the needs of an individual small farmer, through village plantations and fuelwood plantations for a town or a region, to those intended to supply timber for the nation as a whole. They may also, as mentioned above, be needed to supply the needs for a particular industry. Such plantations should be considered as an essential part of the industry and their costs included in the costs of establishing the industry, in the same way as factories and machinery.

Constraints on plantation establishment

By far the most important technical constraint is the ability of a species to grow well on the site available. Whatever other desirable qualities a tree may have it is pointless to plant it on a site where it will die or grow badly. This may seem so obvious as to be scarcely worth mentioning but numerous examples can be seen of trees planted on obviously unsuitable sites.

Unfortunately many sites available for plantations in Nepal are very poor and the number of species which can be successfully planted on them is small. This is the main reason why *Pinus roxburghii* is so widely planted; it does not produce fodder and there are species which produce better fuelwood, but it will grow well on nearly all sites in the hills. A corollary to this is that planting of untried species should be limited to small trial plots until their suitability for different sites has been demonstrated.

Other constraints may include difficulties of raising certain species in the nursery, or lack of knowledge of satisfactory techniques for raising them; difficulty in obtaining seed, especially of species which have infrequent seed years; high risk of browsing by wildlife; and high fire danger. In many cases it is possible to overcome these constraints. Improved nursery techniques can be developed, and staff trained to use them. In species with infrequent seed years, seed can be collected in a good year and stored. Species may be planted that are unpalatable to wild animals or resistant to fires and so on.

Another sort of constraint is inherent in community forestry plantations. The individual plantations are small and scattered, and supervisory staff have large areas to cover, often having to walk for hours or days between individual nurseries or plantations. In many places the only means of transportation for materials and plants is by porters. Nurseries are small, often with only the nursery foreman and perhaps one more labourer permanently employed; the small scale of the operations precludes the use of mechanical irrigation devices and similar equipment. The nursery foreman, though he may have attended a training course, is usually of a low educational level. Labour is mostly provided by local peasant farmers in their spare time, and they are usually inexperienced and unskilled. All this calls for the simplest possible techniques to be used, and these techniques should also be robust, so that even if optimum standards of work are not attained the result will not be a complete failure, though of course the aim should be to attain as high a standard of work as possible.

To a certain extent these constraints may be regarded as socio-economic rather than technical. Other social constraints are availability of land, especially land of good quality for plantations; availability of labour, especially during periods of high agricultural activity; and reluctance of local people to change their practices in grazing their livestock, in lopping trees for fodder, and felling trees for fuelwood within plantation areas. It may be possible to reduce the problems of labour availability to some extent by planning forestry work so that as much as possible takes place during periods where demand for agricultural labour is low, though there are difficulties in this, as the best time for planting trees usually coincides with the best time for sowing crops. In large schemes these difficulties can be reduced by employing a permanent labour force. Many of them can also be reduced, in village plantations, by involving user groups in the planning process.

The availability of land is a big problem in most of Nepal, with its growing population and limited areas of cultivable soil. There are, however, quite large areas of land which at present only produce very poor grazing, which might be more productive under forest plantations, and probably produce more grass and other fodder at the same time. Here again the involvement of local user groups is essential as they can decide whether they would benefit by having this type of land made into forest plantations; extension and demonstration may be needed. Involvement of user groups is also a great help, almost a necessity, in preventing damage from uncontrolled grazing, lopping and felling, and the careless or deliberate use of fire. This has been achieved in some districts, but the process requires a good deal of tact and patience.

Other constraints are administrative and financial; unfortunately it is often difficult for the field forester to overcome them. They include the availability of properly trained staff and of adequate funds, released at the right time. Shortage of trained staff prepared to undertake the somewhat arduous work of a forester in Nepal may severely limit the activities that can be carried out and the effectiveness of their execution. In future much of the work of management of forests for local needs is likely to be undertaken by user groups, but the establishment of such groups, and helping them to draw up operational plans, is difficult and time-consuming. It is estimated that in Sindhupalchok District alone there will eventually be between 800 and 1000 user groups, while there are at present 16 field workers to advise them (A.L. Joshi, 1991). These field workers will also need quite different skills from those needed to establish plantations by direct labour.

Adequate funds are also essential. No government has unlimited funds for forestry, or for any other activity, but the plantation programmes undertaken by government or other large organizations should be geared to the funds available. In plantations established by smaller groups it is also important that the work should be within the capacity of the people undertaking the work. If funds or other resources are short it is better to reduce the size of the programme, rather than to attempt to economize by skimping essential work. In planning plantation expenditure it should also be borne in mind that costs do not only consist of raising seedlings and planting them, but also of weeding the plantation until the trees are free from serious competition. This is likely to take a minimum of two years and may often be longer. Assurance is needed before beginning a plantation programme that provision will be made for weeding and maintenance costs, in addition to the original costs of planting.

In work financed by government it is also important that funds are made available at the time they are needed. If planting should be in June, it is not much use if the funds for it are released in August. This should be impressed on the financial authorities. For further discussions of this type of constraint, which is by no means confined to Nepal, see J.K. Jackson (1984).

Types of plantation

Large and small plantations

It has already been pointed out that a plantation may range in size from a few trees planted by a farmer for his own needs to a large industrial plantation in which a thousand hectares may be planted each year, and that different techniques may be required for large and small plantations. Some of the constraints involved in small-scale plantations have been mentioned. In a large-scale plantation there will be technically qualified staff available for the day-to-day supervision of work and a permanent labour force can be trained, who will become experienced in their work. This will enable more refined techniques to be developed than are practicable in small community nurseries. There is also the possibility of much greater capital investment in such items as mechanical irrigation systems, machinery for land clearance and preparation, transport for materials and seedlings, housing for staff and labour, and workshops for the repair of machinery. Plans will need to be prepared for a road network, and for fire protection. Also in a large-scale plantation much more detailed forecasts will be needed, especially of costs and returns.

Plantations not in blocks

So far the types of plantation considered have been mainly in the form of solid blocks of trees, but other forms are possible. These include planting in lines or belts along roads, rivers, canals or cultivation terraces. Such plantations can make an appreciable contribution to the supply of forest produce, as is the case in India and China. In China there is a programme of 'four around' plantations, which consists of planting along roads, along rivers and canals, around houses and villages (FAO, 1978).

In Nepal such plantations of lines or small groups of trees could be of great value in helping, at least partially, to overcome the growing fuelwood and tree fodder shortage. This is particularly true of trees planted by farmers along terrace risers, near their houses and in other odd spots on their farms which may be unsuitable or inconvenient for growing agricultural crops. In the Terai in particular planting in lines along roads and canals could make an important contribution to the supply of forest produce. At present in Nepal roadside plantings are virtually confined to shade and ornamental trees. This is by no means to be discouraged, but such plantings could in many cases also provide timber, fuelwood and fodder. For example it has been pointed out (Anon., 1981c) that the poplars planted along roads in Kathmandu could, if pruned, provide useful material for the match industry. The essential character of the avenue could be preserved by felling in any year say one tree in six, or one in ten, depending on the rotation to be adopted. Other forms of linear plantations are shelter belts and windbreaks which, in addition to protecting crops from desiccating winds, could also provide fodder or fuel.

A different type of plantation would be where the trees were planted at a wide spacing, and the interval between them used for growing agricultural crops or pasture. The use of fodder trees in such conditions would often be very appropriate, or leguminous trees could be used to help to provide crops with nitrogen. Shade trees in tea plantations are another example of this type. All these types of plantations have a useful function, and all will require rather different techniques in their establishment, especially with regard to choice of species, spacing, and protection.

Enrichment planting

This usually means modifying the composition of existing forest by planting other species within it. Traditionally this involves clearing lines or gaps in existing forest, planting the seedlings in the cleared areas, and then gradually widening the openings to give enough light for the planted seedlings to grow. It is an operation needing considerable skill, as it is not easy to judge how much light can be given to the planted seedlings without encouraging a luxuriant growth of weeds. Experience in various parts of the world has shown quite a high number of failures in attempting to introduce this type of planting. It is not likely to be of great importance in Nepal.

What in Nepal is termed 'enrichment planting' could be more accurately defined as 'gap planting' and consists of planting gaps or very poorly stocked areas in natural forest. The techniques used differ little from those needed in normal plantation work, except that if there are existing trees in the areas to be planted these may hinder the growth of strongly light-demanding species. It should also be borne in mind that gaps in natural forest may be due to unfavourable site conditions. Gap planting is a technique which could be used by user groups in natural forest, and need not necessarily involve planting seedlings. Dibbling oak seeds in gaps would come under this head.

Mixed plantations

Mixed plantations are sometimes advocated as being more akin to natural forest than pure plantations, and hence less 'artificial', and less susceptible to pests and diseases. Not all natural forests, however, are mixed; in Nepal *Pinus roxburghii* and in some places *Shorea robusta* occur naturally in pure or almost pure stands. The main problem in establishing mixed plantations is that it is very difficult to find two or more species which are compatible in their rates of growth. Nearly always one species will become dominant and suppress the others. This has been shown in Adabhar in trial plots of various species mixed with *Eucalyptus camaldulensis*. Of the species tried *Cassia siamea* reduced growth of the eucalypts; the eucalypts tended to suppress *Dalbergia sissoo* and *Acacia catechu*; while only in the mixture with *Artocarpus lakoocha* was the growth of the two species approximately equal. Of course one or the other species can be favoured in subsequent thinning, but even then it should be considered whether the objectives of a mixed plantation would not be achieved just as well by pure plantations, perhaps of each species individually.

It is sometimes possible to mix a slow-growing shade-tolerant species with a faster-growing light-demander; eventually the light-demander is removed and the shade-bearer left to grow on. A somewhat similar technique has been used in India where *Pinus wallichiana* has been mixed with *Cedrus deodara*, but here one practice suggested was to plant the deodar under the pine when the latter was 2–3 m high. Care must be taken to remove any pine trees which are overtopping and shading out the *C. deodara*. Another possibility in Nepal would be to combine a very fast-growing species, such as *Leucaena leucocephala* with a slower-growing species and to cut out the *Leucaena* or thin it heavily when it was three or four years old. Trials are being made of such techniques but results are not yet available.

One case where mixed plantations are probably preferable is when a valuable species is very liable to insect attack and for this reason cannot be grown satisfactorily in pure stands. It is said that growing such trees in mixture reduces the intensity of insect attack but this needs more investigation. Examples are *Toona ciliata*, which is liable to borer attack and, in India, *Michelia champaca*, which is attacked by a sap-sucking bug. In the hills of Nepal it is very desirable that such species as pines should have an understorey of another species. This often comes in naturally and may sometimes be more valuable in providing local needs than the pine which has been planted. In other circumstances the possibility of planting an understorey, especially of useful fodder species, could be considered. On exposed sites it has often been found that valuable fodder trees grow better if planted under pines than in the open. The pine trees may have to be gradually thinned out to favour the growth of the fodder species. Otherwise until more is known about the techniques of raising mixed plantations it is best to continue to plant the trees pure. If different species are required for different purposes it is better to plant them in small pure blocks rather than mixed intimately together.

Choice of species

The choice of species for any site will depend primarily on the nature of the site and what the planted trees are expected to provide. The following points are among those which should be considered.

- Will the species survive and grow well on the site?
- Does it provide what is needed in the form of fuelwood, fodder, timber or other products?
- How fast will it grow? Other things being equal fast-growing trees are to be preferred; for some purposes, including fuelwood production, weight increment is more important than volume increment. In fodder trees the annual yield of fodder is important. Trees which grow fast after planting will need less weeding than slower-growing trees.
- Is seed readily available?
- Can it be raised easily in the nursery?
- How much tending does it need in the field?
- How susceptible is it to frost, fire, browsing, and damage by insects and fungi?
- How well does it protect the soil?
- Does it serve any other useful purpose, such as nitrogen fixation?

As regards the choice between indigenous and exotic species it is impossible to generalize, and the species which best meets requirements should be chosen, whether it is native or not. It should also be borne in mind that a tree may be indigenous to Nepal, but may not occur naturally in the region where it is to be planted. Trees occurring naturally in an area are obviously adapted to that area but still may be very difficult to grow artificially, or not be as suitable for the required purpose as certain exotic species.

It is sometimes held that exotics are more susceptible to pests and diseases than indigenous trees, but this is by no means always the case, and indeed the opposite is often true because the exotic tree may have left its pests and diseases behind in its country of origin. This is why *Hevea brasiliensis* (rubber) grows so much better in Malaysia than in the Amazon basin where it is native; in the Amazon economic cultivation of rubber is almost impossible because of a leaf blight which has not travelled to Malaysia. There are many other similar cases. Also, some of the most devastating tree diseases, such as Dutch elm disease in Britain and chestnut blight in the United States, have occurred when an indigenous tree species has been attacked by an exotic pathogen. Certainly before any exotic species is planted on a large scale it should be tried out on a small scale first, but this applies to all previously untried species.

One important point to consider when selecting exotic species for trials is that as a rule, with very few exceptions, species growing naturally in regions of predominantly winter rainfall perform very badly if transferred to summer rainfall areas such as Nepal. Even with a species such as *Eucalyptus camaldulensis* which has a natural range covering winter, all-season and summer rainfall regimes, the provenances from summer rainfall areas perform much better than those from winter rainfall areas, though the latter will survive. The poor performance in Nepal of such species as *Robinia pseudoacacia* and *Gleditsia triacanthos* may be attributed in part at least to the fact that in their native habitat they receive a good deal of their annual rainfall during winter.

Alternatives to plantations

Plantations are not the only, nor necessarily the best, means of ensuring supplies of timber, fuelwood, fodder or other forest produce. Such objectives may often be met more efficiently and more cheaply by protection and management of natural forest. This is discussed at greater length in Chapter 12.

Example of a plan for a small plantation

In planning plantations it is necessary to think ahead, often several years. Nurseries take several months to prepare and construct, and negotiations for the site may take longer. Seed may take a year to obtain, and some plants may need two years in the nursery. What follows (Table 7, pages 138–140) is intended as an example of the sort of things which need to be thought of in preparing a plan. The numbers of man-days for each operation are mostly derived from the Ministry of Forests and Soil Conservation's *Standard Norms* (1983). Labour requirements will obviously be based on local experience. Some of the nursery tasks listed would normally be carried out as part of their routine work by the *naike* and permanent nursery labourers; also some of the plantation weeding would be done by the forest watchman (*heralu*). Other items such as sowing dates, sowing directly into pots as against pricking out, and choice of species will also depend on local conditions.

This plan is for a one-off operation, which would be unlikely to occur in practice, as most plantations will be part of a continuing programme. For example it would be unusual to collect only the very small quantities of seed needed for replacement planting: this would be combined with the collection of seed for other purposes. Year 0 is the actual planting year in the western calendar. Year -2 is the calendar year two years before, i.e. if the planting year were 1995, year -2 would be 1993. Some adjustments will be needed if the Bikram Samvat calendar is used; for instance January–February in year 0 according to the western calendar will be Magh year -1, in the BS system. It should be noted that even for such a small plantation as this it is necessary to begin planning eighteen months to two years before planting begins.

Assumptions: An area of 20 ha is to be planted, 70 per cent with *Pinus roxburghii*, 20 per cent with *Melia azedarach*, and ten per cent with *Alnus nepalensis* at a spacing of 2.5 m x 2.5 m (1600 plants ha^{-1}). Thus requirements of plants are *P. roxburghii* 22,400; *M. azedarach* 6400; and *A. nepalensis* 3200. To each of these quantities 25 per cent is added to allow for nursery losses and culling of poor plants, resulting in the following figures: *P. roxburghii* 28,000; *M. azedarach* 8000; *A. nepalensis* 4000; total 40,000.

The plants will be raised in standard 3 inch x 7 inch (7.5 cm x 18 cm) lay-flat polythene bags, and will require about 200 m^2 of nursery space for the bags (200 plants m^{-2}, allowing for spacing.) This space is available in an existing nursery 3 km from the plantation site.

The potting mixture will consist of three parts of topsoil to one of sand, both of which are available at 500 m distance from the nursery. The quantities needed are 9000 kg of topsoil and 3000 kg of sand (300 g per bag), equivalent to 480 *doko* loads altogether. In addition 840 kg of mycorrhizal soil will be needed for the pines equivalent to 35 *doko* loads. The sand and topsoil are to be collected in the dry season before the plants are sown in the nursery, but the mycorrhizal soil is better collected shortly before the seed is to be sown. It is estimated that a porter carrying a *doko* load of soil 500 m can make ten round trips in a day.

The pine seed is to be sown directly into polypots at the rate of two seeds per bag; for 28,000 seedlings this comes to 56,000 seeds or about 6 kg. This seed ripens in January and will be collected locally. It will be sown in September. *Melia azedarach* and *A. nepalensis* seed will be sown in beds and the seedlings pricked out into bags. *Melia azedarach* seed ripens in February or March, and if sown then will produce plantable seedlings by the rains. Experience has shown that about 1200 plants can be raised from 1 kg of seed, so about 7 kg of seed will be needed. *Alnus nepalensis* seed ripens about December, but should be sown about September; it will therefore need to be collected and stored. There are well over a million seeds per kilogram, but the average number of seedlings raised in Nepal is only about 30,000 kg^{-1} (this could be improved by better nursery practice), for 4000 plants about 150 g of seed will be needed. To be on the safe side 200 g should be collected. New shade will be needed for the nursery beds; local bamboo is available, and a total of 52 bamboos 10 m long, or their equivalent, will be needed.

There are good relations with the local people, so fencing will not be needed on this site. Planting will begin as soon as possible after the monsoon breaks, and will be completed by the end of July. There will be one weeding immediately after planting, and one in September–October. In the year after planting provision is made for replacing 25 per cent casualties; the plantations will also be weeded towards the beginning and the end of the rainy season. Other estimates of labour needs are based on the norms of the Ministry of Forests and Soil Conservation (1983). It is assumed that routine watering, weeding, and root pruning will be done by the nursery *naike* and other permanent nursery staff, if any.

Table 7—Schedule for planning of a small plantation

Year	Month	Operation	Man-days	Materials
-2	—	Select site and species to be planted	—	—
-2	Dec	Collect, dry and store *Alnus nepalensis* seed	1	*seed 200 g
-1	Jan	Collect, dry and store *Pinus roxburghii* seed	2	*seed 6 kg
-1	before Jun	Order polypots	—	40,000 polypots (90 kg)
-1	before rains	Collect sand and topsoil	48	*sand 120 *doko* and soil 360 *doko*
-1	Aug	Prepare seed bed for *A. nepalensis* (2 m^2)	1	
		Collect mycorrhizal soil	3.5	*soil 35 *doko*
		Mix and sieve soil	40	
		Fill polypots	160	
		Collect bamboos for shade	5	*bamboos totalling 520 m
		Obtain mats for shade	—	50 mats
		Erect shade	10	
-1	Sep	Soak *P. roxburghii* seed and sow in polypots	14	
		Sow *A. nepalensis* seed	1	
-1	Oct	Prick out *A. nepalensis* seedlings	16	
-1	Sep–Oct	Water, weed and tend seedlings (done by permanent labour)	—	
-1	Dec	Collect *A. nepalensis* seed for replacements	—	*seed 40 g

Table 7 cont.—Schedule for planning of a small plantation

Year	Month	Operation	Man-days	Materials
0	Jan–Feb	Clear site	200	
0	Jan	Collect *P. roxburghii* seed for replacements	1	*seed 1.2 kg
0	Feb–Apr	Do pitting	500	
0	Feb–Mar	Prepare seed bed for *Melia azedarach* (4 m^2)	2	
		Collect and sow *M. azedarach* seed	2	*seed 7 kg
0	Before May	Erect fence (not necessary in this case)	—	
0	Mar	Prick out *M. azedarach* seedlings	32	
0	Before Jun	Order polypots for replacing casualties	—	8000 polypots (18 kg)
0	Before rains	Collect sand and topsoil	10	*sand 24 *doko* and soil 72 *doko*
0	Jun	Sort out plants, rejecting culls	8	
0	Jun–July	Transport plants	250	
0	July	Plant and weed seedlings	500	
0	Aug	Prepare seed bed for *A. nepalensis* replacements	—	
		Collect mycorrhizal soil for replacements	1	*soil 7 *doko*
		Mix and sieve soil for replacements	8	
		Fill pots for replacements	32	

Table 7 cont.—Schedule for planning of a small plantation

Year	Month	Operation	Man-days	Materials
0	Sep	Sow *P. roxburghii* and *A. nepalensis* seed for replacements	3	
0	Sep–Oct	Weed plantation	400	
0	Oct	Prick out *A. nepalensis* seedlings for replacements	4	
0	Jun–Dec	Protect plantation	*heralu*	
1	All year	Protect plantation	*heralu*	
1	Feb-Mar	Prepare seed bed for *M. azedarach* replacements (1 m^2)	0.5	
		Collect and sow *M. azedarach* seed for replacements	0.5	
1	March	Prick out *M. azedarach* seedlings for replacements	6	
1	Jun	Sort out plants for replacements, rejecting culls	2	
1	Jun–July	Transport replacements	50	
1	Jun–July	Weed plantation	400	
		Plant replacements	100	
1	Sep–Oct	Weed plantation	400	
2	Onward	Protect plantation	*heralu*	
		Total	3213.5	(excluding *naike* and *heralu*)

Note: * = materials available locally

Chapter 8

SEED

In the following chapter the term seed is not always used in its strictly botanical sense of a fertilized and matured ovule, but in the more general sense of the part of the plant which is sown to produce a seedling; it may include what are strictly speaking fruits.

Obtaining seed

Seed may be collected from places near where the trees are to be grown, from other parts of Nepal or be imported from abroad. Seed of species which are not native to Nepal will obviously have to be imported until plantations of these species are old enough to produce seed. For native trees it is generally better to use Nepal-grown seed where this is available. This is usually cheaper, and saves foreign exchange; also trees growing in Nepal will tend to be better adapted to local conditions than those growing in distant areas, often with very different conditions of climate and soil. There will be exceptions, such as where a particular provenance of a species from outside Nepal has been found to be clearly superior to local provenances, or to avert temporary shortages due to such factors as poor seed years. Storing surplus seed collected in good seed years for use in poor seed years will reduce the need for such imports.

Within Nepal, seed collection may be organized on a national basis through the National Tree Improvement Programme, on a divisional or district basis, or by the staff of individual nurseries from nearby forests. Which method is used will depend on a number of circumstances, including seed availability, storage facilities, the storage life of the seed, and the length of time between seed collection and the best sowing date. Seed with very short viability will clearly have to be collected from as close as possible to the nursery where it is to be sown, whereas seed which has to be stored for long periods, or which needs to be stored under conditions of controlled temperature and humidity, should be held in the central seed store. The National Tree Improvement Programme should also undertake distribution of seed from one part of Nepal to another. Here again seed collected from near to the locality where the trees are to be planted will generally give better results than seed from more distant areas.

However there are exceptions to this, particularly when trials have revealed superior provenances. *Dalbergia sissoo* is a case in point.

If seed is collected from plantations of exotic species special care may be needed to avoid collecting hybrid seed. This is especially important where several species of a genus such as *Eucalyptus* are planted close to each other. Stands used for seed collection should be isolated from other stands whenever there is a risk of hybridization, especially when selected provenances or genetically improved trees are being used.

Importing seed

Importing of tree seed will usually be arranged through the National Tree Improvement Programme. However they may need to be informed about what type of seed is required. The following categories of seed genetic value can be distinguished (Matthews, 1964).

- Unclassified seed in which little information about seed origin is given other than the species.
- Source-identified seed from good natural stands and plantations which have been officially recognized as seed stands.
- Selected seed, collected from superior phenotypes in natural stands or plantations.
- Certified orchard seed, usually from clonal (vegetatively propagated) trees, or elite trees planted in seed orchards, whose genetic superiority has been proven by progeny tests.

Another category of seed, which does not fit exactly into this classification, is seed of known provenance. This is seed collected from a population of trees growing at a specific place and representing a local population (Callaham, 1964). The provenance should come from a restricted area such as 'Laura, Queensland: latitude 15°36'S, longitude 144°27'E' rather than merely 'Northern Queensland' or, even worse, 'Australia'. Trees of different provenances often behave very differently in plantations, and when seed is imported the supplier should be required to state the provenance as accurately as possible. Any additional information such as the soil and climatic conditions at the site of collection is also very valuable. Provenance is also important when seed is collected within Nepal.

Some commercial seed suppliers are also prepared to supply seed-orchard seed of certain species. It should be borne in mind, however, that trees in seed orchards have been selected on the basis of their performance at the place where they have been planted, and this may have different soil and climatic conditions from those in Nepal. Trees from orchard seed from distant countries should first be tested in comparative trials before the seed is used on a large scale, especially as it tends to be expensive. A good supplier will also be prepared to certify the purity and germination percentage of seed lots but these may need to be checked on receipt.

Imported seed needs to be accompanied by a phytosanitary certificate otherwise entry to Nepal may be refused (this does not apply in all cases to seed imported from India). Seed should always be imported by air freight, to avoid the danger of it being held up for weeks or months at docks or in godowns under conditions of high temperature and humidity. An exception is seed imported from India by road, but only if it is accompanied by someone who can arrange immediate customs clearance and transit at the frontier. Once seed is received at Kathmandu airport it should be cleared as quickly as possible. The National Tree Improvement Programme can give up-to-date recommendations on suppliers of seed from abroad.

Seed collection

Seed should be collected from healthy trees of good form. For timber and poles good form implies a straight stem, but for fodder species a vigorous crown with many leaves is of greater importance. In some localities particularly good natural stands or plantations of well-formed trees may exist and seed should be collected from such stands where possible. If exceptionally good stands are known the possibility should be considered of setting these aside and managing them specifically for seed production, by removing all badly shaped trees and thinning the remainder heavily to reduce competition between the crowns and hence increase seed production.

To obtain seed of high quality, careful supervision is needed to ensure that the seed comes from healthy well-shaped trees. Buying seed in bulk from villagers or other people is often the easiest and cheapest way of getting seed supplies, but such seed is likely to be collected from the most accessible trees, which are often heavily branched or of otherwise poor quality. Fodder trees are often lopped so heavily that little seed is produced; there are also trees of which the flowers or fruit are collected for sale in the market, or for food. In such cases it may be necessary either to buy the trees, or to make an arrangement with the owner that he does not lop the trees or collect flowers or fruit before adequate seed has been collected.

Seed should generally be collected when the fruits are fully ripe. In fleshy fruits this may often be recognized by a change of colour. Dry fruits which open to shed the seed should be picked just before opening begins. Ripe, healthy seed when cut with a knife is firm and white. The approximate dates for seed collection are given under the description of the individual species, but these dates may vary considerably between different localities, as they are affected by such factors as rainfall, altitude and aspect. Dates may also vary from year to year, according to the weather. For some districts lists have been compiled giving local dates of seed collection, and the localities where the different species can be found (Fujiwara, 1982; Margolis, 1982), and similar lists should be compiled for all districts. Such lists will also help rangers to remember when seed of different species should be collected. Seed of some species may remain on the trees for considerable periods after ripening, and this may account for some of the discrepancies in the literature on dates of seed collection. However even for these species it is better to collect the seed as soon as possible after it has ripened, otherwise there may be losses due to the seed being scattered, or by insect attack.

Seed is usually best collected from the trees, rather than after it has fallen to the ground, because seed collected from the ground is liable to be damaged by insects. This will generally mean climbing the trees. Small fruit-bearing twigs may be cut and the fruit allowed to fall to the ground, but this should not be taken as permitting large branches to be lopped to make seed collection easier. When collecting small fruit or seed from standing trees it may be useful to spread polythene sheets or cloth beneath the trees to make finding the fallen fruit easier, or else the ground beneath the trees can be hoed or swept clean. Tools used for collecting seeds from standing trees are described and illustrated by Napier and Robbins (1987), and methods of climbing trees for seed collection are described in Robbins *et al.* (1987).

As soon as seed or fruit has been collected from the trees it should be labelled with the species, place of collection and date. Two labels should be used, one on the outside and one on the inside of the container used to transport the seed or fruit. Transport of fruit to the place where the seed is to be extracted should be in containers such as open weave cloth or hessian sacks which allow free circulation of air. For short distances the ordinary *doko* can be used. The fruit should be kept in such containers in a cool, dry, well-ventilated place, well clear of the ground, and protected against rodents. It should never be stored in sealed containers or piled up in large heaps. In general the seed should be extracted from the fruit as soon as possible after it has been collected, especially when the fruits are fleshy. If it is to be stored it should be prepared for storage as soon as possible after receipt.

Seed extraction

In some cases the seed, as it is sown in the nursery, consists of the whole fruit (e.g. *Shorea*, *Tectona*, *Acer*, *Fraxinus*) and in such cases no extraction is needed, though unwanted parts such as the wings of *Shorea* fruit and the cups of *Quercus* fruit may be removed to reduce the size and facilitate storage and sowing. In other cases it is possible simply to open the fruit by hand and pick out the seeds. For other types of seed however, special methods of extraction are needed and these are described below.

Extraction by drying in the sun

This method is used for conifers, in most of which the seeds are borne between the scales of cones, which open on the tree to release the seeds. In the nursery it is necessary to speed up this opening by artificially drying the cones. In some countries special drying kilns are used for this, but in Nepal drying in the sun is adequate. Similar methods are used with other trees with cone-like fruits, such as *Betula*, *Alnus* and *Casuarina*, and certain trees which have very fine seed in capsules (dry fruits which open to release the seed), such as *Eucalyptus*, *Callistemon*, *Schima* and *Rhododendron* species.

Generally the fruits should be kept under shade until they are just about to open, and this is particularly important when the fruits are green. Such fruits should be kept under shade until they turn brown, as excessive heating of green fruits may damage the seed. At night they should be covered or kept under shelter so that they they do not absorb water from the humid night or become moistened by mist or dew. They may need to be protected against rodents and birds. Once the fruits are ready they should be spread out on a drying tray with a wire mesh bottom, or a *nanglo* or *gundri*, supported above the ground on poles or stones so that the air can circulate, with a mat or cloth below to collect any seed which falls through. If the seeds are light, care should be taken not to exposed them to the wind, otherwise they might be blown away. An alternative is to cover the fruit with netting while it is being dried.

After the fruits are open they should be shaken to extract the seeds. Fruits like pine cones can be shaken by hand, or knocked together. Seeds may be extracted from other types of fruit by putting the fruit in a bag and shaking it, or knocking it against a wall; or they may be threshed by beating the fruits on mats, tarpaulins or trays. Threshing should only be used for hard seeds, as it is liable to damage the coats of softer seeds, and should always be used with care. The fruits should be shaken frequently while they are being dried, and not only at the end of the day. This increases the seed yield, especially of pines. Drying and shaking should continue until all the seed has been extracted from the fruits. The seed should then be cleaned to separate it from dirt and unwanted plant debris of various kinds. This can be done by sieving, using a sieve with a mesh larger than the seeds to remove large debris, and then one with a mesh that the seeds cannot fall through to remove dust and smaller debris. Final cleaning can be done by winnowing.

Removal of pulp of large-stoned fleshy fruit

This type of fruit has a layer of more or less juicy flesh covering a hard stone, which may contain one or more seeds. If there are more than one seed the stone is usually sown whole, without the individual seeds being extracted. The pulp should always be removed as soon as possible after the fruit has been collected, as if left on the stones it will often cause the viability of the seeds to be considerably shortened, and may also inhibit germination. In some fruits the pulp can be removed from the stones by hand, though great care is needed to ensure that all the pulp is removed. In other cases soaking the fruits in water may be necessary. The fruits should be soaked in water for about 2–3 days, the water being changed daily; it may help to break the fruit skin first. After the fruits have become soft they are put into a strong cloth bag and kneaded under water to remove the flesh. Mixing the fruit with coarse sand or sharp gravel in the bags may help to rub off the flesh, but the method should only be used for fruits with hard stones. Another method is to rub the fruits over a coarse sieve under a stream of water. After the flesh has been broken up it can be separated from the stones by putting the fruits into a container of water and stirring the stones and pulp together so that the stones sink and the flesh, which tends to float, can be skimmed off. This should be repeated, with changes of water, until all the flesh has been removed, and the stones are completely clean.

Extraction of small seeds from fleshy fruit

This method is used for fruits which have one or more small, and relatively soft-skinned, seeds embedded in a fleshy pulp, for examples *Ficus* and *Morus* species. The fruit is soaked in water until it is soft, which may take several days, with the water being changed daily. It is then broken up with the fingers, or the fruits are rubbed together until the seeds are separated. Seed and pulp are separated by stirring them together in a bucket of water. Alternatively the broken fruit can be rubbed through a sieve over a container of water, the meshes of the sieve being large enough to permit the seed to drop through. The seed is then collected from the water, and dried. The seed of certain species such as *Saurauia napaulensis* and *Guazuma ulmifolia* is surrounded by jelly which inhibits germination. *Saurauia napaulensis* seed is separated by putting the fruit in a muslin bag and kneading it under water, and washing the seed several times to remove the jelly which surrounds it. *Guazuma ulmifolia* seed has to be treated with boiling water to remove the jelly. For details see the accounts of the respective species. After the seed has been cleaned it should be dried thoroughly especially if it is to be stored.

Storage of seed

The most common occasion when seed will need to be stored for a period is when the date of seed ripening does not coincide with the optimum date for sowing the seed. For example, *Pinus roxburghii* seed usually ripens between January and March, but for some nurseries the best time for sowing the seed is September to October, so that the seed may need to be stored for six or seven months. Another occasion when seed may need to be stored is when a species does not produce a good crop of seed every year. In such cases it is desirable to collect surplus seed in good seed years and store it, so that in poor years there will be enough seed available for requirements. This may entail storing seed for two or three years, and such storage is best done where proper facilities are available, such as at the National Tree Improvement Programme. It may be possible, however, to store seed under field conditions for species which do not lose their viability quickly. The notes which follow refer to storage of seed under field conditions, and not to more sophisticated storage where it is possible to keep temperature and humidity under strict control. Pre-treatment of seed to accelerate germination should always be done after the seed is removed from storage and never before.

Classes of seed and storage methods

Seed may be divided into two main classes: orthodox and recalcitrant. Orthodox seed can be dried to a moisture content of 5–10 per cent, and successfully stored for long periods, especially at low temperatures. Recalcitrant seed cannot be dried below a relatively high water content (20–30 per cent) without losing its viability, and must therefore be kept moist under storage; even then it cannot be stored for long periods (Robbins and Shrestha, 1986). The viability of orthodox seed is extended by minimizing its rate of respiration; with recalcitrant seed respiration must be allowed to continue, and good aeration is necessary. Both classes store best if kept in as cool a place as possible (storage under refrigeration is not dealt with here).

To know which species fall into each class is largely a matter of experience. It can be safely assumed that seed of any species which is reliably recorded in the literature as having a viability of a year or more is orthodox seed, and seed that comes from a fruit that naturally dries on the tree will generally also be orthodox. On the other hand many large seeds (e.g. *Quercus*) or seeds from fleshy fruits that do not dry on the tree (e.g. *Artocarpus*, *Mangifera*) are recalcitrant. Seed which falls from the tree during the rainy season and germinates almost immediately after falling is often also recalcitrant; this applies to many dipterocarps, including *Shorea*. It is likely that many seeds known to have very short viability are recalcitrant and it would be wise to treat them as such until the contrary is proved. It should be noted, however, that some orthodox seeds have short viability. The great majority of species have orthodox seeds which can be dried, and recalcitrant seeds are the exception.

Storage of seed that can be dried

In the field the only practical way of drying seed is by exposure to the sun. If the seed is moist, however, for instance if it has been extracted by soaking the fruits in water, it should be kept for a day in a warm, dry, well-ventilated, but shaded, place before it is moved out into the sun to complete drying. If moist seeds are subjected to high temperatures their viability may be reduced. During this period they should be moved or stirred every few hours. The best way of drying seed is to use special trays of wood with wire-gauze bottoms. If such trays are not available a *nanglo* or *gundri* can be used, raised above the ground to allow free circulation of air. If possible the seed should be spread in a single layer; otherwise in layers not more than two or three seeds deep. If more than one layer deep the seeds will need to be turned over every hour.

Usually two to three days in the sun will be sufficient. At night the trays should be put under a roof, or covered with cloth, so that they do not absorb water from the moist night air. It is especially important that they should be covered well if there is any chance of rain. In very hot weather in the Terai it may be necessary to shade the seed during the hottest part of the day. In cloudy and humid weather the trays should be kept under cover until dry, sunny weather returns. When the seed is dry enough it should be kept in the sun until the afternoon, and then put immediately into containers. If left overnight the seed will absorb moisture, so the seed should not be packed in the early morning.

It is important that the containers used are completely airtight. The simplest are thick polythene bags of high density (at least 0.004 mm) as thin polythene is permeable to water vapour. If thin bags have to be used two should be used, one inside the other. After having been filled the bags should be squeezed to expel excess air and the necks tied tightly with a twist of soft copper wire, or string. Glass or plastic jars may also be used, provided they can be sealed tightly; such containers should be filled as full as possible so that there is no excess air from which the seed can absorb moisture. Once the containers have been sealed they should be opened as infrequently, and for as short a period, as possible. Cloth bags should never be used for storing orthodox seed; experiments have clearly shown that seeds of most species very rapidly lose their viability if stored in this way (Napier and Robbins, 1987). If it has not been possible to dry the seed completely before storage, as might happen during a spell of wet or misty weather, it should not be placed in sealed containers, otherwise it will lose its viability rapidly and there is the danger of mould formation. Such moist seed should be stored in well-ventilated conditions until the weather improves and the seed can be thoroughly dried.

Seed should be stored in as cool conditions as possible. The containers should be kept in a cool, dry, well-ventilated room with adequate protection against rodents. In a two-storeyed building the lower, shaded rooms are best, provided they are dry and well ventilated. Lofts or areas immediately below roofs, especially corrugated iron roofs, should be avoided as they are likely to become very hot. A suitable seed store can be constructed by screening off part of an office or store with a framework of wood and wire mesh, the mesh being fine enough to keep out mice, and storing the containers on shelves with plenty of space round each container. Care should be taken that mice have no other way of entering the store, for instance under doors or through holes. Where such facilities are not available metal trunks, such as are available in any market place, can have holes punched through them for ventilation, and be used to store the seed in polythene bags. Among other things these give excellent protection against rodents. In some places a domestic refrigerator may be available for seed storage. This can be used for storing small sealed lots of seed in the main compartment, not the freezer. However in places where the electricity supply is unreliable and the refrigerator is liable to be out of action frequently it should not be used for storage of seed, as fluctuating temperatures are more harmful than a constant, if rather high, temperature.

Generally fungicides and insecticides should not be mixed with seed which is to be stored, as they tend to cause more damage than they prevent. Properly dried seed should not develop mould. Seed under storage should be inspected from time to time, and if it smells musty, indicating mould formation, it should be removed from the container and dried as soon as possible. If seed is free from insects when placed in storage, and is properly dried and sealed, insect damage should not occur. An exception however must be made of seed of certain species of Leguminosae—*Acacia*, *Albizia*, etc.—in which boring beetles may lay their eggs within the developing ovules before the seed ripens. In such cases mixing a small quantity of a contact insecticide dust with the seed in the container may be essential if serious insect damage is to be avoided.

Storage of seed that must be kept moist

Two types of recalcitrant seed can be distinguished. The first is when seed of very short viability germinates almost immediately after it has fallen. Examples are *Shorea robusta* and *Artocarpus lakoocha*. The second is when the seed ripens and falls in autumn, but does not germinate until the following spring.

Meanwhile it remains on or just below the soil surface, but must remain moist. Examples are oaks and *Castanopsis*. The only reliable method of dealing with the first type of seed is to sow it as soon as possible after collection. Occasions may arise when this is not possible, as for instance the occurrence of a long holiday immediately after the seed has been collected. It may also be necessary to transport recalcitrant seed over long distances, with dangers of delay in transit, and in such cases special treatment and packing may be needed. It must be emphasized that the methods suggested have in general not been tried for Nepalese species; they offer the best prospects for prolonging the viability of recalcitrant seed, but should be tried out on a small scale before being put into general practice. The important factor in dealing with recalcitrant seeds is to keep them moist. If they are contained in fleshy fruits it may be possible to store them within the fruit for a few days. The outside of the fruits should be kept dry to prevent mould formation, and they should be kept in a cool, well-ventilated place.

For storage for longer periods the most promising method is to remove the seed and leave it for a few days in water to allow it to imbibe the water fully. The moist seed must then be kept as cool as possible, and in the dark, to restrict germination. Despite this some germination may occur, and the seed should be inspected frequently and any that has germinated removed. (It may be possible to use such germinated seed by pricking it out immediately into plastic tubes.) Seed that is kept moist needs to respire, so it must not be kept in sealed containers. Suitable containers are thin (0.002 mm) plastic bags sealed with copper wire or rubber bands. These will prevent the seed losing its moisture, but will allow air to permeate slowly to the seed. Storage in moist sawdust or powdered charcoal has also been used for some recalcitrant seeds. A cool, dark cupboard is a good place to store seed which must be kept moist. The use of a refrigerator is not recommended, at least with the present state of knowledge, as seed of some recalcitrant species will not withstand low temperatures. Moist storage of recalcitrant seed will slow down its loss of viability but only for a limited period; the viability will in most cases be increased from a few days to a few weeks only. Storage of such seed for long periods should not be attempted under field conditions.

Storage of seed of *Quercus* and *Castanopsis* species

The seeds of some species of these genera are recalcitrant, in that they cannot be dried and must be kept moist, but in addition they have a period of dormancy and often appear to need a period of low temperature before they will germinate. The seeds fall between October and January but even in nurseries often will not germinate until the next March or April; in the natural forest they germinate at the beginning of the monsoon. They can be sown in nurseries at the time that they fall from the tree, but then are liable to be eaten by rodents before they germinate. If they dry out they are quickly killed.

The recommended method of storage is to mix the seed, without drying it, with twice its volume of moist sand, and store it in earthenware pots with lids, filled to the top with moist sand. The pots are then buried in pits a metre deep, with a layer of moist sand at the bottom, and covered with more moist sand, after which the pits are refilled with the excavated soil. Where the pots have been buried should be marked, so that they can be located again. Fine wire mesh bags, or tins with well-perforated sides, can be used instead of earthenware pots.

An old method used in Europe to store oak seed is described by Sharpe (1981c). The seed is spread out under shade on an earth or clay floor, in a layer about 15 cm deep, in a cool place. At first this layer must be turned daily with a shovel to ensure even drying and to prevent premature germination. After two weeks the intervals between turning the seed can be increased to two or three days, and after a further two weeks turning every month should be enough. The seed needs to be inspected frequently to ensure that it does not heat up, and that it does not begin to wrinkle, a sign that it is drying out. If the seed begins to wrinkle it should be sprinkled lightly with water to keep it plump. It is again important to keep rodents out. This method is only suitable for cool conditions, such as occur in winter at relatively high altitudes, and storage in jars buried in the ground is probably simpler.

Treatment of seed before sowing

Seed of many species will germinate reasonably rapidly after sowing, but some seed shows dormancy of various types and unless this dormancy is removed before the seed is sown germination may be much delayed, or be prolonged over a considerable period. The two main classes of dormancy are that which is induced by properties of the seed coat or pericarp and that which is caused by characteristics of the embryo (the infant plant) or factors inhibiting its development.

Seed-coat dormancy

Seed-coat dormancy may be physical, chemical or mechanical. In physical dormancy the seed coat is impermeable to water, and the seed will not germinate until this impermeability is removed and water can reach the embryo. In chemical dormancy there are inhibitors in the seed coat which prevent germination. While in mechanical dormancy the seed coat is permeable to water but is so tough that development and expansion of the embryo is prevented.

Physical seed-coat dormancy can be overcome by cutting or abrading the seed coat, or softening it by soaking in cold or hot water, or treating it with acids or other chemicals. One of the simplest methods is by chipping, that is cutting or nicking the end with a sharp knife, clipping off a small piece of the seed coat with nail clippers, or pricking it with a needle. This should be done at the end of the seed furthest from the hilum, the scar showing where the seed was attached to the fruit. This is effective and safe, but is laborious if large quantities of seeds have to be treated. The process can be speeded up considerably by using a hot wire scarifier. Commercial versions of these exist, but home-made ones are relatively cheap and easy to construct. A suitable design can be found in Robbins (1986); see also Sandif (1988). Another method is to abrade the seed coat by rubbing it with sandpaper. One way of doing this is to mix the seed with an equal quantity of sharp sand and put it into a tin lined with sandpaper. The tin is then shaken until the seed has become dull.

A common method used especially with leguminous seed (*Acacia*, *Albizia*, *Cassia*) is to treat the seed with hot water. Water equal in volume to about four times that of the seed is brought to the boil and allowed to cool for a short time; then the seed is thrown into it and left for 24 hours. The seed should not be boiled in the water. After treatment in hot water the seed should be washed in clean water. Seed of some species, such as *Acacia mearnsii*, produces a lot of mucilage and may need to be washed in two or three changes of water. Seeds with very hard and impermeable coats may occasionally need to be treated with strong acids. In the Sudan, *Acacia nilotica* seed is treated by soaking it for one hour in concentrated sulphuric acid. Fortunately no species commonly planted in Nepal has seeds which need such drastic treatment, which can be dangerous if done by untrained staff.

Chemical seed-coat dormancy, in which a chemical substance in the seed coat inhibits germination, can often be overcome by soaking the seed in cold water. The inhibitor causing this type of dormancy is often present in the flesh of fleshy fruits; this is one reason why the flesh should be removed from the seeds before they are sown. The seed should be soaked in water and the water changed every 24 hours to remove the inhibitor. For all species, soaking the seed in water before it is sown usually helps germination. It can also be used to separate empty seeds from full ones, as normally the empty seeds will float, while the full ones sink.

No species of tree commonly planted in Nepal has seeds with mechanical seed-coat dormancy, as far as is known, though it has been recorded in some species of *Prunus* and *Crataegus* in temperate countries. Such seed should not be treated with hot water. The recommended treatment is to soak the seed for

48 hours in water at approximately 3–5°C, and then to store it in moist sand or vermiculite at temperatures of 20–30°C (Willan, 1985).

Dormancy due to internal factors

In Nepal the commonest type of dormancy caused by internal, i.e. not seed-coat, factors, is where the seed needs a period of chilling to remove dormancy. This is characteristic of species growing at high altitudes of which the seed falls in late autumn and germinates in the following rains. This type of seed, if sown in the nursery at the time of collection, will not germinate until the next spring and is in the meantime exposed to damage by rodents and other pests. Often moist storage (the seeds are frequently recalcitrant) over winter at high altitudes is enough to break dormancy. Methods of over-winter storage in pits or jars, in which the seed is mixed with sand, have been described in a previous section. Occasionally dormancy is caused by the embryo not being fully developed at the time of seed fall; the seed thus needs a period of after-ripening before it will germinate. Overcoming this type of dormancy is thus merely a matter of storing the seed until the embryo is fully developed. Examples from Nepal which may be due to this cause include *Lagerstroemia parviflora*, with ten per cent germination of fresh seeds, and 40 per cent after four years, and *Morus alba*, ten per cent fresh, 60 per cent after three years (M.W. Campbell, 1983a). The germination of the seed of some species is accelerated by exposing the seed to dry heat. *Tectona grandis* is the only species commonly planted in Nepal which is known to have this type of seed, but other species may possibly have it. Some species (e.g. *Fraxinus*) have seeds which germinate rapidly if they are sown before they are fully mature, but go into dormancy once they are mature. Care should be taken in collecting such seeds, because if they are too immature they will not germinate at all. Immature seed should not be stored as it loses its viability very quickly.

Miscellaneous treatments

It is sometimes useful to dust the seeds with a fungicide just before they are sown. This will prevent harmful fungi which may be on the seed coat from being introduced into the nursery beds, and may help to reduce such diseases as damping-off. Coating of the seed with a repellent may help to reduce the amount of seed eaten by small birds and rodents. Red lead was at one time widely used for this purpose. The formation of nitrogen-fixing nodules on the roots of some leguminous plants may be facilitated by inoculating the seed with a culture of the appropriate strain of *Rhizobium*. The inoculum is applied to the seed after this has been treated with hot water. The most important tree species in Nepal which may need this sort of treatment is *Leucaena leucocephala*.

Field germination tests

Before seed is sown in a nursery it is of considerable advantage to know what percentage can be expected to germinate. If germination percentages are very low much time and labour can be wasted in sowing non-viable seed. The expected percentage germination also affects the density at which seeds should be sown in seed beds or in polythene pots. Germination testing is particularly important for seeds which have been transported for long distances, or stored for long periods.

A simple method of testing germination in the field has been described by Robbins and Shrestha (1986), which should be consulted for further details. It recommends the use of containers 5–6 cm deep, with straight sides, and a base area of 90–180 cm^2, equivalent to a circle 10–15 cm in diameter. These are filled to a depth of about 18 mm with sieved and washed river sand which has been previously sterilized while damp by heating over a fire for an hour, and then dried. To carry out the test, the sand is poured into the containers and water added until the sand is moist, but not saturated. A hundred seeds are then individually pressed into the sand until their tops are level with the surface, at a minimum distance apart of one seed's width, and evenly spaced. If the seeds are too large to permit 100 to be sown, 25 or 50 may be used. For very small seeds such as those of *Eucalyptus* or *Alnus* a measured or weighed quantity (1 ml or less) should be sprinkled uniformly over the surface of the sand. The seeds are then covered with just enough dry sand to hide them. Each container is then placed within a thin, transparent, polythene bag, which is sealed at the mouth with wire or string. The containers in their bags are then placed indoors, near a window, but out of direct sunlight. Each bag should be labelled with details of the seed (species, place of origin), the date of sowing and numbers of seeds sown. If seed is normally pre-treated before sowing in the nursery, for example by putting it in hot water, the same treatment should be applied to the seeds which are being tested. After a few days each container should be examined by removing it from the bag; if water has accumulated on the inside of the bag it should be poured back into the container at one side. After about ten seeds have germinated and produced healthy seedlings they should be carefully uprooted, and the number removed and the date noted on the label. This should be done for one container at a time, and the container should immediately be replaced in the bag.

This procedure should be repeated at regular intervals until no further seeds germinate, the numbers of seeds germinating being recorded on the label each time. When no more seeds germinate, the remainder should be removed and cut with a razor blade. If they appear to be healthy the seed may be viable but may need some pre-treatment before sowing. The numbers of seedlings removed at each inspection should be added up, and the percentage germination calculated. For very small seeds germination per unit volume or weight should be recorded.

Labelling and records

It is most important that tree seed should be properly labelled from the time of collection, through storage, until it is sown in the nursery. Each seed lot should be given an Identity Number to facilitate this. The minimum information on labels for locally collected seed should be as follows.

- Species (Latin name or Nepali name)
- Date of collection
- Place of collection
- Ward number
- Village Development Committee
- District
- Zone

Additional information which will be useful includes the following.

- Altitude
- Aspect
- Number of trees from which the collection was made
- Area from which the seed was collected—in *bigha*, *ropani*, hectares, square kilometres, etc.
- Average size (height or diameter) of the trees from which the collection was made
- Soil type
- General vegetation type
- If from a plantation, the date of planting

Each container (sack, basket, bag, tin, jar, etc.) used for transport or storage of seed should have two labels, one on the outside, and one on the inside.

Each seed store or nursery should maintain a seed register, preferably in the form of a foolscap book, which will list each batch of seed collected or obtained under the following headings.

- Identity number given by the particular seed store or nursery. These are best by year, e.g. 044/1, 044/2, etc. will be the first, second, etc. seed lots received in the year 2044 VS.
- Species
- Date of collection

- Place of collection
- Date of receipt
- Collector or supplier's serial number, if any. For instance, if seed is received from the National Tree Improvement Programme, the TIP seed number should be entered.
- Quantity (weight or volume) of seed received
- Date of sowing the seed in the nursery, or of issue to other localities, and the quantities disposed of (including seed thrown away because of old age, disease, etc.)
- Date and result of germination tests (if any)

The serial number should be used in all further records, such as in nursery registers, and for labelling nursery beds.

Chapter 9

NURSERIES

In revising this chapter considerable use has been made of Napier and Robbins (1989) *Forest seed and nursery practice in Nepal*. This is now available in a Nepali translation.

Introduction

To make a good plantation, good nursery stock is essential. According to the 1982/83 survey by the Community Forestry Development Project of causes of seedling mortality in their plantations about 40 per cent were due to the wrong size (generally too small) or poor health of the seedlings at the time of planting (J.G. Campbell and Bhattarai, 1983b). In addition, poor seedlings are likely to have slower growth, to be less able to compete with weeds, and to be more liable to damage by crickets and grasshoppers. Furthermore, in a poor nursery fewer seedlings will be raised from a given quantity of seed, and there will be considerable waste of money and time in sowing seed which does not germinate, in filling pots which are not stocked with healthy plants, in raising seedlings which die in the nursery, and from many other causes. Sound nursery practice is the foundation of a successful plantation scheme.

There are a number of different types of nursery. They may be temporary or permanent; they may range in size from small village nurseries raising perhaps 20,000 plants a year to large nurseries, established as part of plantation schemes, which may raise one or two million plants a year; they may be intended to raise plants for a specific plantation project, or mainly for issue to local farmers. Each type of nursery will have its own features and problems.

A temporary nursery is designed to provide the seedlings needed to plant a particular area and when the area is completely planted the nursery will be moved elsewhere. The main advantage of temporary nurseries is in reduction of transport distances between the nursery and the plantations, thus reducing costs and the risk of damage to seedlings in transport. Temporary nurseries should be within the planting area, or as close to it as possible. Their disadvantages are that permanent installations such as irrigation schemes and specialized buildings are often ruled out, and that the smaller scale of work, and lower level of supervision, result in higher costs per plant. There are also the additional costs of more frequent establishment of nurseries, but these can be reduced by building temporary nurseries to simpler standards.

The decision whether to use a number of temporary nurseries or a large permanent central nursery will depend largely on transport facilities. In the plains, where road transport is easy, a central nursery might be preferred, but in the hills, where most of the plants have to be carried by porter, temporary nurseries might be the best solution if it was anticipated that plantation activities in a locality would only last for say three or four years. In Solokhumbu, *shakha* (branch) nurseries were established in some villages. They were usually situated near the house of the village forest watcher (*heralu*) who was in charge of the nursery work, and were built to simple standards without sheds or water-storage tanks, and generally without fencing. Each of such nurseries raised between 4000 and 15,000 plants annually. They have been found to be useful in the supply of seedlings to remote areas (J. Stewart, 1984).

Even when permanent nurseries are to be established the question arises whether it is better to have a large central nursery or numerous small scattered ones? In the hills in Nepal, where roads are often non-existent, small nurseries are the inevitable solution. Recent steps to decentralize forest management to user groups will also increase the tendency to have smaller nurseries, to meet the needs of individual groups, though there is no reason in principle why one larger nursery could not provide seedlings for several user groups.

In small nurseries, staffed by one or two labourers, installation of elaborate equipment will not be possible, and the lack of skilled supervision may mean that operations must be kept as simple as possible. However good seedlings can be grown even in small nurseries if attention is paid to such matters as timing of sowing seed, soil mixtures, weeding, watering and shading. In larger nurseries consideration can be given to installing more elaborate equipment—irrigation systems, cultivation machines, and specially constructed buildings—and continuous supervision by trained personnel will be available. More sophisticated techniques can then be used. Nurseries for supplying farmers with plants will generally be on a small scale, as they will usually be within walking distance of the farmers' houses.

Siting of nurseries

Before a decision is made on where to site a nursery a clear appraisal must be made of the objectives of the nursery, including such factors as the numbers of each species of plants to be raised, and where they are to be distributed. In community nurseries time must be taken for the user groups to discuss different sites, and the technical advantages and disadvantages of each of them, so that agreement on the site is reached at least six months before the first operations begin. It will rarely be possible to find the ideal site, and compromises between various desired factors will have to be made. The following are some of the technical factors which need to be considered.

- Water supply
- Soil, either of the nursery itself, or, for plants raised in polypots, availability of topsoil, sand, and (if conifers are to be raised) mycorrhizal soil
- Access
- Aspect
- Slope
- Altitude, exposure to frost, strong winds, and the risk of flooding
- Labour availability
- Possibility of acquiring a sufficiently large area (Applegate, 1983; Drew, 1976)

Water supply

A reliable and adequate water supply is essential for all forest nurseries. The ideal situation is where there is a perennial stream at a higher level than the nursery, and fairly close to it, so that water can be brought in pipes or channels. If there is any doubt about the flow of the stream throughout the year the water flow should be carefully checked at the lowest period, and enquiries made of local people as to whether the stream is likely to dry up or to be reduced to a trickle in unusually dry years. Enquiries should also be made about whether local farmers are likely to divert the stream to irrigate their crops. It is sometimes necessary to depend on an existing irrigation channel for water supplies, but this can be risky, as farmers may divert the water for their own use during critical periods. In such cases a clear understanding on water use should be reached with the local villagers before the nursery is established. The construction of a storage tank in the nursery, which can be filled up overnight, will reduce these problems. The combination of a nursery water supply with an improved supply to a village can be a useful way of increasing goodwill from the local people, but again a clear agreement on the use of the water needs to be drawn up.

In the plains water may have to be obtained from wells. In such cases installation of a pump will be needed. A one-man, hand-operated rotary pump can supply enough water for about 30,000 trees, and a two-man pump enough for 50,000 (Laurie, 1974). For larger nurseries mechanical pumps driven by diesel oil or, where available, electricity will be needed. In such cases there should always be a standby pump in case mechanical breakdowns occur. In some localities the use of wind-driven pumps might be feasible, but before installing a wind pump meteorological records should be studied to make sure that there will be winds strong enough to drive the pump throughout the dry season.

Water requirements will vary with the climate and the species to be grown. In Zambia it is estimated that rather more than 30 litres per day are needed per 1000 *Eucalyptus* plants in polythene tubes (Laurie, 1974); using these figures as a guide a small communal forestry nursery, raising 20,000 plants in a year, will need 600 litres of water a day, or say one cubic metre to allow a margin for safety.

Availability of suitable soil

In nurseries where the plants are to be raised in polypots the soil of the actual nursery itself is not important, but there must be a suitable source of soil, preferably forest topsoil, and sand if this is needed, within easy reach of the nursery. To fill ten thousand 3 inch x 7 inch (7.5 cm x 18 cm) lay-flat polypots about 3 m^3 of soil, or 2 m^3 of soil plus 1 m^3 of sand, are needed. Larger containers will of course need more soil; 4 inch x 7 inch (10 cm x 18 cm) lay-flat polypots will need about 5.5 m^3 of potting mixture per 10,000 pots. The weight of soil in one pot is about 300 g (both weight and volume have been checked by actual measurements) so a nursery raising 20,000 plants in 3 inch x 7 inch polypots each year will need about four tonnes of topsoil plus two tonnes of sand, or six tonnes together, equivalent to 240 *doko* loads. Seed beds or seed trays will require additional quantities of soil. If pines are to be raised a source of mycorrhizal soil will also be needed. To begin with this will have to be carried from the nearest stand of pines to the nursery, but eventually it may be possible to establish a pine plot near the nursery to provide mycorrhizal soil to the nursery. Such a plot should not be planted within the nursery because of the dangers of spreading brown needle disease.

Access

The nursery should be as close as possible to the centre of the area to which plants will be provided. Where roads exist the nursery should be near a road, and it should be possible to drive vehicles into the nursery to transport materials and seedlings. It may be necessary to construct a short access road to connect the nursery to the main road; if at all possible this access road should be usable at all seasons of the year.

Aspect

Slopes facing south are much warmer than those facing north, so at high altitudes, above about 1200 m, a southerly aspect is preferable; the nursery should also be sited to avoid being in the shadow of nearby ranges of hills, if this is possible. At low elevations in hot areas a north-facing slope is preferable.

Slope

Completely flat land should be avoided if possible, as it is likely to become waterlogged during heavy monsoon rains. If use of a completely flat area is unavoidable a drainage system should be constructed. At high altitudes flat areas, especially in valley bottoms, are more liable to frost than gently sloping areas. The ideal slope is about five degrees, which is steep enough to allow proper drainage, but is not so steep that erosion is a problem. Steeper slopes will have to be terraced and on very steep slopes it may be difficult to make terraces wide enough to accommodate a normal nursery bed of a metre in width, plus paths on each side to allow access to the beds. Also a steeply sloping nursery means that labourers spend a good deal of energy climbing up and down slopes. Difficulty in obtaining land may mean that nurseries have to be established on slopes steeper than would be desired, but this should be avoided as far as possible.

Exposure to frost, strong winds and flooding

At high altitudes, sites which are particularly liable to frost damage should be avoided. These include valley bottoms and other sites where the downward flow of cold night air is obstructed either by the topography, or for example, by a dense belt of trees or shrubs below the site. Sites exposed to strong winds should also be avoided. The ideal, therefore, is to have a fairly sheltered site but one which is not in a frost hollow. For obvious reasons nurseries should never be established on sites where there is a danger of flooding or landslides.

Labour availability

Nurseries should be sited where it is possible to obtain labour without great difficulty, and preferably near a village. Even if only one or two labourers are employed they should not have to walk long distances each day to their place of work. Siting a nursery near a village is also likely to increase public awareness of forestry work. In large nurseries it may be necessary to construct special quarters for labourers, and large plantation schemes may include forest villages, with amenities such as schools, dispensaries and temples.

Availability of land

It is important that at the site chosen for the nursery there should be enough land to raise the numbers of seedlings needed, and if possible room for expansion. To raise ten thousand seedlings in standard polypots about 62.5 m^2 of stand-out beds are needed, allowing for 20 per cent losses in the nursery and spacing out the seedlings, and assuming one year or less in the nursery; 10,000 seedlings in 4 inch x 7 inch polypots will need about 112 m^2. This area should be increased by a half to allow for paths between the beds, and trebled if the nursery is on terraced land, to allow for a path on each side of the bed, and for the terrace risers. If the seedlings are to remain in the nursery for more than a year the area needed for such seedlings will need to be doubled again. In addition space will be needed for seed beds, normally about 10 per cent of the area of the stand-out beds. Provision will also be needed for buildings, water tanks, soil storage areas and drains. If stumps or bare-root transplants are to be raised, larger areas will be needed. For bare-root plants one square metre will be needed for 125 plants (Sharpe, 1983b); thus 10,000 seedlings will need 80 m^2 of bed. The area needed for stumps is approximately the same, or a little less.

How to calculate the area of a nursery for a known planting programme is described in Napier and Robbins (1989). A very small village nursery, raising 20,000 plants in 3 x 7 polypots, and keeping the plants in the nursery for a year or less, could be established on one *ropani* (500 m^2) of land, but the average is likely to be of the order of three or four *ropani*.

Before constructing a nursery, enquiries should be made about the legal ownership of the land. If government land is needed for a village nursery an application must be made to the Forest Department to transfer the land to the control of the village development committee or user group. If it is privately owned land the agreement of the owner should be obtained in writing.

Nursery layout and construction

Nursery layout will vary according to the type of plants to be raised, the facilities to be provided, and the topography of the site, especially in the case of a nursery established on terraced land where its layout will, to a large extent, be dictated by the arrangement of the terraces. In designing the layout of a nursery, provision will need to be made for seed beds or areas for holding seed trays, stand-out beds for seedlings in polypots, and paths. In addition, a water distribution system, including a storage tank, areas for storing soil and making compost, and a store for tools and materials (which can also serve as an office and shelter for the nursery foreman) will be needed. In some places it will be necessary to dig drains. If stumps or bare-root transplants are to be raised space will need to be allotted to beds for them. Additional needs, depending on the size and nature of the nursery, may include a shade house in which seedlings are pricked out, a seed store, garages for machinery, and so on. The whole nursery will need to be surrounded by a stock-proof fence or stone wall; to reduce the costs of this the shape of the nursery should be as nearly square as is practicable. Before work on constructing the nursery begins a plan should be drawn up showing where the different items are to be sited.

Water supply

Water is usually fed into the nursery from a stream, by a buried pipe or in an open channel. If possible it should first be fed into a sedimentation tank and then in plastic pipes to a storage tank, the size depending on the number of seedlings to be raised. The sedimentation tank should be about 1.5 m square by 1 m deep, lined with clay and supplied with a stone-paved overflow, with a pipe about half-way up the side to take the water to the storage tank. The walls and base of the storage tank should be made of good quality concrete, with one part of cement to two of sand and four of gravel, and should be 25 cm thick. An alternative is to build walls of brick or stone with cement mortar, 30 cm thick, and lined inside with a layer of cement mortar, made of one part of cement to three parts of sand, 2 cm thick. Tanks should be rendered inside with a skin of one part of cement to one of sand. Concrete tanks are expensive to construct and unless well-built often develop cracks and become useless. As a substitute for them, empty forty-gallon (180-litre) oil drums may be used. It is not difficult to fit hose connections or taps to these if necessary. In larger nurseries in accessible localities galvanized iron tanks can be used.

The storage tank should, if practicable, be sited at the highest part of the nursery, so water can be brought down to the beds by gravity, in channels or pipes. These channels can lead to several smaller water holes, near to the beds, to reduce the distance water needs to be carried in watering cans. Surplus water must be carefully diverted into the drainage system, to avoid the dangers of erosion. Plastic pipes should be of hard plastic, and should be buried 30 cm beneath the ground to prevent deterioration in sunlight, and damage by trampling. In large sophisticated nurseries irrigation may be by sprinklers or through perforated pipes. These will need pressure to operate them, either from pumps or from a tank well above the level of the nursery. For more details irrigation engineering manuals should be consulted.

Drainage

A drainage system may need to be constructed to prevent damage from heavy rain; this will be especially necessary on steeply sloping sites, where drains should be constructed along the top edge and sides of the nursery, and if the nursery is a large one, at intermediate levels as well. Terraces should slope very gently inwards and be given a slight fall along their length, so that the water flows to the back of the terrace and into drains. Water should be led off from drains in gently sloping channels (not more than one per cent gradient) to a place where the water can do no damage either to the nursery itself or to other land. If drains have to be laid out on sloping land, they should be stepped, that is they should be divided into lengths of gentle gradient separated by almost vertical steps faced with stone. It is important that drainage systems should be well designed, as badly located drains are one of the most serious causes of soil erosion. This can be seen along many roads in the hills of Nepal.

Beds

Beds should be 1–1.2 m wide, whether seed beds, stand-out beds for polypots, or beds for raising stumps or bare-rooted plants. This is to enable the seedlings in the centre of the bed to be weeded easily from the side. The length of the beds is relatively unimportant, though five or ten metres may be convenient. If possible the beds should be oriented from east to west to provide better shade against the midday sun. Seed beds and stand-out beds should be provided with frames on which shade can be placed; whether this is needed for beds for stumps or transplants will depend on the species being raised. There should be a path 50–60 cm wide between beds, and between the beds and the surrounding fence. This means that on terraced land the terraces should be at least 2 m wide.

Other facilities

Areas should be set aside to store the soil and sand needed for pot filling and for seed beds, and should be large enough to hold all the soil needed. Sometimes special storage bins are constructed of stone or other convenient materials. They should have three walls and be open at the front, and preferably have a thatched roof, as soil should, if possible, be stored under shade, and be protected against rain. Mycorrhizal soil should always be stored under shade. For storage of potting mixture a thatched storage shelter is desirable. This should have walls at one end, against which soil can be piled up. For a nursery producing 25,000 plants a year such a shed should be 4 m x 2.5 m. This shelter can also be used for pot filling, and for keeping germination trays.

For larger more permanent nurseries a store combined with an office will be needed; its size and design will depend on the type of nursery and the number of plants to be raised. In its simplest form it can be a one-room building constructed of local materials and fitted with shelves, a chair and a table. In larger nurseries it may include, for example, a seed store and other facilities.

In larger nurseries a shade house is very useful for such operations as filling pots, and especially for pricking out small seedlings. It should be about 2.5 m high to allow people to stand up comfortably. A simple shade house can be constructed using round poles for the framework and bamboos spaced far enough apart to give one third to a half shade for the roof. The sides should also be covered with bamboos but these can be spaced wider, say 3–4 cm apart. If there is access to a road the nursery should be designed so that vehicles can drive right into it, and be able to offload soil and sand directly into the storage area.

Construction

The land should first be cleared of all tree stumps and stones. If new terraces have to be built they should be set out using string and pegs, and the drainage network should be planned. If the terraces are to be used only for stand-out beds of polypots, disposal of the topsoil is not important; if, however, they are to be used for stump or transplant beds the topsoil should be first carefully removed from the surface of the terrace and put in a pile, and after the terrace has been made it should be replaced on the terrace surface. The outline of beds, buildings, etc. should be made using pegs and lines and then the necessary construction completed.

Types of planting stock

The following are the main types of planting stock which might be raised in nurseries in Nepal.

- Container-raised plants (plants in polypots)
- Bare-root plants
- Large ball-rooted seedlings
- 'Stumps' (root and shoot cuttings)
- Cuttings and other vegetatively propagated material

Container-raised plants

The advantage of raising seedlings in containers, such as polythene bags, is that the cylinder of soil which surrounds the plant in the nursery remains intact until, and after, the seedling is planted out in the field. Being surrounded continuously by water-containing soil the roots do not dry out during transport and planting, and the reserves of water in the soil round the roots help the plants to survive dry periods after planting, provided that these periods are not too long. Growth within the cylinder of soil is continuous, and so the shock to the plants of being uprooted from the nursery is avoided. Even when other types of nursery stock could be used successfully under favourable conditions, the use of container-raised stock reduces the risk of failure when conditions are unfavourable. They also reduce the risk of failure due to careless handling by inexperienced labour.

Other advantages are that nurseries do not need to be sited where there is good soil (though soil has to be brought in to fill the bags), the area of nursery needed to raise the plants is relatively small, and it is possible to incorporate fertilizers and insecticides within the potting mixture, to be transported to the planting site with the seedlings. Also the technique of raising plants in polypots is relatively simple and well known.

The main disadvantage of using container-raised plants is the weight of soil which has to be carried in the bags from the nursery to the planting site—an important consideration when plants have to be carried long distances by porters in *doko* (baskets on their backs). Other disadvantages are the cost of the polypots and the need for transporting soil to the nursery.

Raising plants in polythene containers has become general practice for afforestation in tropical countries, mainly because the rate of survival of seedlings is higher, especially under unfavourable conditions. The containers used in Nepal are nearly always closed polythene bags. Polythene is light, relatively cheap, easy to handle, and sufficiently durable under most conditions. Use of polythene bags has almost completely replaced other types of containers such as baskets, earthenware pots or tins.

Bare-root plants

The main advantage of bare-root plants is that they are much easier to transport than plants in containers. This is particularly important when plants have to be transported by porters. A porter using a *doko* can carry up to 100 seedlings weighing about 30 kg, whereas he could carry several hundred bare-root plants (100 bare-root plants of pine and *Schima wallichii* weigh 1.5 kg) (Fujiwara, 1982). There are also savings in planting as a man can easily carry a supply of bare-root plants in a plastic bag, and plant them as he walks along; also in some circumstances simpler planting methods, such as notch-planting, can be used.

However these advantages are greatly outweighed by the fact that, with a few exceptions, survival of bare-root plants in Nepalese plantations has been much worse than that of plants raised in polythene bags. Sometimes good results have been obtained with bare-root plants when the work has been well supervised, but when supervision has been less intensive results have been poor (Grunenfelder, 1980a). This is an important point in community forestry where much of the labour available is inexperienced and there is often little chance of skilled supervision.

Among the few species raised satisfactorily as bare-root plants are *Alnus nepalensis* and *Cryptomeria japonica*. In the southern part of Lalitpur District, on the very wet south-facing slopes of the Mahabharat Range, bare-root plants of *A. nepalensis* with the roots and stems trimmed have been supplied to farmers with successful results. This species and *Cryptomeria* have also been successfully planted as bare-root plants in Ilam District, another wet area, though only above 1500 m (Olsson, 1983). Even *A. nepalensis*, however, failed at Jiri when the plantations were not well supervised (Grunenfelder, 1980a) and again in 1983 (Neville, 1985a) despite good supervision, and this technique is no longer used there. In Solokhumbu bare-root planting of pines, *Abies, Tsuga, Betula* and *Fraxinus* 'turned out to be a failure in every case' (J. Stewart, 1984). Unless techniques for raising and handling bare-root plants, suitable for use by unskilled labour with a minimum of supervision, can be devised, the use of such plants in Nepal is not recommended, other than in the exceptional cases mentioned above.

Note: Bare-root plants have occasionally been produced by removing seedlings from the polypots in the nursery, and transporting them with naked roots to the planting site. This technique is to be strongly discouraged; trouble and expense have been incurred by raising the seedlings in polypots, and the advantages in increased survival of container-raised seedlings are lost.

Large ball-rooted seedlings

These are plants 75–150 cm tall, grown in the nursery for 15 months or longer, and lifted with a ball of soil around their roots 10–15 cm in diameter, which is usually wrapped in grass, sacking, etc. to keep it moist during transport. This is a traditional method in Europe, particularly for raising ornamental trees, but has been largely replaced by growing plants in large containers of plastic and other materials. It is still of potential value in Nepal for providing small numbers of plants of relatively valuable species (for example, valuable fodder species) to farmers and other individuals. Its advantages are that the plants have had two or three years growth in the nursery, before they are planted out in the field, and so get off to a good start, and that the greater height means that they are less liable to be browsed. The disadvantages are the long time and relatively large area needed in the nursery, weight and bulk for transport, and necessity for careful protection against drying out of the plants between the nursery and the planting site, and avoiding delay in planting.

Stumps (root and shoot cuttings)

Stumps are prepared by digging up plants from nursery beds, cutting off the stems a few centimetres above ground level, and shortening and trimming the roots. Their advantage is that they are much easier to transport than container-raised plants, but are much less subject than bare-root plants to damage by drying out or through bad handling. Their main disadvantages are that they can only be used for a limited range of species, and that growth of the plants is interrupted until they can develop new roots and shoots after being planted. However, the ease by which they can be handled and transported is a very great advantage, and the use of stump plants of certain species could be very useful in afforestation in Nepal. It is very desirable that more investigations should be made of the use of stumps.

Cuttings

The main use of cuttings and other vegetatively propagated material is when species are difficult to raise from seed, or seed is not readily available. They also have the advantage of reducing the time needed in the nursery to obtain plants large enough for planting in the field. Another advantage of cuttings is that they are genetically identical with their parent trees, so that trees of good form and vigour can be reproduced easily. They are used in Nepal mainly for *Salix* and *Populus* species and certain *Ficus* species but might be useful for other fodder species. In some countries cuttings have been used for large-scale plantations such as eucalypts in Brazil (J. Evans, 1982). This has the advantage of producing uniform plantations of trees known to have good form and high growth rates. There are possibilities of using such techniques in Nepal in large-scale industrial plantations, though a number of years of research work will be needed first. However it is unlikely that these techniques will be of much importance in community forestry work in the near future. An interesting development in this field is the successful reproduction of *Dalbergia sissoo*, using tissue culture, by the Department of Medicinal Plants in Kathmandu. This opens the way to establishment of plantations of this species from clonal material, or from seed orchards derived from selected clones. However this work is still at a relatively early stage of development.

Types of container

In Nepal the standard container for raising plants in the nursery is a polythene pot (polypot), 3 inch x 7 inch (7.5 cm x 18 cm) lay-flat, closed at the bottom and made of transparent 200 gauge polythene. When filled each pot is about 2.5 cm in diameter. Measurements have shown that such a pot has a usable volume of 300 ml and contains 300 g of soil. There are some advantages in using black polythene, as it is slower to degrade under the effects of sunlight, and also prevents the growth of algae within the pot. Especially in nurseries above 1500 m, or where seedlings have to be kept in the pots for more than a year, black polythene is preferable. However transparent polythene is more readily available, and has proved to be satisfactory in practice in most cases.

At present the pots supplied by manufacturers have eight 5-mm holes punched in them for drainage. There is evidence that this number of holes is not enough, and that 12 holes would be better. There is also a tendency for the holes to be punched too high in the pot leaving the bottom 2–3 cm undrained. In future manufacturers should be instructed to modify the pots they produce. Meanwhile if the number of holes is insufficient, or they are too far from the bottom of the pot, it is a simple matter to punch extra holes using an ordinary paper punch. Another simple technique to improve drainage is to snip off the two bottom corners of the pot with scissors, and to make an additional V-shaped cut in the centre of the bottom of the pot. Care needs to be taken that these cuts are not so large that large quantities of soil are lost when the pots are filled. In some countries tubes open at the bottom are used instead of closed pots, and have the advantage of giving better drainage and reducing root curl at the bottom of the polypots. However such bottomless tubes are difficult to fill and might lose quite a lot of soil during transport in Nepalese conditions. Thus closed containers are to be preferred.

In order to keep down the weight of soil in the pots, and hence to reduce transport and handling costs, the size of pots should be as small as possible, provided that this is consistent with satisfactory growth of the plants in the nursery and in the field. The pots used in Nepal are already quite small and reduction in their size is unlikely to give satisfactory results.

For some species, especially fodder trees, larger pots are needed, though use of such pots increases both nursery and transport costs especially when seedlings have to be transported by porters. The volume and hence the weight of soil in a pot is proportional to the square of the circumference; hence a 4 x 7 pot holds 16/9, or nearly double the weight of soil in a 3 x 7 pot. However the better growth and survival of certain species would justify the extra costs involved, particularly when only small numbers of trees are to be planted. Even larger pots could be used for some species such as walnut. For fairly large-scale afforestation work, using reasonably hardy species, the size of pot used at present gives acceptable results, though some care is needed in their use, especially in avoiding root-curl.

Potting mixtures

An important reason for the poor quality of much nursery stock raised in Nepal is the poor quality of the potting mixture. Care should be taken to collect suitable soil, and if this is not available near to the nursery it may have to be brought in from further away—an important point to consider in siting nurseries. The soil used in the potting mixture should be of the consistency of sandy loam to loam, with 40–70 per cent sand content. Soils with too high a proportion of clay drain badly, tend to cake at the surface, and may tend to impede root development. Soils which are too sandy do not retain water well, and are not only poor in nutrients themselves, but tend to lose nutrients rapidly through leaching.

Soil of a suitable texture can be recognized by taking a small quantity of soil, moistening it, and rolling it between the fingers until a roll about as thick as a pencil is obtained. The roll should then be bent in a horseshoe shape. If this is possible without the roll breaking then there is too much clay in the soil; if it is impossible to make a roll at all, there is too much sand. Another test is to fill several polythene tubes with soil and then water them. If the water lies on the surface and does not soak in rapidly there is too much clay, and if it drains out quickly when the tube is picked up there is too much sand. The ideal potting mixture should be:

- light in weight;
- homogeneous—the same through out;
- fertile, retaining nutrients well;
- slightly acid (pH 4.5–6.0);
- well-drained, but retaining sufficient water;
- sufficiently cohesive so that the root ball remains intact after the polypot is removed;
- easily obtainable.

The local forest topsoil may be satisfactory as a potting mixture without further treatment, but most Nepal soils are too heavy and need the addition of sand or compost. In particular the addition of well-rotted compost would have beneficial effects on most soils. Compost improves aeration, fertility and the ability to retain nutrients; it increases the water-holding capacity of light soils, and improves drainage of heavy ones; it increases the cohesiveness of the root ball; and reduces the weight of the soil. For preparation of compost see below. Napier and Robbins (1989) give the proportions for suitable soil mixtures as in Table 8.

Only topsoil should always be used, not subsoil, and if possible it should have a good content of humus. Any lumps should be broken up, and then the soil riddled through a 10–20 mm sieve. Topsoil should be collected and prepared during the dry season. Sand will usually be collected from a river and should be passed through a fine sieve before being used. The sand should not look dirty, as then it will contain a lot of silt. If additions such as mycorrhizal soil, and fertilizers other than those which are to be applied as a top dressing, are to be used they should be mixed into the potting mixture before the pots are filled. Insecticides needed to protect the plants against termites should also be mixed into the potting mixture; this however is only necessary in rare cases in Nepal.

Table 8—Proportions of different ingredients in potting mixtures

Topsoil	Sand	Compost	Remarks
3	1	1	For slightly infertile soils with too much clay
3	2	1	
1	2	1	
2	2	1	
3	0	1	For soils that are too sandy
4	0	1	
3	1	0	For soils with slightly too much clay
4	1	0	

The simplest way of mixing the soil is to put the ingredients, in measured quantities, on to a hard, level surface (a concrete pavement is excellent) and stir them together with a spade or shovel. The soil, sand, etc. can be measured by using any suitable container. One four-gallon kerosene tin contains about 18 litres of soil, and six such tins contain enough soil to fill 360 standard polythene pots. Mixing should be very thorough, and the whole mass should be turned over several times with the spade, until all the ingredients are thoroughly mixed. In larger nurseries a small cement mixer is very useful for mixing soil.

Soil sterilization

It is strongly desirable that the sand, or soil and sand mixture, in seed trays and seed beds should be sterilized before use. Although various chemicals such as methyl bromide and formalin can be used for soil sterilization many of these are dangerous to human beings, if carelessly handled, and their use is not recommended at the present time.

Simple methods of sterilization by heat are available. One method is to heat the moistened soil mixture in 40 gallon oil drums, cut in half, at a temperature of 100°C for 15 to 30 min, cover the mixture to prevent contamination and allow to cool. An alternative is to spread the soil in a thin layer on a sheet of metal and heat it over a fire for half an hour. The soil may be used as soon as it has cooled down, while any surplus can be stored in sealed polythene bags (K.J. White, 1979). This has the disadvantage of causing any organic matter which may be in the soil to decompose, and this decomposition often produces toxic compounds. It is however very suitable for sterilizing pure sand for use in seed trays.

Another method is to sterilize by using steam, which does not cause such high temperatures and is less likely to produce toxic compounds. As described by Herklots (1972), an empty oil drum is stood on bricks so that a fire may be lit under it. Within the drum three bricks are placed with an expanded metal disc or a perforated plate laid on them, covered with a circular piece of sacking. Water is poured into the drum to within about 5 cm of the disc. The soil mixture is put in open containers (not plastic) stacked above the disc, and the top of the drum covered with a metal plate. The fire is then lit, and the water allowed to boil for about half an hour, care being taken that the drum does not boil dry. This should bring the temperature of the soil in the containers to about 80°C. Various modifications of this method are possible. Soil which has been inoculated with mycorrhiza should not be sterilized.

Preparation of compost

Compost is produced by the decomposition of organic matter by micro-organisms, especially bacteria, in a warm, moist, aerated environment. During its production the organisms need moisture, oxygen, carbon, nitrogen and other nutrients, and at the same time they generate quite a lot of heat, which is useful in killing off weed seeds and insects.

Compost is widely used by Nepalese farmers. However they generally use it in a state which is unsuitable for forest nurseries, as it is insufficiently decomposed. While bacteria are decomposing plant material they use up large quantities of nutrients, especially nitrogen, and this is taken from the nutrients provided for the growing plants in the potting mixture. Thus the use of undecomposed compost (and of other raw vegetable materials such as rice-husks) in the potting mixture often causes nitrogen deficiency, resulting in yellowing of the leaves and poor growth. Also in undecomposed compost fungi, weeds and insects may become a problem, as not enough heat has been generated to kill them. Raw compost also is not as effective in improving the physical condition of the soil as well-rotted compost.

Almost any organic material can be used for compost, including forest litter, crop residues, weeds, household vegetable refuse, animal bedding, and dung; in fact anything which is readily available. Ban mara and other vigorous weeds are very useful in supplying a large bulk of vegetation. Some materials such as crop residues and pine needles take longer to compost than recent weed growth and litter, as they contain too much carbon in relation to nitrogen. Their decomposition can be speeded up by the addition of liquid manure, or large quantities of recent weed growth. Artificial fertilizers containing nitrogen, such as urea and ammonium sulphate, can also be used. Large material such as wheat or maize straw should be chopped up before composting.

The best time to begin making compost is during the monsoon. Compost can be made either in pits or heaps. During the monsoon heaps are preferable, as pits may become water-logged. The volume of the pit or heap should be not less than 1 m^3 or more than 4 m^3, with a height or depth not more than 1.5–2.0 m. At the bottom there should be a layer of brushwood, old branches, or rocks, on which the materials to be composted are placed. Materials with a high nitrogen content, such as farmyard manure, animal bedding, liquid manure (one part of dung to ten parts of water) and chemical fertilizers, if these are being used, should be applied in thin layers 20–30 cm apart. Also layers of a good loamy soil can be added every 20–30 cm. Layers of lime at the rate of half a kilogram per cubic metre will help to speed up the decomposition of acid materials such as pine needles. Dry materials should be wetted for a few days before starting the heap.

When a compost heap is ready it should be covered with a large polythene sheet, to prevent the compost becoming too wet during the monsoon, to conserve heat, and to prevent drying out after the monsoon. Pits should also be protected against flooding; sometimes thatched roofs can be used for this. Two to four weeks after the heap is finished it should have heated up to its maximum level, and will need to be turned. To check the temperature insert a thin metal rod into the middle of the heap. If the heap is ready the rod will be too hot to touch. Then the heap should be turned over to build a new one alongside. The heap should be inspected occasionally to check whether decomposition is taking place. If it is not remedial action should be taken as described in the Figure 5, page 174.

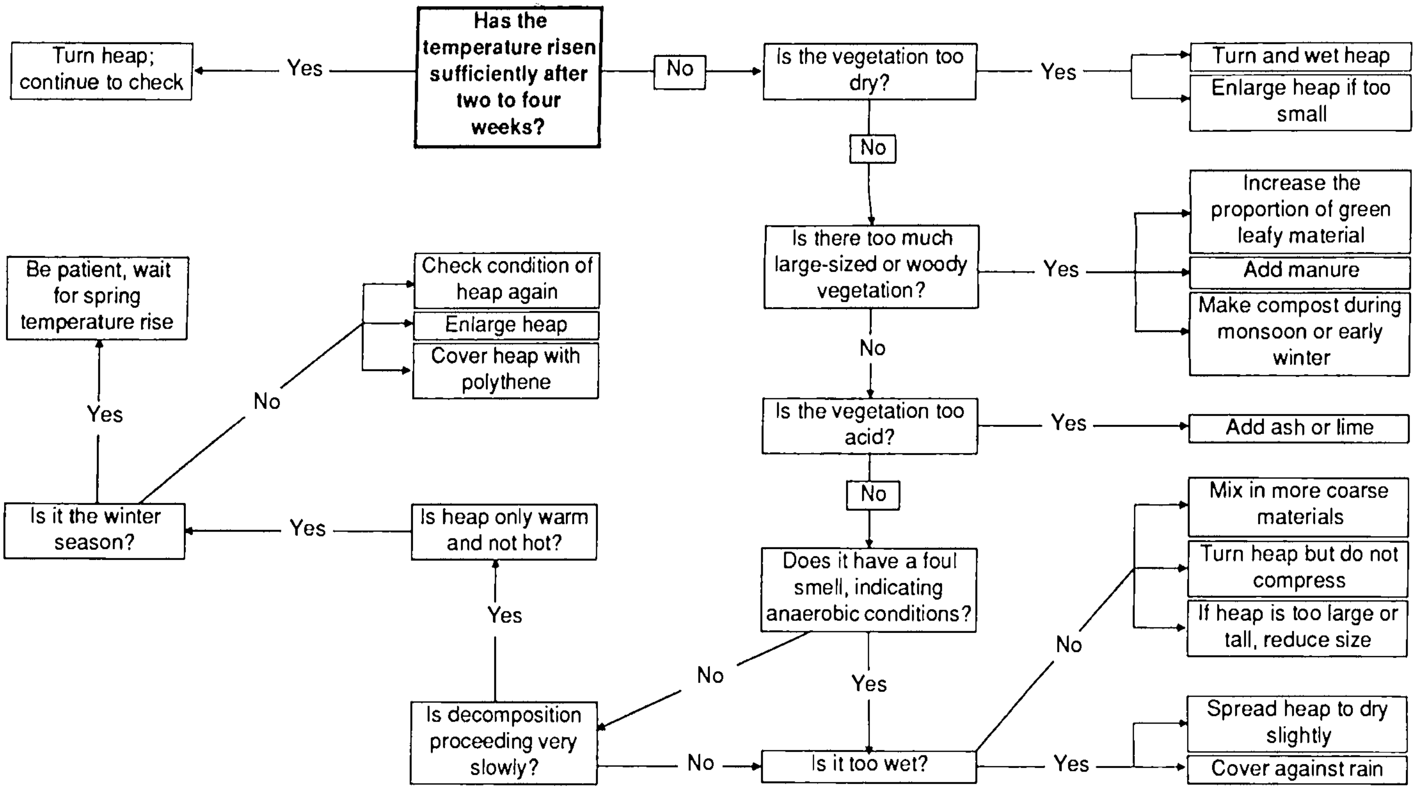
In the lowlands compost-making may take only two to three months, if correct techniques are used, but over 2000 m more than six months may be needed. When large quantities of pine needles or crop residues are included a longer period will be needed and special care must be taken.

When the compost has been made it should be sieved before it is mixed into the potting mixture. Pieces which do not pass through the sieve can be used for starting up another heap. Between 400 and 600 kg of fresh green vegetable matter, such as ban mara, will produce about 35 kg of compost. That is about 20 *doko* piled up with fresh green vegetation will produce one *doko*, rim full, of compost. One litre of compost weighs about half a kilogram.

Mycorrhiza, *Rhizobium* and other symbiotic organisms

Many if not most trees grow best if their roots are associated with certain organisms or symbionts which help in their nutrition. Very often the trees acquire these organisms naturally, but in some cases artificial inoculation is needed to ensure that the trees grow well. These symbiotic organisms fall into

Figure 5—Problem solving when making compost



three groups; fungi, which form mycorrhiza, especially on conifers, but on many other species as well; bacteria (*Rhizobium*) which form nodules on the roots of Leguminosae, and fix nitrogen; and actinomycetes, organisms in some respects intermediate between bacteria and fungi, of which *Frankia* species form nodules on the roots of *Alnus*, *Casuarina*, *Myrica* and some other genera, and which also fix nitrogen.

There are a number of strains of *Rhizobium*. Some trees can use a number of different strains, and there are also some strains of *Rhizobium* which can form nodules on a number of different species of trees. There is a good chance that a suitable strain of *Rhizobium* may occur naturally in the soil and that artificial inoculation of tree seedlings will be unnecessary, as indeed is often found in practice. It can do no harm if, for instance, when *Albizia* seedlings are being raised, some soil from beneath *Albizia* trees is added to the potting mixture; it may possibly improve growth. But it is often found possible to dispense with this procedure. *Alnus nepalensis* also appears to find *Frankia* without difficulty, and artificial inoculation is rarely practised, though again it will do no harm and may be beneficial.

One species which may require artificial inoculation with *Rhizobium* is *Leucaena leucocephala*. Suppliers of legume seeds will usually supply a peat-based inoculum which contains several strains of *Rhizobium* selected for compatibility with *Leucaena*. The seeds should be coated with it immediately before they are sown. A sticker is prepared by mixing 40 g of gum arabic in 100 ml water, and stirring in 2.4 g of calcium carbonate. The seeds are put in a plastic bag, a small quantity of sticker solution added, and the bag is swirled for about a minute until all the seeds are coated with the sticker. Then enough inoculum is added to coat the seeds. Sometimes after inoculation the seed tends to stick to the fingers; this can be avoided by mixing a little fine sand with the seed.

Many broadleaved trees have mycorrhiza, and obtain it readily without inoculation. The case of conifers, and especially of pines, is different however, and unless the local nursery soil is well infected by mycorrhiza-forming fungi, as will happen in an old nursery where pines have been grown for a number of years, artificial inoculation with mycorrhizal soil will be needed. If there is any doubt it is better to inoculate.

The symptoms of deficiency of mycorrhiza in pines include stunted growth and pale yellow colour, while the needles remain in the primary stage of single needles about 2 cm long. On examination of the roots, fungus mycelium and short, blunt-pointed, Y-shaped rootlets, signs of the presence of mycorrhiza, will not be found. (Normally these mycorrhizal rootlets should develop within two months of pricking out the seedlings.) It often happens that in a nursery bed, or among seedlings in polypots, a few trees will be dark green and growing vigorously among a mass of stunted seedlings. The vigorous trees have developed mycorrhiza; the rest have not. Given time the mycorrhiza will spread from the vigorous trees to the rest, but this may take two or three months and there is in consequence a loss of growth. The occurrence of this sort of thing often indicates that mycorrhizal inoculation has been inadequate, or that the mycorrhizal soil has not been properly mixed with the rest, but it may also be due to unsatisfactory potting mixtures.

To ensure good inoculation with mycorrhiza the soil in the potting mixture should include about one part in ten of fresh topsoil from a well-growing pine stand. The species of pine is relatively unimportant, as most of them form associations with a wide range of mycorrhizal fungi. The mycorrhizal soil should be used as soon as possible after it is collected, and should be kept moist, though not wet, and stored under shade, since many mycorrhizal fungi are killed by extremes of heat and drought. It should be well mixed in with the potting mixture.

It is also possible to add mycorrhizal soil to individual pots. The pot should be half filled with the potting mixture, and then about a tablespoon of mycorrhizal soil should be added, before the remainder of the pot is filled with the normal mixture. This ensures that each seedling has some mycorrhizal soil, but makes pot-filling slightly more complicated. If seedlings growing in pots show signs of mycorrhizal deficiency a teaspoonful of pine topsoil should be mixed with the surface soil in each pot, but this gives less satisfactory results than incorporating the pine soil into the potting mixture.

Because of the dangers of brown needle disease, pines to provide mycorrhiza should not be planted within a nursery. Mycorrhizal soil should be collected from stands in which all trees below three metres in height have been removed, and which is not less than 50 m from the nursery. All surface vegetation and litter should be removed, and only the top 25 cm of soil used. The mycorrhizal soil should be sieved before it is mixed into the potting mixture.

Filling plastic pots

Filling is done by hand, using a scoop. The potting mixture should be very slightly moist, and the pot filled by stages and the soil pressed down firmly at each stage. In Nepal, pot-filling is often done by piecework, but supervision is necessary to see that the pots are well filled, and that there are no air pockets left in the middle of the pot.

Sowing the seed directly into pots

Seed may be sown directly into the pots, or it may be sown first in seed beds or seed trays and the seedlings later pricked out into the pots. The first technique has the advantage that the labour needed for pricking out is saved, and damage to the tender young seedlings is avoided, including damage caused by root distortion. It is also commonly found that seedlings sown directly into pots take a week or so less to reach plantable size than those sown in beds and later pricked out. The disadvantages are that if seed is very light (e.g. *Alnus* and *Eucalyptus*), it is difficult to measure the correct number of seeds to be sown in each container, and unless the germination percentage of the seed is high, several seeds will need to be sown in each pot to ensure that a reasonable proportion are stocked with seedlings. Thus sowing directly into pots tends to be somewhat wasteful of seed. If several seeds are sown in each pot, some of the pots will contain more than one seedling. The surplus seedlings can be removed to fill up the empty pots, or can be pricked out and used elsewhere, but this is not altogether desirable as removal of the surplus seedlings may disturb the root system of the single seedling that is left to grow on.

Generally sowing directly into pots should be used only with fairly large seeds having a germination percentage of more than 40. An exception can be made if seed is cheap and plentiful, and the waste can be tolerated. Table 9 shows the expected results from sowing seeds of different germination percentage directly into pots. The basis for preparing this table is given in Appendix D at the end of this chapter.

Table 9—Number of seeds for sowing directly into pots

Seed germination (%)	Seeds to be sown per pot (%)	Expected empty pots (%)	Expected percentage of pots with more than one seedling (%)
Over 80	1	0–20	0
60–80	2	4–16	26–64
40–60	3	6–22	35–67
Under 40	Sow in beds or trays and prick out		

Empty pots may be filled by pricking out seedlings from pots that have more than one. It is probably better, however, to raise a small number of seedlings in beds or trays to prick out into the empty pots. It is always possible, of course, not to use the empty pots. If seed is cheap and plentiful a lower germination rate can be accepted, and more seed sown in each pot. For a 20 per cent germination rate it would be necessary to sow eight seeds in each pot to ensure that no more than 20 per cent of the pots were empty. Fruits which are sown entire and which produce several seedlings from each fruit (e.g. *Choerospondias, Melia*) should be sown in beds and the seedlings pricked out.

Pots in which seed is to be sown directly should be filled to about one centimetre from the top, so that after sowing the seed can be covered with sand. The day before the seed is sown the pots should be well watered, and a light watering should be given just before sowing. Fairly large seeds such as those of pines should be pushed into the soil until their tops are level with the soil surface; smaller seeds should be scattered over the soil surface. After sowing the seeds should be covered to no more than twice their thickness with sand or fine-sieved soil mixed with sand. Clay soils should never be used to cover the seed, as they form a crust over the surface which seedlings have difficulty in penetrating. After sowing, a mulch of straw or similar material should be spread on the surface of the pot.

After the seed has germinated the seedlings should be thinned out to one per pot. Unless the surplus seedlings are to be pricked out, this is best done by cutting the hypocotyl (the seedling stem) near the soil. It should be done before the seedlings reach 2 cm in height. The pots should be kept under shade until the seedlings have reached about 2 cm in height after which, for most species, the shade may be removed.

Sowing into seed trays or seed beds

Either trays or beds can be used for raising seedlings which are later to be pricked out into containers. Trays are preferable as they can be carried about and, for instance, be brought under shade for pricking out the seedlings. Their main disadvantage is the cost, which may be beyond the means of village nurseries. Very large seeds, such as those of *Quercus* and *Juglans*, are best sown in beds.

Trays can be made of any suitable material, including wood, plastic or metal, but whatever material is used free drainage from the bottom of the tray is essential. A suitable wooden tray is about 40 cm x 30 cm x 10 cm, with gaps between the slats at the bottom for drainage. Various types of plastic and metal trays are available; if necessary, metal trays may be improvised by cutting mustard oil or kerosene tins in half longitudinally, and punching drainage holes in the bottom. After they have been filled with soil, trays should be light enough to be carried about by one or two men.

For seedlings which are to be pricked out within a week or two of germination it is possible to use pure sterilized sand as the germination medium in the trays. The sand should be washed in a bucket or drum to remove silt. It is mixed with five times its volume of water, stirred vigorously, and the dirty water poured off. This is repeated several times until the water is clean. Washing improves the drainage of the sand and prevents surface crusting.

For species which have fairly large seeds containing adequate food reserves, such as pines, no fertilizers will normally be needed. However very small seeds such as those of eucalypts have low food reserves, and it occasionally happens that growth of the seedlings stagnates. In such cases it may be necessary to use fertilizers, if large enough seedlings are to be obtained in a reasonable time. A suggested rate of application is 10 g complexol or ammonium sulphate in 10 l of water, but this should be checked first by trying it on a few seedlings. The safest way of applying it is by sub-irrigation, standing the seed tray in a larger tray containing the fertilizer solution. If a larger tray is not available a basin can be improvised from polythene sheeting.

When seedlings need four to eight weeks in the trays before they are pricked out they will need nutrients, and a sand-soil mixture is preferable to pure sand. A rather sandier soil mixture than the one used in polypots is desirable. In many cases a mixture of 50 per cent sand and 50 per cent forest topsoil will be suitable, but this will depend on the nature of the topsoil. It is desirable that soil used in seed beds and seed trays should be sterilized before use. Compost should not be used in seed beds or seed trays.

If seed is to be raised in seed beds rather than trays it is worth the trouble to see that the beds are well made, with a good frame. If no frame is used the beds tend to erode away at the edges, and there is a danger of soil and seedlings being washed away. Seed beds should be not more than 1.2 m wide, so that they can be weeded from the side, and there is no need to step on to the bed. First a frame should be constructed, 1–1.2 m wide and 15–20 cm high; it can be as long as is convenient. The frame can be constructed of boards, bamboos, bricks stood on end and sunk about 5 cm into the ground, or stones. The bottom of the bed should be filled with a layer about 5 cm deep of gravel, small stones or broken brick, to provide drainage. This is covered with a layer of forest topsoil 2–3 cm thick, and the remainder filled with the mixture of topsoil and sand described above. The top 2 cm should be left unfilled to prevent the topsoil and seed being washed away by rain. It is very important that the surface of the bed (and of soil in seed trays) should be completely level; if there are hollows or low places water will collect in them, often carrying with it quantities of seed. Before levelling, the bed should be raked to a depth of 5 cm, and then levelled and firmed up using a heavy board. The soil should be so firm that a clenched fist pressed into the surface will leave only a slight impression.

Before sowing the seed, beds or trays should be lightly watered, so that the surface is moist, but not wet, to the touch. Small seeds are sown broadcast at a rate of about 4000 viable seeds m^{-2}. Larger seed, such as that of *Quercus* and *Castanopsis* should be sown in drills about 15 cm apart with about 2 cm between the seeds. After sowing the seed should be lightly pressed into the soil surface by using a wooden board or similar means. Then the seed should be covered lightly with fine sand. (Not necessary with large seeds such as *Quercus* and *Castanopsis* which can be merely pushed into the ground.) Immediately after the seed has been covered the soil should be given a thorough watering, enough to soak the soil but not so much that water begins to run off from the surface. This should be done by using a light spray, such as a watering can with a fine rose, or a knapsack sprayer. Watering with a heavy spray can wash out soil and seedlings. Subsequent watering should be done whenever the surface of the soil becomes dry, again by the use of a fine spray. An alternative is sub-irrigation (see Watering, page 192).

Very light seed should be handled with special care. Techniques for germinating small seeds were studied by Burslem (1988; 1989a). He found that although on the whole sand was the best germination medium, soil or soil-sand mixtures could also be used satisfactorily, provided that the material used was sieved and no clay or compost was included. The soil should be sterilized before being incorporated. The best cover for the seed was washed, sieved sand, which should be just deep enough to hide the seed from view. Sub-irrigation (see Watering, page 192) was the best method of watering, though the damage from using a coarse watering can rose could be reduced by mulching with 1 cm of rice husks; straw or newspaper mulches gave poorer results.

Enough seed should be sown to produce a density of about 4000 seedlings m^{-2}, though in experiments higher densities (up to 20,000 m^{-2}) showed no ill effects. The newly germinated seedlings should have dense shade, but exposure to full sunlight (by gradually reducing the shade) for a short time before pricking out might be desirable to harden off the seedlings. Protection against heavy rain was essential. After watering, the beds or trays should be shaded, with the shade preferably at between 18 and 30 cm above the soil level. The shade should be moderately dense, such as is provided by bamboo laths or hessian. For most species the shade should be removed after most of the seed has germinated, but for very small seedlings such as those of *Ficus* and *Alnus* the shade may need to be left until the first true leaves (those following the cotyledons) appear. Certain species benefit from having a longer period under shade; such cases are mentioned in the accounts of individual species. It is often necessary to protect seed beds and newly emerging seedlings against rodents and birds, by using wire mesh screens.

Pricking out

This is a delicate operation and should be done with great care if the very tender young seedlings are not to be damaged. The best time for pricking out for most species is when the seedlings have produced one to two pairs of true leaves in addition to the cotyledons; at this stage they will usually be 2–4 cm tall. Delaying pricking out until the seedlings are larger than this causes the risk that they will already have developed a long root which is liable to be damaged during pricking out. Pine seedlings should be pricked out soon after the seed coat has been shed from the cotyledons; in Malaysia they are pricked out at an even earlier stage, the so-called match-stick stage, while the seed coat is still adhering to the seedling.

Pricking out should be done under shade, in a well-ventilated but not windy place. One advantage in raising seedlings in trays is that the trays and the containers which will hold the young seedlings can be carried into a suitable place for pricking out. In larger nurseries a special building can be made for this purpose, with partial (about three-quarter) shade about 3 m above ground level, so that people can work under it without difficulty.

Immediately before lifting the seedlings the trays or beds should be watered lightly. The seedlings should be lifted carefully by using a flat piece of stick or a similar instrument to lever out seedlings and soil; they should not be dragged out by their roots. The seedlings should always be held by the leaves or cotyledons, and not by the stems, as holding them by the stem is very liable to damage the tender stem tissues. The time between lifting the seedlings and pricking them out into the polypots should be as short as possible, so only a few seedlings should be lifted at a time, and pricked out immediately. For very small seedlings it is useful to have a shallow bowl of water into which the roots are put immediately they have been removed from the seed bed.

To prick out the seedlings a hole is made in the soil of the container using a pointed stick a little thicker than a pencil. The hole must be deep and wide enough to contain the seedling without the roots being bent; in particular great care must be taken not to bend the taproot into a J or U shape. If the taproot is slightly too long it can be shortened by cutting it with a sharp razor blade or a pair of scissors. The seedling is then held in the hole with its root collar level with the surface of the soil, so that it is at the same depth as it was in the seed bed. The leaves should not be in contact with the soil.

The hole can then be filled by using a mixture of finely sieved soil and sand (supplies of which must be ready at the pricking-out place) or the stick used for making the hole may be dug into the soil at two places beside the seedling and gently pressed sideways until the hole is closed. Care must be taken that no pockets of air are left within the hole. Immediately after pricking out the seedlings are watered, using a fine spray, and put under shade. The soil round the roots should remain fairly moist, but not waterlogged.

Use of pre-germinated seed

This method can be regarded as intermediate between sowing seed directly into polypots, and raising seedlings in beds and pricking them out. There are various methods of pre-germinating the seed. In research nurseries in northern Nigeria pine seed was mixed with a mixture of 50 per cent sand and 50 per cent vermiculite, to which a little copper sulphate (or other appropriate fungicide) was added to prevent fungal diseases. It was then put in transparent polythene bags and kept slightly moist. Germination usually began after four or five days, after which the bags were examined daily and the germinated seed (when the radicle had appeared) removed and pricked into polythene pots. During germination the bags containing the seeds were shaded by covering them with black polythene buckets, but the amount of shade needed by germinating seed varies with the species. Pure sand can be used instead of the sand and vermiculite mixture, but gives rather poorer results (J.K. Jackson, 1974). *Dalbergia sissoo* seed has been pre-germinated in India by soaking it in water, placing it in a layer about 15 cm deep, covering it with grass or sacking, and watering it regularly (Kaushik, 1961). Similar techniques could be devised for other species that have fairly large seeds that germinate fairly rapidly.

Stand-out beds

After the seed has been sown in the pots, or the seedlings pricked out, the pots should be transferred to stand-out beds. These should again be 1–1.2 m wide, and they should be given a frame about 15 cm high so that the seedlings at the edge of the beds do not fall over. Such a frame may be made of split bamboo, wooden planking, bricks stood on end, or flat rocks such as slate. It is also possible to use two or three strands of plain galvanized wire fixed to supports and well tightened, but this is less satisfactory as it exposes the outside row of pots to the sun, which may heat up the soil so much that the seedlings are damaged. The beds should be at the level of the ground in the nursery, or ideally slightly raised above it. The base of the beds should be hard firm soil if possible; it is not necessary to use concrete for this purpose. The pots containing the seedlings should be stood upright in the stand-out beds and not placed at an angle.

Spacing in stand-out beds

If seedlings are grown in small plastic polypots, such as the 3 inch x 7 inch lay-flat container commonly used in Nepal, and are placed close together in a stand-out bed, a time will come when they will begin to compete for light. This results in the seedlings in the centre of the bed becoming etiolated, with long, thin stems. The lower leaves may be killed, and if this overcrowding continues some of the smaller seedlings may become suppressed and die. These effects may be avoided by spacing the seedlings about 5 cm apart between the rows, using bricks, wooden poles, or seedling bags filled with soil between the rows of seedlings. Spacing within the rows is not needed. If nursery space is limited spacing between pairs of rows may be used as a compromise. The seedlings should be spaced as soon as competition sets in. This will vary with the growth rate and habit of different species under different conditions. Broadleaved species such as *Ficus* will need spacing earlier than pines. Some species, such as eucalypts in the Terai, which have a very short period in the nursery, may not need spacing. If the seedlings are to be spaced out in this way, extra space will need to be provided in the nursery beds.

Root pruning

The roots of plants raised in polypots should be pruned regularly as soon as they begin to grow through the bottom of the container into the soil of the nursery bed below. As soon as the roots begin to grow out of the pots, the pots should be lifted and moved, thus breaking the roots off. This result can be supplemented by snipping off roots growing outside the pots with a pair of scissors. The frequency of root pruning will depend on the species and the rate of growth, and may vary from once a month to once a week. It is easy enough to check when root pruning is necessary by trying to lift up the plants. If there is resistance, root pruning is needed. Periodic checks are better than a rigid timetable. The most important thing is to prune the roots before long taproots have gone down into the soil below the pots. Root pruning may cause some water stress to the plants, and should be followed immediately by a good watering. During root pruning the opportunity can be taken to grade plants according to size, putting the tall ones at one end of the stand-out beds, and the smaller ones at the other. The tall plants should be the first to be planted out.

Raising bare-root transplants

Elaborate techniques have been developed in Europe and elsewhere for raising this type of plant, usually involving frequent root pruning so that the seedlings develop fibrous roots rather than taproots. These techniques require well-trained nursery staff. They have been tried on an experimental basis in Nepal, but have not yet been developed to the stage when they can be used on a large scale. For further details see Sharpe (1983b).

Simpler techniques have been found to be successful for a few species, and indeed were used widely in plantations in tropical highland areas before the use of container-raised plants became widespread. These techniques usually consist of sowing the seed in a seed bed and leaving them there until the seedlings are large enough for planting in the field; or of pricking out seedlings into beds. Sometimes these seedlings have been root pruned, and sometimes not, but at present there is little good evidence on how beneficial root pruning is. Species known to have been successfully raised by these techniques are *Alnus nepalensis* and *Cryptomeria japonica* in Ilam District. Attention needs to be paid to maintaining the fertility of beds used for raising bare-root plants, by the use of fertilizers or rotation with legumes or grass-legume mixtures.

Raising stumps

The technique of raising stumps (root and shoot cuttings) is relatively simple. The seed is either broadcast or sown in drills in the beds, or seedlings are raised in beds or trays and then pricked out. For some species, of which the seed germinates irregularly, such as teak, the use of pre-germinated seed is an advantage. Rates of sowing, or spacing after pricking out, should aim at producing between 10 and 15 cm between the plants in the bed. If the seed has been sown broadcast it may be necessary to thin the seedlings to a suitable spacing; it may be possible to prick out the surplus seedlings into other beds.

Sowing dates should be arranged so that by the planting season the seedlings are between 8 mm and 15 mm in diameter at the root collar. The plants are then lifted, and cut so that there is about 2–3 cm of stem and 20–25 cm of root left, using a sharp knife and a block of wood to cut stems and roots. Small side roots should be trimmed off. Forked, badly twisted, and undersized stumps should be thrown away.

The best time for planting stumps is during the pre-monsoon rains, when the soil at 20 cm below ground level has become moist, though once planted stumps will survive moderately long dry spells without harm. The best date of sowing to achieve plants of a suitable size by this date will vary with the species and the site. Suitable plants of a number of species, including teak and *Gmelina arborea*, can be raised by sowing the seed in beds during the rains, and lifting the stumps at the beginning of the next rains. It is not necessary to irrigate the stump beds during the dry season, if this technique is used. When raising teak stumps in Thailand it is customary to lift the seedlings and make the stumps in March, while the plants are still dormant, and to store the stumps between layers of sand in pits until the planting season. It is claimed that this gives better results than if the stumps are made when the plants are actively growing.

Beds for raising stumps should be 1.2 m wide, raised above the ground level about 25 cm, and with a well-constructed edge of bricks, stone, wood or bamboo. The soil should be similar to that used in potting mixtures, i.e. loam to sandy loam in texture. If the soil of the nursery itself is unsuitable, either soil will need to be brought in from elsewhere, or else sand mixed with the nursery soil. If the natural soil of the nursery is used it should first be hoed to a depth of 25–30 cm, and then re-hoed and raked until the surface has a fine tilth; it should then be levelled and gently firmed down. If soil is brought in, or sand is mixed with the existing soil, the subsoil of the bed should first be thoroughly hoed, and then the required mixture put in a layer 25 cm deep to fill up the bed.

As the soil in stump beds, unlike that in polypots, is not renewed every year it will be necessary to take steps to maintain soil fertility. One way of doing this is to add well-decomposed compost at the rate of one *doko* load (35 kg) per 10 m^2 of nursery bed. An alternative is to use artificial fertilizers; a suggested rate of application is 60 g of Complexol (20:20:0) plus 10 g of muriate of potash for each m^2 of nursery bed, though these quantities may need to be modified in the light of experience. Artificial fertilizers should be applied to the bed at least a week before the seed is sown. Before the fertilizer is applied the bed should be well cultivated and levelled; the fertilizer is then broadcast over the surface and lightly worked into the top 5 cm with a rake.

Another method of maintaining fertility is to allow the bed to lie fallow every other year, and growing a cover crop of a legume such as *Crotalaria juncea* which is then dug into the soil. Use of compost or fallowing will help to maintain the physical structure of the soil, as prolonged cultivation, especially under irrigation, can destroy the crumb structure.

Large ball-rooted seedlings

These seedlings will be planted out when 40 cm to 2 m tall. They are raised in open beds and usually need 18–30 months in the nursery. The nursery soil should be sufficiently cohesive to form a ball round the roots of the seedlings when they are lifted. Spacing for larger seedlings is 20–25 cm apart; for those under a metre tall 15–20 cm could be used. Frequent root pruning or transplanting is needed; in India this is usually at about six month intervals. Root pruning is performed by digging a trench in a half circle 10 cm from the plant to sever the lateral roots, and cutting the taproot at the same time; at the next pruning the trench is dug on the other side of the plant. Another method is to insert a sharp spade at an angle to cut the taproot 20–25 cm below the surface, and to lever it upwards to shatter the side roots. This method can only be used before root development is far advanced. When the plants are lifted a ball or plug 10–15 cm in diameter and 15–20 cm long is preserved round the roots. Any roots protruding beyond the ball are cut off with a sharp knife. For transport the ball is wrapped in grass, leaves or old sacking or similar material, tied firmly round it.

Raising plants by vegetative means

A number of species are commonly propagated by vegetative means. One very important group which are propagated vegetatively is the bamboos, but for these special techniques are used; see Volume 2, page 403. Vegetative methods can also be used for a number of other species; see P.M. Amatya (1982); M.W. Campbell (1983a); Napier and Robbins (1989). The advantages of using vegetative methods have been discussed previously; see Cuttings, page 168.

Hardwood cuttings

Hardwood cuttings are taken from wood of the previous season's growth, or the one before it. They are taken during the dormant season before the leaf buds begin to swell, and should be taken from healthy vigorous trees growing in full sunlight, from well-ripened branches in the lower part of the tree crown. Where cuttings are raised on a large scale, stool beds can be established in the nursery.

Cuttings should be 15–25 cm long and 0.8–2.5 cm in diameter, with at least two, and preferably four, nodes. Long thin side branches, with elongated internodes, should not be used. The top should be cut square across the shoot, about 2 cm above a bud, while the bottom of the cutting should be cut diagonally. This is to distinguish the top from the bottom, so that the cuttings are not planted upside down. Care should be taken to avoid crushing or splitting the ends, or tearing the bark. The cuttings should be prepared on the same day as the shoots are collected, and set at once into pots or beds. If polypots are used they should be at least 4 inch x 7 inch lay-flat. The soil in the pots or beds must be free draining, sandy loam or loamy sand, with at least 50 per cent sand content; this means that for most nurseries special soil must be used to fill the beds, and this soil must be 30 cm deep.

The cuttings are inserted vertically into the pots or beds so that only one bud remains above the soil level. In beds they should be 30 cm apart. The soil must be well firmed up after the cuttings have been set. Beds and pots should be well watered and shaded until roots have formed on the cuttings. New shoots will develop a few weeks after the cuttings have been set. Shade must be continued, as such shoots often develop vigorously and remove water by transpiration well before the roots are established. Once the roots have been developed the shade can be removed and root pruning begun. When cuttings in beds have taken root they can be transplanted into large polypots for transport to the field.

Branch cuttings of some species tend to retain their branch character and to grow at an angle to the ground, rather than vertically. *Dalbergia sissoo* is an example. Branch cuttings of such species should not be used when the production of a straight stem is important.

Establishment of stool beds

Stool beds should be established in nurseries where large numbers of cuttings are to be raised. The beds are prepared by cultivating the whole area to a depth of 30 cm, and digging in one *doko* (35 kg) of well-rotted compost for every 5–10 m^2. Pits for seedlings are prepared at 100 cm x 50 cm spacing. Seedlings are planted in these pits at the beginning of the rains. It should not be necessary to water the beds after the monsoon, but they should be cultivated and kept completely free from weeds. The plants are allowed to grow for two seasons (one season may be enough at altitudes below 500 m) and in February all stems are cut at 10 cm above ground level. These stems can be used for cuttings, but even if these are not needed coppice shoots should continue to be cut back in February each year. This can continue for at least five years. Two or three months after the stems have been cut back the shoots should be thinned to 4–6 per stool.

Large stem cuttings

In some species very large cuttings up to 2 m long by 8 cm thick will root by merely being planted in the ground like fence posts. This is a method which has long been used by farmers for a number of fodder species; see Robinson and KC (1990). According to them the cuttings used are between 2.5 and 13 cm in diameter, taken from branches 1–4 years old. Leaves and side branches are removed. Cuttings from young trees are best. The cuttings are planted in pits 40–100 cm deep, to which dung is added. They need support to prevent them from moving, and protection; they may need to be watered. Sometimes the cuttings are first rooted in moist soil, but they are more often planted directly. These large cuttings, besides being easy to obtain and to establish, have the advantage of escaping the period of slow growth in the first two years or so after planting, which many species show, and of being above the height when they are liable to browsing damage.

Semi-hardwood cuttings

These are taken from one-year-old wood during the monsoon. Shoots used for semi-hardwood cuttings are relatively supple and can be bent without snapping. The growing tip is usually retained. The leaves from the lower nodes should be removed, to avoid infection by pathogens when the leaves decay in contact with the soil. Upper-node leaves should be trimmed to reduce transpiration. Semi-hardwood cuttings can be made either straight, as for hardwood cuttings, mallet when a short section of the parent stem or branch remains attached to the base of the cutting, or with a heel, when the cuttings are bent away from the parent stem so that a small portion of cambium remains attached to the base of the cutting. This type of cutting has mainly been used for propagating ornamental trees.

Root cuttings

A section of the root is taken from the parent plant and placed in the soil just below the surface. The method is said to have been used successfully for *Artocarpus lakoocha*.

Layering

In this method adventitious roots are formed on the stem while it is still attached to the parent plant. There are two variations. In air layering the stem is girdled by removing a strip of bark 3–8 mm wide, and the surface scraped to ensure the removal of all phloem. The area is then covered with two or three handfuls of damp moss or similar material, and wrapped round with a strip of polythene. When the roots have grown to 1–2 cm long, usually in 4–6 weeks, the layer is cut from the parent tree and planted in a polypot. Farmers use the method for propagating some species of *Ficus*, in addition to its widespread use in horticulture. In soil layering the branches are bent down to the soil, pegged down, and covered in a layer of soil. The portion covered may be wounded to encourage root production. The soil in which the new plant is established can be in a large polypot or other container. In mound layering or stooling the parent plant is cut off just above the ground in spring, and as new shoots develop their bases are successively covered with soil. After roots have developed the rooted shoots are separated from their mother plant, and planted into pots or beds. For more details and diagrams see Napier and Robbins (1989).

Grafting

Various methods of grafting are used to propagate especially desirable varieties of fruit trees, such as walnut (okhar), jack fruit (katahar) and mango (amp). Such techniques belong to horticulture rather than forestry (except in tree breeding) and will not be discussed further here. More information can be obtained from Napier and Robbins (1989) or standard horticultural text books.

Date of sowing

The date of sowing will vary with the species and the climate of the nursery. Seed which loses its viability quickly will have to be sown as soon as possible after it has been collected, but when the seed can be stored sowing can be delayed until the best time for producing seedlings of plantable size. Some species grow very fast in the nursery and, in warm localities, may produce plantable seedlings within six weeks or less; against this slow-growing species at high altitudes may need two, or even three, years in the nursery.

The aim is usually be to produce seedlings of plantable size by the beginning of the monsoon. What size is plantable will vary with the species, but for most species plants between 20 and 30 cm tall are best. However the height of the seedling is not the only important factor; it should also have produced a good woody stem. For instance in pines the stem should be at least 4 mm in diameter. Very tall, thin, floppy seedlings are not good planting stock. Oversize seedlings are also undesirable, and seedlings should not stay in the nursery too long. If plants are kept too long in polypots the roots will tend to curl in circles round the inside of the pots, and this may cause trouble even some years after the seedlings have been planted out (Bohora and Basnet, 1983). Also oversized seedlings are likely to have an unsatisfactory root to shoot ratio.

It is occasionally possible to salvage seedlings which are growing too large. To some extent growth can be slowed down by reducing the supply of water to large plants. The shoots of plants of a few species can be cut back to about 30 cm to make a better root/shoot ratio. *Alnus nepalensis*, which tends to develop a fibrous root system rather than a long taproot, is one of these. But such measures should only be undertaken as a last resort. Oversized plants grown in polypots will often have developed a congested or severely curled root system. Such plants are better thrown away. Surplus plants left in the nursery at the end of the planting season should also be discarded or given away. If left to grow on for another year they are certain to be too large for planting.

The temperature during the cold season is also important in governing the time that plants need in the nursery. Sharpe (1984a) has gone into this question in considerable detail. He found that for most species a mean daily temperature between 16°C and 18°C was necessary to ensure speedy and high percentage germination. Also during cold periods the seedlings do not grow. The fastest growth, once seedlings have been established, is in the last few months before the monsoon when humidity and temperatures are high; and also during the monsoon itself.

Where fast-growing species are raised at lower altitudes careful timing is needed in the sowing dates, so that the seedlings are at the right size when they are planted. With species such as *Leucaena*, *Dalbergia sissoo* and eucalypts, raised in polypots, seedlings which would be the right size for planting in late June would be too big if planting was delayed until mid-July. When it fits in with the eventual size of seedling required it is preferable to sow seed in warm, dry weather. If seed is sown just before the monsoon, or during it, the small seedlings will need protection against heavy rain. If it is sown towards the end of the monsoon, or soon after it, care must be taken that the plants will be well established by the time the cold weather comes, so that they can survive the winter without damage or serious check.

It is possible to slow down the rate of growth of seedlings which are getting too big by reducing the water supply, but this requires quite a lot of judgement by the nurserymen. It is also possible to speed up growth to some extent by using fertilizers, but here there is the danger of producing weak, sappy plants which are more susceptible to damage by drought and frost. Such methods should be regarded as emergency measures, and avoided as far as possible by correct timing of operations.

Shading and shelter

There is a tendency in some of the smaller nurseries in Nepal either to use no shade or shelter at all, or to keep far too heavy shade over the beds permanently. Both practices are harmful. Shade reduces the daytime temperature of the beds or trays beneath it, and thus evaporation of water and the dangers of drying out. It makes conditions more uniform during day or night. However if left on too long it will produce etiolated plants—tall, thin, weak plants which may become yellowish for lack of sunlight. If such plants are removed from the cool humid conditions of the nursery to the much more rigorous heat and drought of plantation areas they are very likely to die.

Shade is usually needed during germination, and to protect small seedlings against heat and drought. It is also necessary, at different times of the year, for protection against heavy rain, hail and frost. Young seedlings of most species benefit from shade for two or three weeks after the seed has germinated; if there is any danger of rain, shade over germinating seed should be waterproof if possible. Newly pricked out, small seedlings similarly require shade, but usually only for a few days after pricking out. After new leaf development is seen the shade should be gradually removed by giving the plants full sunlight for a short period in the morning and afternoon, and lengthening this period daily until no shade is required. This may take one or two weeks.

The amount of shade needed will vary with the species of tree and also with the weather, as obviously shade is more essential during very hot, dry spells than in cool, cloudy weather. If overused in cool, humid weather it may cause damping-off. Shade to protect seedlings against frost, hail, and heavy rain should not be used when these conditions are absent, except as a precaution at night or when staff are absent. It is essential that shade should be movable and it should therefore be in sections not more than 2 m long which one man can shift, or else be capable of being rolled up. To protect seedlings against the sun it is better if shade is not complete, that is there should be gaps in it through which some sunlight can penetrate, or it should be of a material which is not quite opaque to light.

Suitable forms of shade include wooden or bamboo slats (these have the advantage that the distance between them can be varied, to vary the amount of light reaching the plants, or they can be closed up completely to protect against hail), woven split bamboo or nigalo mats, bamboos either split or whole tied together with string so that they can be rolled up, or such materials as hessian from old gunny bags stretched on to a frame. A cheap temporary shade can be made from maize stalks tied together so that they can be rolled up. Shades of straw, grass or leaves are less satisfactory; if they are thick enough to protect against hail they cast too dense a shade. Shade over seed beds and newly pricked-out seedlings should be about 30 cm above ground level. To protect larger seedlings against hail, hot sun, etc. it can be higher, up to 75 cm. If the beds are aligned east and west, it is useful if the shade slopes downwards from north to south, as this will give better protection against the midday sun, and the slope will help to shed excess water.

A method of constructing frames for shade, so that the height of the shade is adjustable, was used in the KHARDEP project in eastern Nepal (A. Greaves, pers. comm.). Large-diameter bamboos were used for the vertical supports at the corners of the beds, and in each of these holes were cut, parallel to the width of the bed at the desired heights. A smaller diameter bamboo was run through the pairs of holes at each end of the bed. Two other small diameter bamboos rested on these end supports and ran parallel to the length of the bed, and on these in turn short, easily handled bamboo shade mats were placed. The holes in the bamboos at the ends of the beds should be aligned so that the shade slopes slightly to the south. The use of pairs of holes at different levels enables the shade to be adjusted rapidly from say 30 cm to 60 cm above ground level.

For protection against frost the shades should be as close to the top of the seedlings as possible. During winter, in areas liable to frost, shade should be put over the seedlings every day when the labourers leave their work in the afternoon, and removed in the morning as soon as the frost has gone. In areas liable to hail storms the nursery labourers should put shade over the seedlings as soon as threatening thunder clouds appear, which is usually in the late afternoon. If the nursery has to be left unattended for any reason protection against hail should be left over the seedlings at periods of the year when hail may be expected. In areas subject to hot, drying winds additional protection may be needed during the hot season, consisting of mats or other shade placed vertically against the beds on their windward side. The harmful effects of such winds can also be reduced by planting a hedge round the nursery.

Cloches

In nurseries at high altitudes, during the winter, cold can severely slow down the growth of seedlings. This can be mitigated to some extent by erecting cloches of clear plastic over the seed beds or seedlings sown directly into polypots. Such cloches can be simply made from plastic sheets supported by arched split bamboo. They should be kept under shade even in winter, otherwise the greenhouse effect can cause temperatures to reach harmfully high levels. If the purpose of the cloche is to protect against low night temperatures they should be opened during the day, otherwise very high humidities also develop. For raising cuttings high humidities may be needed and the cloches should be kept closed but care still needs to be taken that temperatures do not rise too high. The use of tents made of transparent polythene has been found very useful in a number of nurseries for accelerating the growth of seedlings; again care needs to be taken to avoid overheating through the greenhouse effect.

Watering

In large nurseries it will usually be economical to install spray irrigation equipment. There are various types including rotary sprinklers, rotating or fixed aluminium spray lines, or perforated plastic piping with spray nozzles at intervals. The last is a relatively cheap method and is simple to operate. For raising large numbers of small seedlings mist spray equipment is useful. All spray equipment needs a certain pressure of water to operate it; details can be obtained from the manufacturers. In most nurseries in Nepal it will be necessary to rely on the use of watering cans, supplemented by the use of hosepipes if the water pressure is high enough, such as from a storage tank above the level of the nursery beds. A hosepipe fitted with a fine rose can be used for watering the seedlings directly, but care must be taken to ensure uniform application, and to avoid washing out seedlings by using too high a pressure. Hoses are also useful for filling watering cans.

It is very important that the roses for both watering cans and hoses should have small holes so that they to produce a fine spray, not the large droplets produced by the home-made watering cans so often used in Nepal. An Indian make of a fine rose is available in Kathmandu, and the extra cost of a good rose is well justified by the reduction of damage to seedlings caused by heavy watering with a coarse spray. If watering cans and hoses fitted with good roses are available the spray should be directed upwards so that it can arch over and fall on the plants under the influence of gravity. In particular the strong jet of a hosepipe should never be directed straight at the seedlings as it may wash them out of the soil. If all that is available is a locally made watering can with large holes in the rose it should be held as close to the plants as possible during watering, while damage to the seedlings can be considerably reduced by covering the surface of the soil by rice bran mulch 1 cm thick. For watering very small seedlings the type of knapsack sprayer used for applying insecticides is very useful, with the jet set to produce a fine mist. A flit-gun can be used in the same way.

However a superior method for watering very small seed is sub-irrigation. For this two trays are needed, a smaller one to contain soil and seed, and a larger one for water. The smaller tray can be made from half of a cooking oil or motor oil tin, with holes made in the base to allow water to enter it. This is placed in the larger tray, which is filled either with water, or sand kept very wet. Water from the large tray passes through the holes in the base of the smaller tray, to water the seedlings from below. Water is poured on to a stone put in one corner of the larger tray, to prevent the seed tray from being undermined. Details and illustrations can be seen in Burslem (1989a).

Watering should not be on a fixed schedule, but be arranged according to the needs of the plants. Soil in seed beds, seed trays, and polypots should be kept moist but never be saturated; this may need frequent light watering, sometimes twice or more each day. Plants which have begun to grow after pricking out will usually need watering once a day, in the evenings; in very dry, hot conditions watering twice daily may be needed. If seedlings are growing too quickly the amount of water should be reduced, and it should be also be reduced about four weeks before the seedlings are planted in the field, in order to harden them off, unless the seedlings are to stay a very short time, say six weeks or less, in the nursery.

In beds the amount of water applied should be enough to wet the soil to a depth of 20–25 cm, and in pots, to wet all the soil in the pot, so that it is moist but not so wet that water can be squeezed out of it by hand pressure. Watering should be done early in the morning or late in the afternoon rather than in the middle of the day. Weed, lichen and moss growth on the soil surface hinders water infiltration, as does the formation of a surface crust. Thus the surface should be kept free of weeds, and any crust formed broken up.

In raising seedlings in beds, especially when the seed is small, the bed should be thoroughly watered after the seed is sown and covered with a layer of sand. If the bed is thereafter kept under low shade (30 cm) no more watering may be needed until the seed germinates. As long as the surface of the bed feels moist to the touch there is enough water. As soon as puddles of water begin to form on the surface of the soil watering should stop. If necessary it can be resumed after the water has soaked in. Before small seed is sown in plastic or metal trays, the soil in the trays can be watered by immersing the whole tray in water, and allowing the soil to get water by capillary action.

In nurseries on level ground, where an abundant supply of water is available, flood or capillary irrigation may be used to water plants grown in beds, especially stumps or bare-root plants. Water is distributed to the beds through a canal from the water source, which must be above the level of the beds, and from this into a series of smaller canals, and eventually to the beds. The smaller canals should usually be 10–20 cm deep and 10–40 cm wide, with a gradient not exceeding two per cent to reduce erosion dangers. Irrigation may be capillary, in which the canals are built below the level of the beds, about a metre apart, and kept full, so that water moves into the beds from beneath; or by flooding, in which water from the canals is flooded on to the surface of the beds. Another method is to make small ridges across the beds, on which the plants are raised, and to irrigate by letting water into the furrows between the ridges.

These types of irrigation need well-planned bed and canal systems, and large quantities of water. Flood irrigation in particular can damage the plants by depositing silt on them, and may block up the pores in the soil surface to form a hard crust. If continued for long periods it tends to destroy the structure of the soil; it also tends to increase the spread of fungal diseases. None of these types of irrigation is likely to become important in small nurseries in Nepal.

In general it should be emphasized that overwatering can do as much damage as underwatering. If the roots of a seedling are continually in wet soil they will eventually die. Also overwatering is very conducive to damping-off and other fungus disease. Proper watering can only be learned by experience. A good nurseryman will know how often and how heavily to water; a poor or inexperienced one will not.

Weeding

Nurseries should be kept free of weeds, not only in the pots and beds, but also on paths and surrounding areas, as weeds growing in these areas are not only sources of seed but also may harbour insect pests and disease organisms. Frequent weeding, removing the weeds before they are strongly developed, saves time in the long run. Removal of small weeds complete with roots is easy, and danger of damage to tree seedlings is greatly reduced. Weeding of plants in seed beds, seed trays and polypots is done by hand; in practice if the soil mixture in seed beds and seed trays is reasonably free of weed seed, particularly if it has been sterilized, little weeding should be necessary. Before beds or pots are weeded they should be watered. Weeding of plants in polypots should be done with great care so as not to disturb the roots of the tree seedlings. Sometimes a growth of algae, moss or lichens develops on the surface of the soil, and reduces penetration by water and air. This should be prevented by stirring up the soil surface with a small stick; this also breaks up any soil crust which may have formed. If plants in stumps beds are laid out in lines, a narrow bladed hoe or *chuchche* can be used for weeding between the lines, but this may need to be supplemented by hand weeding near the plants. Paths and other open places can be weeded by *kodali*. Chemical weedkillers are unlikely to be used on a large scale in Nepal nurseries in the near future.

Use of fertilizers, composts and manures

There has been some reluctance to use artificial fertilizers in nurseries in Nepal, partly on grounds of cost and the difficulty of transporting materials to remote nurseries which can only be reached on foot. However these difficulties have been exaggerated. According to figures given in Sharpe (1984b) the total cost of fertilizers needed to raise 20,000 plants would be about 12 rupees, and the weight of fertilizer to be transported would be 5 kg. These quantities are almost negligible.

In many cases it has been found that the use of chemical fertilizers is unnecessary. In the large nursery at Sagarnath, where up to a million seedlings were raised annually, no artificial fertilizers were used. In smaller nurseries an alternative to the use of fertilizers may be to keep the plants rather longer in the nursery. Nevertheless there may be occasions when use of fertilizers would be desirable, to shorten time in the nursery and to provide nutrients not readily available in local soils. One difficulty is lack of experience and trials in Nepal. The need for different types of fertilizer varies not only with the soil type, and the species of tree grown, but also the climate. In most countries pines have responded to fertilizers containing phosphorus, but response to nitrogen has varied considerably, from no response (or even a negative response) to considerable improvement in growth. This shows that it is dangerous to generalize, and that trials using a number of species and soil types are necessary before sound prescriptions on fertilizer use can be drawn up.

The nutrients required by plants in large quantities, the so-called macronutrients, are nitrogen (N), phosphorus (P) and potassium (K). Other elements, the so-called micronutrients, are needed in much smaller quantities. Up to the present no instance is known of deficiency in micronutrients in forest nurseries in Nepal; hence only macronutrients will be considered here. The fertilizers available in Nepal are listed in Table 10. The nutrient content of commercial fertilizers is usually given in the form of 15:15:15, indicating a content equivalent to 15 per cent nitrogen, 15 per cent phosphorus pentoxide, P_2O_5, and 15 per cent of potassium oxide, K_2O. P_2O_5 contains approximately 44 per cent of elemental phosphorus, and K_2O contains 83 per cent of elemental potassium; thus a 15:15:15 fertilizer contains approximately 15 per cent nitrogen, 6.6 per cent of phosphorus and 12.5 per cent potassium.

Table 10—Composition of fertilizers available in Nepal

Commercial name	Chemical formula	N (%)	P_2O_5 (P) (%)	K_2O (K) (%)
Sulphate of ammonia	$(NH_4)_2SO_4$	21	0	0
Urea	$CO(NH_2)$	46	0	0
Triple superphosphate	$CaH(PO_3)$ + impurities	0	48 (21)	0
Muriate of potash	KCl	0	0	60 (49)
Complexol	(Unknown)	20	20 (9)	0
Diammonium phosphate	$(NH_4)_2HPO_3$	18	46 (20)	0

Nitrogen is the element shortage which is most likely to limit growth of seedlings. Severe deficiency causes yellowing of the leaves and stunted growth. If deficiency is apparent, or seedlings need a boost, nitrogen fertilizer should be applied in solution: 20–30 g of ammonium sulphate, complexol or diammonium phosphate should be dissolved in 5 l water, and put on with a watering can. This quantity is enough for 500 plants in polypots; if the plants have been spaced, it should be applied to the area which would have been occupied by 500 unspaced plants. Immediately after the solution has been watered on the plants should be washed with 5 l water to remove any fertilizer still remaining on the leaves. Nitrogen fertilizer will usually need to be applied only once or twice during the growing season, and should not be used within six weeks of the planting date. Too much nitrogen can cause the plants to become too tall, with soft stems. Such plants often die when they are exposed to the harsher conditions of the plantation.

Phosphorus is necessary for good growth of roots; symptoms of deficiency include stunted growth and often purplish discoloration of the leaves. Phosphate fertilizers are somewhat difficult to dissolve in water, and rather than being watered on they should be dug into the bed or mixed with the potting mixture. In beds for stumps or bare-root plants triple superphosphate or diammonium phosphate is broadcast on the soil at the rate of 500 g 10 m^{-2}, and dug into the top 20 cm of the bed. For polypots the simplest method is to put the fertilizer into each individual pot while the pots are being filled. The pot is about half filled with the potting mixture, a pinch (the quantity that can be held between the thumb and the forefinger) of fertilizer added, and then the pot filled up. This is very crude and imprecise but excess superphosphate is unlikely to harm the plant. The method should only be used for superphosphate and not for other types of fertilizer. Potassium deficiency is rare in Nepal; if it has to be corrected 5–10 g of potassium chloride (muriate of potash) should be added to the nitrogen solution.

If fertilizers are to be used in small nurseries with unskilled supervision it is necessary to translate the quantities into measures which will be more easily understood. For example 200 g of fertilizer m^{-2} is equivalent to about 70 g per thousand plants, or about 3.5 g per *doko* load or kerosene tin of soil. The necessary quantities of fertilizer per unit could be prepared in a central office and distributed in small labelled packets, or measures (small tins, empty photo film containers, etc.) could be calibrated to hold fertilizers in the required amounts.

Composts, and animal fertilizers such as cow dung, contain relatively small amounts of mineral nutrients. Farmyard manure as used in Europe generally can contain about two per cent N, and 0.5 per cent P_20_5. The main advantage of using organic manures is to improve the physical structure of the soil. The preparation of compost and its use in potting mixtures has been described previously.

Sometimes the acidity of the soil may need to be amended, especially for conifers, most of which prefer a pH of 5.5 or less. Some Nepalese soils have a rather high pH; for instance Bagmati sand has a pH of 8.4. It is recommended that the pH of soils for nurseries should be tested before use, and that soils with a high pH should not be used in pine nurseries. If there is no alternative it is possible to reduce pH by adding dilute sulphuric acid (1:1000) or sulphur to the soil, or by heavy fertilization with ammonium sulphate.

Nursery diseases and pests

Fungus diseases

The most serious group of diseases affecting seedlings in nurseries in Nepal is damping-off. This is caused by a wide range of fungi, including species of

Pythium, *Phytophthora*, *Fusarium* and *Rhizoctonia*. There are two types. Pre-emergence damping-off attacks the seed, causing the radicle to rot before the shoot emerges from the soil. It can easily be confused with poor germination due to other causes. In post-emergence damping-off the tissues of the seedling stem are attacked at ground level, causing the seedling to fall over, shrivel and dry. This can be confused with damage to seedlings caused by heavy rain, or by watering with a spray which is too coarse, but the characteristic collapse of the stem tissues causing a thinning of the stem at ground level will distinguish it. Once post-emergence damping-off has occurred it will spread very rapidly, leaving patches of dead seedlings with the most recently killed at the edge of the patch. Should this be seen control measures must be taken immediately, as otherwise all the plants in a seed bed can be killed within 48 hours.

Another disorder caused by the same fungi that cause damping-off is root rot, which usually affects rather older seedlings. The leaves of the seedlings become yellowish, usually from the top of the stem downwards, and this is followed by wilting, discoloration and death of the shoot. When the seedling roots are examined they will be found to be soft and rotten or already dead. Root rot can be caused by other factors than damping-off fungi, such as shortage of nutrients, too much or too little water, and damage by insects or nematodes.

The best way to control damping-off is to prevent its occurrence through correct cultural methods. The damping-off fungi thrive in warm, humid and shady conditions, and in the presence of organic material. Thus damping-off can be considerably reduced and often eliminated by not overwatering, by removal of shade from seedlings as soon as they will tolerate exposure to sunlight, and by avoiding the use of organic material in the potting mixture unless it is sterilized. Nursery beds should be open to a free circulation of air, without exposing the plants to strong winds. Seed should not be sown too densely in beds or trays. If possible seed should be sown in the dry season, using a well-drained sandy germination medium. Damage caused to young seedlings by bruising the stems during pricking out, and by planting them too deeply, will increase the danger of damping-off. If seed can be sown directly into polypots, rather than seedlings being pricked out, dangers of damping-off will be reduced. A soil with a high pH value will tend to encourage damping-off. If pines are to be grown in a soil with a pH greater than six, it may be necessary to acidify it (see previous section).

If damping-off does occur despite these precautions measures to control it must be taken urgently. Shade should be removed, and watering reduced to just enough to keep the seedlings alive. All dead and diseased seedlings must be removed and burnt. If the materials are available the plants and beds should be watered with a fungicide such as Blitox or Dithane 45, at the rate of 5 g l^{-1} of water twice a week until the disease has disappeared. To prevent damping-off in large-scale production of eucalypt seedlings the following measures have been undertaken: the soil in seed trays is sterilized, and protected to ensure that it is not contaminated by air-borne spores; only sterilized water is used for watering (treated by Cuprox at 3 g l^{-1}); all vessels, tools and equipment used in handling small seedlings are also sterilized; and sterilized water is always at hand with which to wash hands, equipment, etc. (K.J. White, 1979). Such elaborate precautions will not be possible in a small village nursery but they indicate the importance of doing everything possible to prevent damping-off.

One other serious fungal disease in Nepal is brown needle disease (*Cercoseptaria*) of pines, which not only causes damage in the nursery, but also causes numerous deaths when the pines are planted in the field. Measures to control it are given in the section on *Pinus* species (see Volume 2).

So far no other really serious fungal disease has been found in Nepal nurseries. Good nursery hygiene can greatly reduce the dangers of disease. This includes immediate removal and burning of all seedlings which are diseased, from whatever cause. Pots in which seedlings have died should not be used for other seedlings, as the deaths may have been caused by disease organisms. The nursery should be kept free from weeds as quite often these weeds act as alternate hosts to tree diseases. Too much water and too much shade also increase the danger of fungal diseases.

Insect pests

White grubs are a serious pest in some nurseries. These are the larvae of beetles of the subfamily Melolonthinae including cockchafers and their allies, and are particularly damaging to plants raised in beds. The larvae are thick and white, and usually C-shaped; they pass the winter deep in the soil and come up to feed nearer the surface in spring, eating the roots of plants which then wilt and die. They are most commonly found in open beds, as sieving the potting mixture usually eliminates them from polypots. They can be controlled by applying Gamma BHC dust at the rate of 1–2 g m^{-2} and digging this into the top 10 cm of the soil. However Gamma BHC is a persistent organochloride, and the use of these substances is becoming more and more restricted. Other soil insecticides such as bromophos are effective, but may be difficult to obtain in Nepal. Watering on a solution of malathion is effective, but malathion is prohibited in India (though permitted in Europe) and may also be difficult to obtain in Nepal.

Insects eating the leaves and stems of young seedlings can be a problem. When the insects are large, such as caterpillars (larvae of moths and sawflies) they can be picked off by hand. Chemical control can be effected by use of insecticides containing methyl parathion, such as Metacid and Paramar. One millilitre of the insecticide should be mixed with two litres of water, and applied with a sprayer (a flit-gun can be used), or in a watering can with a fine rose. The addition of 2 ml of a sticker, such as Triton AE, to the solution will help the insecticide to stick to the leaves and stems of the seedlings, and thus make it effective for a longer time.

Crickets and grasshoppers are sometimes a problem, especially such species as the mole crickets which live underground, and come out at night to cut off young seedlings at ground level and take them into their burrows to feed on. If their burrows are seen the insects should be dug up and destroyed. Other harmful crickets and grasshoppers lay their eggs in the soil in later summer and autumn, and the nymphs emerge in the spring. They can be reduced in a nursery by regular cultivation in winter to a depth of about 10 cm, which will bring the eggs to the surface where they will die. All land not under regular cultivation including paths and empty spaces should be treated in this way. Application of Metacid as described above will also help in control. If the infestation of crickets or grasshoppers is severe the insecticides should be sprayed not only on the nursery beds, but on all grassy patches and waste ground within the nursery. Wire cages to protect plants against birds and small mammals will also help to keep out crickets, except those that live underground.

Birds and mammals

Considerable losses can be caused in nurseries by small rodents and birds. The only practicable means of protection is to enclose seed beds in cages made from fine wire mesh, digging the edges of the mesh into the soil. Use of such cages in research nurseries increased the number of seedlings produced by over 80 per cent (Sharpe, 1983c). This effect was due not only to protection against rodents, but also to keeping out crickets and similar insects. Domestic animals can cause a great deal of damage in nurseries, and this does not apply only to grazing animals such as cattle, buffaloes and sheep. Dogs lying on seed beds can flatten large numbers of seedlings, and chickens can cause much damage by eating seed and scratching up beds. All domestic animals should be rigorously excluded.

Preparing plants for the plantation

Hardening off

Plants in a nursery should be growing under ideal conditions, with enough water, shade when needed, and protection against competition from weeds. In the plantation they will be exposed to much more difficult conditions, and if the transition from nursery to plantation conditions is too abrupt, the seedlings may suffer. To make this transition a gradual process known as hardening off is used. This consists of removal of shade, well before (usually several weeks) the seedlings are planted out, spacing, root pruning, discontinuing the use of fertilizers and reduction of watering. The aim should be to produce rather stiff, woody seedlings with firm leaves, rather than floppy seedlings with soft fleshy leaves.

Culling

Before seedlings are sent to the field they should be sorted according to size, and all weak, diseased, undersized or badly formed plants should be culled and thrown away. Overgrown plants should also be discarded. Culling should be done quite ruthlessly, and it should not be considered at all abnormal to discard 20 per cent of the nursery stock; if the nursery stock is of poor quality even more may have to be thrown out. Planting out poor stock does not save money, but wastes it. If plants are so poor that they are going to die after they have been planted in the field it is better to destroy them in the nursery. This will at least save the cost of planting them, and also of the replanting which will later have to be done. All seedlings and stumps not meeting the following criteria should be burnt.

Seedlings suitable for plantation should be:

- 20–30 cm in height, to the base of the newest leaf or bud;
- have stems well lignified for at least half their length;
- have straight, undamaged, unforked stems;
- have a root collar diameter of over 4 mm;
- be of a healthy deep green colour;
- be quite free of insects or fungal disease.

Stumps should:

- have a root-collar diameter between 7 and 20 mm, and a root diameter of at least 7 cm;
- not have forked roots or stems;
- be undamaged and straight;
- be free from pests and diseases.

Watering before transport

Plants in polypots should be well watered two or three days before they are to be transplanted to the field, and again lightly watered the evening before. They should not be watered heavily immediately on the day of transport. Wet soil subject to vibrations and jolts caused by mechanical transport on rough roads tends to disintegrate, until at the end of the journey the seedlings are sitting in a sort of slurry of wet soil. Plants carried by porters will not be jolted quite as much, but very wet soil is undesirable. So soil before transport should be moist but not wet; there should be enough water to enable the seedling to withstand a dry period after planting, but not so much that the soil loses cohesion round the roots of the plant. Transport of plants to the plantation is dealt with in the next chapter.

Plans and records

Keeping good nursery records is most important. The person in charge may think he can remember what has been done, what species have been raised, where the seed came from, and so on, but memories can be fallible, and also people move. So essential information should be written down systematically. The Community Forestry Development Division, assisted by the Community Forestry Development Project, has prepared a form in Nepali for a Nursery Register at the user group level. A translation is appended (see Appendix E, page 206). For use with this register all beds should be numbered. It could be modified for use with different programmes, and additional information, such as size of polypot, details of potting mixture, dates of spacing and pruning, and explanation of any mishaps (damping-off, insect damage, etc.) included as needed.

Another register should record plant distribution. A possible example is appended (see page 206). A seed register as described in the previous chapter should also be kept. Naturally these registers can be modified to meet individual needs. In addition to numbering the nursery beds it is also important that seedlings and transplants at all stages should be labelled. These labels should include the name (preferably both local and scientific), serial number in the seed register, date of sowing, and date of pricking out, as a minimum. An example of a label in Nepali is given in the list of flipchart figures appended to Hocking (1983). Each nursery should have a simple plan of operations, see example, Appendix E, page 207. Among the headings to be included are the following.

- Species
- Number of plants needed
- Type of plant needed (polypot, stumps etc.)
- Number to be raised, allowing for failures and culling
- Amount of seed needed
- Date to be ordered or collected
- Date to be sown

- Date to be pricked out
- Requirements in materials, and dates these should be ordered, if not available locally, (a) polypots (by size); (b) soil; (c) compost; (d) other materials

Notes: Number of plants to be raised should include at least 25 per cent allowance for failures and culling; thus if 4000 seedlings are needed for planting, 5000 should be raised. The amount of seed is obtained by dividing the number of plants to be raised by the number of seeds per kilogram (or gram) and again dividing by the expected plant percentage. Thus if 5000 plants are to be raised, there are 25,000 seed kg^{-1}, and, from experience, it is known that 50 per cent of the seed will produce seedlings, the amount of seed required is 5000 / 25000 / 0.50 = 0.4 kg = 400 g. If the plant percentage is unknown, it should be assumed to be 0.25. Thus the numbers of seeds to be supplied should be four times the numbers of plants to be raised. Always allow a little extra for unexpected failures. Space should be provided to record the dates the operations (ordering of seed, sowing, etc.) were actually carried out.

References: The most useful work on nurseries is Napier and Robbins (1989) referred to at the beginning of this chapter. Others are as follows. General: Champion and Seth (1968b); J. Evans (1982); Laurie (1974); Suri and Seth (1959) (rather old-fashioned). Nepal: Applegate (1983); Burslem (1988; 1989a); M.W. Campbell (1983a); Drew (1976); P.T. Evans and Joshi (1989); Hocking (1983); Kessler (1981); Mather (1974) (eucalypts); Neville (1987b) (acacias); Panday (1979) (fodder trees); A.V. Parajuli (1988) (cuttings); Robinson and Thompson (1989); Sharpe (1981a; 1981b; 1981c; 1982; 1983a; 1983b; 1984a; 1984b; 1984c); K.B. Shrestha *et al.* (n.d.); Westwood (1985 (fertilizers); 1986; 1987); K.J. White (1988c) (large-scale nurseries).

Appendix D

Number of seeds to be sown per pot

The mathematical probabilities of obtaining 0, 1, 2, etc. seedlings per pot with seed of known germination capacity can be calculated from the expansion of the binomial expression:

p = proportion of seeds germinating (= germination percentage/100)
q = proportion not germinating (= 1-p)
n = number sown in each pot

Successive terms in the binomial expansion of $(q + p)^n$ give the expected number of pots with 0, 1, 2, ... n seedlings. Then if p = 0.4 (40 per cent germination) and n = 3

$$(q + p)^n = q^3 + n(pq^2) + n(p^2q) + p^3$$
$$= 0.6^3 + 3(0.4\ (0.6)^2) + 3((0.4)^2\ 0.6) + 0.4^3$$
$$= 0.216 + 0.432 + 0.288 + 0.064$$

Thus approximately 22 per cent, 43 per cent, 29 per cent and six per cent of the pots will have 0, 1, 2, and 3 seedlings respectively. Table 11 is derived from this.

Table 11—Effect of sowing different numbers of seeds in containers

Germination percentage (%)	Seeds sown per pot	Percentage pots with following number of seedlings (%)						Percentage pots with 1 or more seedlings (%)	Pots stocked per 1000 seeds (no pricking out)	Number of seedlings per 100 seeds needed to fill empty pots	Surplus seedlings per 1000 seeds
		0	1	2	3	4	over 4				
80	1	20	80	—	—	—	—	80	800	—	—
	2	4	32	64	—	—	—	96	480	20	300
70	1	30	70	—	—	—	—	70	700	—	—
	2	9	42	49	—	—	—	91	455	45	200
60	1	40	60	—	—	—	—	60	600	—	—
	2	16	48	26	—	—	—	84	420	80	100
	3	6	29	43	22	—	—	94	312	21	267
50	1	50	50	—	—	—	—	50	500	—	—
	2	25	50	25	—	—	—	75	375	125	0
	3	12	38	38	12	—	—	88	293	40	167
	4	6	25	38	25	6	—	94	234	15	250
40	1	60	40	—	—	—	—	40	400	—	—
	2	36	48	16	—	—	—	64	320	80	-100
	3	22	43	29	6	—	—	78	260	73	67
	4	13	35	35	15	2	—	87	218	32	150
	5	8	26	35	23	17	10	92	184	16	2
30	1	70	30	—	—	—	—	30	300	—	—
	2	49	42	9	—	—	—	51	255	45	-200
	3	34	44	19	3	—	—	66	220	81	-33
	4	24	41	26	8	1	—	76	190	60	50
	5	17	36	31	13	3	0.2	83	166	34	100
	6	12	30	32	8	6	2	98	163	4	133
20	1	80	20	—	—	—	—	20	200	—	—
	2	64	32	4	—	—	—	36	180	20	-300
	3	51	38	10	1	—	—	49	163	39	-133
	4	41	41	15	3	0.2	—	59	148	53	-49
	5	33	41	21	5	1	0.03	67	134	66	0
	6	26	39	25	8	1	0.2	74	123	44	33
	7	21	37	28	12	2	0.5	79	113	30	53
	8	17	34	29	15	5	0.1	83	104	21	75

Appendix E

Examples of registers

Nursery Register

(1) Species . . . .
(2) Seed sources . . . .
(3) Sowing date and bed no. . . . .
(4) Pretreatment . . . .
(5) Quantity of seed sown or number of seeds . . . .
(6) Date of germination . . . .
(7) Number of plants pricked out from bed to bags . . . .
(8) Germination percentage . . . .
(9) Date pricked out and bed number . . . .
(10) Number of full size seedlings produced . . . .
(11) Other descriptions (watering, shading, insect control, etc.) . . . .

Register of Plant Distribution

(1) Species . . . .
(2) Seedlot number . . . .
(3) Date . . . .
(4) Number of seedlings . . . .
(5) Where or to whom distributed . . . .
(6) Type of recipient . . . .
(7) Cost (if recipient charged) . . . .
(8) Remarks . . . .

Notes: under (5) give name of forest, plantation, or individual, e.g. village plantation, ward 3, Deorali ;government plantation, Nijgad, Bara District; trial plot, Tistung, Makwanpur District; Ram Bahadur Tamang, Ward 6, Deorali. Under (5) indicate whether government, user group, private individual, etc.

Nursery operation plan for ....Range/VDC

Fiscal year .... Ranger .... *Naike*... Date ....

Planting targets and species of local preference										
Community forest: .... ha .... plants Species:.				Private planting: .... plants Species:				Total: .... ha .... plants		
Nursery operations										
Species	Current target	Usable plants from last year	Total seedlings to be raised for current year's planting	Total seedlings to be raised for planting next fiscal year	Estimated number of plantable seedlings from 1 kg	Total number of seeds required	Time of seed collection	Seed source	Date of seed sowing	Remarks
Total										

....

Chairman of user group

....

Ranger

Chapter 10

PLANTATION TECHNIQUES

Site preparation

The principal object of site preparation is to eliminate the existing vegetation on the site, wholly or in part, in order to reduce competition to the planted trees and to provide access for planting. It may also be needed to allow cultivation between the trees with or without the use of agricultural crops. Some forms of site preparation are intended to increase the ease of root penetration and infiltration of water. On steep and eroded sites it may be necessary to construct terraces or other soil and water conservation works before the trees are planted, while on waterlogged sites drainage may be needed. The intensity of site preparation and the methods used will depend on the nature of the existing vegetation, the plantation techniques and species to be planted, and on economic factors.

Manual site preparation

The use of manual labour to clear sites is the normal method used in Nepal, and the only circumstances in which the use of machines for land clearance needs to be considered are in the plains, for the establishment of large-scale industrial plantations, especially where existing forest is to be converted for this purpose. Mechanical site preparation will be discussed later. On many sites, such as plantations established in short grassland in the hills, little if any site preparation is needed before planting, apart from, in some cases, digging of pits (see page 214). The area around each plant will need to be kept free of grass and weeds, but the initial weeding can be done at the time of planting or shortly after. In other cases site clearance may be confined to removal of scattered trees and bushes, using saws, axes or *khukri* as appropriate.

Generally it is best to fell scattered trees in areas which are to be planted, otherwise they cause excessive competition to the new crop. Most local species (except pines) will coppice and their coppice shoots will eventually add to the biomass of the plantation, which is desirable in fuel and fodder plantations. In community plantations, valuable fodder or fruit-bearing trees will usually be retained. In areas subject to frost it may be useful to leave scattered bushes and coppice shoots of trees, about a metre high, in the plantation area but these should be removed if they are competing with the planted trees. In areas of denser vegetation more intensive clearance will be needed. In the plains, if there are dense stands of tall grasses or shrubs, the simplest method is to slash the vegetation at ground level during the dry season, allow it to dry, and burn it in March or April. In the hills, however, clearing the site by burning should be avoided and dense stands of such species as *Eupatorium* (ban mara) and *Berberis* should be slashed in the March or April before planting.

If fire is used for clearing, great care must be taken that fires do not spread outside the area which is to be cleared. Firelines should be hoed to a width of at least a metre around the whole area. The fires should be lit so that they burn against the wind, or, on slopes, downhill. Enough labourers must be available, spread round the perimeter, to put out any fire which escapes from the fireline. Burning should be done only on days with little wind, and preferably in the early morning. After it is finished the site should be inspected to ensure that there are no glowing embers left which might burst into flame if the wind should rise. Land that has been cleared by burning should be planted early in the monsoon of the same year, otherwise grasses and weeds will invade the site and much of the benefit of the burning will be lost. Burning also often brings about a flush of nitrates in the soil, which will stimulate plant growth. This benefit will be lost if planting is delayed.

Unless the forest is very open, clearance of natural forest for plantations will involve felling the trees, removing any usable produce, and then piling the remaining branches and debris and burning them. The precautions needed to prevent the fire spreading have already been described. In view of the high cost of establishing plantations on natural forest sites it should always be considered whether protecting and managing the natural forest would not be better than replacing it with plantations. If the new plantation is to be weeded mechanically it will usually be necessary to remove the stumps of felled trees. This can be done by hand but it is very expensive and if weedings are to be mechanized it is generally better to mechanize the whole operation, including land clearance.

Mechanical site preparation

This will only be discussed briefly. Mechanical site preparation has been used partially at Sagarnath (K.J. White, 1988b), but in general mechanization is only required when large areas of commercial plantations are to be established. Further details can be found, for instance, in Chapman and Allan (1978). The trees are pushed down with bulldozers, heavy tractors fitted with a stinger, or by heavy chains drawn between two crawler tractors. It is much easier to push down a standing tree than it is to first fell the tree and then extract the roots. In Sagarnath, however, where felled-over *Shorea robusta* forest was cleared for planting, machinery was not used to push down the trees, but those remaining after logging were felled by chain saw, and villages encouraged to collect other unmerchantable material. Stumps of trees over 20 cm in diameter were cut by chain saw as near to ground level as possible, to allow disc harrows to ride over them. Very large scattered stumps were ignored. After the trees are down they, together with other debris, are pushed into windrows by crawler tractors or powerful wheeled tractors fitted with root rakes. The material in the windrows is later burnt, after any usable material has been extracted. Charcoal production is often a useful way of utilizing the felled material. More details on windrowing are given in White (1988b). The land is then ploughed using a heavy disc plough, with discs over 75 cm in diameter, drawn by a crawler tractor. The final stage before planting, though this is sometimes omitted, is to harrow the area using agricultural disc harrows drawn by wheeled tractors. These tractors are later used to cultivate between the rows of trees to keep the area free from weeds. If agricultural crops are to be planted by local farmers this harrowing by light disc harrows is generally unnecessary.

The timing of operations is important. In Sagarnath felling the old forest, harvesting and stumping was planned to take place between September and February; windrowing between November and March; and discing between December and March. This meant that planting could begin in the pre-monsoon period, in mid-May, but there was also an area available in January for cultivation of winter crops by farmers before the trees were planted in the monsoon.

In the past rippers have been used in Nepal plantations (Thomsen, 1976). These consist of heavy metal tines mounted either singly or in multiples behind heavy tractors, and which penetrate 40–70 cm into the subsoil. Their main use is to break up compacted layers in the soil which prevent root development; they also help infiltration of water. However unless there is really a problem with compacted soil layers the use of rippers will rarely be justified, especially as they need heavy tractors to pull them and are expensive to buy and operate. Ripping was found to be of little advantage in the Sagarnath plantations (K.J. White, 1988b). The use of machines in land clearance may be cheaper in cash terms than the use of hand labour, though capital and foreign exchange costs are high. Apart from cost factors a big advantage of mechanization is that it enables work on a large scale to be done at the correct time. For example, it is likely to be difficult to obtain and organize the labour force needed to clean weed 500 ha in one month by hand; with machines it is relatively easy, provided that the machines do not break down. However in a country at the stage of economic development so far attained by Nepal there are considerable drawbacks to large-scale mechanization. It needs high capital investment, and both capital and running costs need large amounts of foreign exchange. Also for a mechanized scheme to be successful good maintenance facilities and supplies of spare parts are essential. If a key machine breaks down at a critical time, and cannot be repaired immediately, most of a season's work may be lost. In a country where there is a shortage of capital, and at the same time considerable rural unemployment, it may be thought more desirable to concentrate on labour-intensive schemes. Certainly before large-scale mechanization is considered very careful estimates should be made of the costs, including such factors as depreciation and the interest on capital costs of machinery, and possible alternatives should be considered.

Land preparation on difficult sites

On very steep or badly eroded sites special methods of land preparation may be needed to prevent further erosion and to direct run-off to the places where it is needed, and will do least damage. There are numerous techniques of doing this, including terracing, contour steps (gradoni), contour furrowing, contour ridging and contour trenching. Trenches and ditches may be continuous or staggered in short sections, with the gaps between the sections in the upper line opposite to the ditches in the lower line. It is not possible to go into details here; further information may be obtained from Chapman and Allan (1978); Ghosh (1977), where about a score of different types of trenches and ditches are illustrated; and Schiechtl (1980). Howell *et al.* (1991) describe a number of techniques which can be used to stabilize slopes along highways.

When terraces are being constructed, if any topsoil remains on the area it should be carefully collected and piled above the terrace, so that it can be replaced when the excavation work is completed. Terraces were used in all the Nepal–Australia Forestry Project's *Eucalyptus* trial plots established in the Kathmandu Valley between 1973 and 1977 but this may not have been really essential on all the sites planted. Community forestry plantations have been established on fairly steep slopes without terracing, with no obvious ill effects. Terracing is expensive and should only be used when essential.

If planting is to be done on badly waterlogged sites, drains may be needed or the trees may be planted on mounds. For details see Chapman and Allan (1978). Drainage is expensive; it may be better to plant species with some tolerance to excess water, such as *Salix*, or to plant other areas.

Spacing in plantations

The optimum spacing in forest plantations depends on a number of factors. These include the rate of growth of the tree, its form, the availability of nutrients and soil moisture, the effects of grass and weed competition, the danger of fire, the rotation to be used, whether it is proposed to thin or prune the trees, whether it is proposed to cultivate between the trees, the purpose of the plantation, and the costs of plantation establishment and maintenance.

Once the canopy has closed and trees are competing with each other the annual increase of volume will be largely independent of the original spacing, as it depends on the amount of energy received from sunlight, the fertility of the site, and the growth characteristics of the species planted. Roughly the same volume increment will be obtained from many closely planted trees or a few widely spaced trees, providing the canopy is closed and all the site occupied by trees. However, closely planted trees will close canopy sooner than trees planted at a wide spacing, and so the total volume produced in the rotation will be higher if the initial spacing is lower. Thus for high total volume production such as in fuel plantations close spacing is desirable. Also small trees are easier to use for fuelwood than very large ones, so large numbers of small trees are preferable to small numbers of large trees for this purpose.

Where saw-timber production is the main objective of the plantation other factors have to be considered, as the unit value of large trees is greater than that of small trees, and there are big advantages in producing timber-sized trees as quickly as possible. This result can be obtained either by spacing the trees closely initially and progressively thinning them out to the final spacing desired, or by planting the trees at a wider spacing initially which will necessitate less thinning. If early thinnings cannot be used, and the plantations have to be thinned 'to waste', there are advantages in initial wide spacing, but in Nepal, where there is a heavy demand for fuelwood in most places, this does not apply. Generally villagers would be only too pleased to thin the trees for nothing, and might even be prepared to pay for the privilege.

Most trees grown for fodder, and fruit trees such as *Juglans* and *Choerospondias*, need ample space for their crowns to develop and should be planted at a wide spacing such as 5 m x 5 m or more. This means that for a number of years the ground between them is not fully utilized. It may provide grazing, and this could be improved by planting fodder grasses or legumes between the trees. Alternatively some fast-growing fuelwood species or such trees as *Leucaena* could be planted between the fodder and fruit trees, to be cut as the latter develop their crowns; care would need to be taken that the interplanted trees did not suppress the trees intended to form the final crop. (Some fodder trees of which the whole stem is lopped at short intervals, such as *Leucaena*, can be planted at very close spacing.) The advantages of close spacing are as follows.

- The canopy closes faster, thus reducing weeding costs and fire risks.
- If a few deaths occur, these do not cause large gaps in the plantation.
- The trees tend to grow straighter and produce lighter branches.
- The total volume of wood produced is higher, especially on short rotations.

- If the trees are eventually intended for saw-timber production, there is an outturn and probably revenue from early thinnings.

The main disadvantage is the cost. At a spacing of 1 m x 1 m, 10,000 plants are needed per ha; at 2.5 m x 2.5 m only 1600. Thus to plant 1 ha at 1 m x 1 m will need over six times as many nursery seedlings, and will cost over six times as much in pitting, planting and initial weeding than planting at 2.5 m x 2.5 m. Hence the spacing of 2.5 m x 2.5 m has become standard in Nepal; it can be regarded as a reasonable compromise. Another factor to be considered is that one of the purposes of plantations in Nepal is to protect hillsides from erosion. The same number of plants planted at 2.5 m x 2.5 m spacing will protect six and a quarter times as much land as if they were planted at 1 m x 1 m. This should not be regarded as an excuse for using extremely wide spacing to cover large areas of ground, as the productivity of the plantations must also be taken into account. Here again a spacing of 2.5 m x 2.5 m is a reasonable compromise.

There may be situations where closer spacing would be desirable. For example, in a village where there was an acute shortage of both land and fuelwood, planting small plots at dense spacing, such as 1 m x 1 m, could be considered. Also such species such as *Leucaena*, which grow very fast and can be cut several times a year for fodder, can profitably be planted at a very close spacing if fodder production is the main object of the plantation. The case of fodder and fruit trees has been mentioned above. Another situation where wider spacing is desirable is when crops are grown between the trees, or where mechanical cultivation between the rows is planned. At Sagarnath the spacing is 4 m x 2 m for *Dalbergia sissoo* and 4 m x 1.7 m for eucalypts (K.J. White, 1984). This will allow three years of crop cultivation between the trees. The possibility of extending the distance between the rows to 5 m is being considered.

Cultivation by tractor and disc harrow requires at least 3 m between the rows of trees. This is the spacing used in mechanized plantations in Zambia and Nigeria, where it is also the practice to plant the trees 3 m apart within the rows, to allow for cross-cultivation. This spacing requires considerable accuracy in laying out the rows of trees, and skilled tractor drivers, otherwise there is a danger of damaging the trees during the cultivation.

Marking out the site for pitting or planting

Before pitting or, if previously dug pits are not used, before planting, it is necessary to mark out the place for each plant within the planting site. If this is not done there is a tendency for the spacing to become very irregular, especially if unskilled labourers are employed. A simple method suitable for most parts of

Nepal is as follows. A chain or rope is marked with the distance between the plants in the row by tying on small pieces of cloth, preferably brightly coloured. Two men, who stand at the ends of the chain, are each given a stick equal in length to the distance between the rows. The chain or rope is stretched along the ground at one end of the planting area, if on sloping ground as near as possible along the contour. A labourer stands by each cloth marker with a hoe, and on a signal from the foreman makes a mark with his hoe at the place where the tree is to be planted. The men at the ends of the rope then measure the distance to the next row with their stick, which must be at right angles to the first row and held horizontally. The chain is then moved to the next position and the process repeated until all the area is covered.

The planting lines should, as far as possible, be parallel to the contour but on hilly ground it is rarely possible to do this exactly, except on broad even slopes, as on steeper parts the contours are closer together. Where there is an abrupt change of slope, such as where a valley crosses the planting area, the chain should be realigned until it is approximately parallel to the slope on the new area. It is important that the stick measuring the distance between the rows should be held horizontally, and not parallel to the ground, otherwise the planting distance will be too small on steep slopes. For more accurate work a square is laid out whose sides are the length of the planting chain, using a compass or optical square to ensure that the corners are at right angles. Then on two opposite sides of the square the chain is laid out and the places where the tags are are marked on the ground, usually by pegs. The chain is then stretched between pairs of pegs, and the sites for individual plants marked on the ground as before. In some countries it is customary to mark the sites where the trees are to be planted by stakes of wood or bamboo 60 cm or more long. This however is quite a costly operation and can be dispensed with if the trees are to be planted or the pits dug immediately after the planting spots have been laid out.

Pitting

Planting in pits prepared well in advance of planting is a common practice in South Asia, but is relatively unusual in other parts of the world, where it is more customary to make holes just large enough to take the seedlings, at or just before the time of planting. Pitting has the advantage that the roots of the young seedlings will be in contact with already worked friable soil, which is particularly important when hard, indurated soils are being planted. It also results in an area immediately around the plant remaining free of weeds for a considerable period after planting. Its chief disadvantage is that it is expensive, and also if it is done badly it can do more harm than good. For the time being, at least, it is recommended that pitting should continue as standard practice in Nepal, but the possibility of using cheaper methods should be considered, and trials of other methods undertaken. For valuable fruit and fodder trees pits are desirable.

Pitting should be done while the ground still has some moisture in it, and so is soft and easy to dig. Fairly soon after the monsoon is a good time, but it may be better to wait until after the festivals of Dasain and Tihar, that is until November and December (Mangsir and Paush). If it is impossible to make the pits at this time, it is better to wait until the pre-monsoon rains of April and May (Chaitra and Jesth) have moistened the soil, but this is a period of fairly high agricultural activity when people are sowing maize and preparing unirrigated land (*khet*) for cultivation. Above 2000 m, the soil dries out less, and pitting may be done from January to May (Paush to Baisakh).

The standard pit in Nepal is circular, at least 30 cm deep and 30 cm in diameter at the bottom. Unless the sides of the pit are vertical the diameter at the top will need to be greater than 30 cm. Workers should be given sticks 30 cm long so that they can check the depth and diameter of the pits. On slopes the depth of the pit should be measured at its centre. The most useful tool for pitting is a modified *kodali*, with its blade at right angles to the handle, and not at an acute angle as in the traditional Nepal *kodali*. The traditional *kodali* can only make pits with sloping sides, which means that more work is necessary to make a pit 30 cm in diameter at the bottom. Mattocks are also suitable.

The topsoil, that is the soil from the top 15 cm, should be dug up and placed to one side of the pit, separate from the subsoil from below 15 cm. After all the soil has been removed the supervisor should check that the pit has been dug to the correct dimensions, and then the soil can be replaced in the pit. Any grass should be separated from the soil, and put on one side, while clods should be broken up. In replacing the soil, the topsoil and the soil from lower down should be carefully mixed, by placing a little topsoil, and then a little subsoil, in layers until the pit is refilled. The soil should be pressed down firmly after it has been replaced in the pit, to prevent rain washing it away and also to reduce the rate at which it dries out. Grass should not be replaced in the pit, as it may grow again.

It is important that the soil should be replaced in the pits at the same time as the pits are made, and not left at the side until the planting season. Soil left in a heap near the pits will tend to be washed away by rain, and in dry weather it will tend to dry out. When pits are being dug by piece work (contract) it may be preferable to leave filling the soil back into the pits until the end of the day, so that the size of the pits can be checked before the pits are refilled; but refilling the pits must always be done on the same day that they are dug.

Reference: Neville (n.d.) *Technical Guideline No. 1: Pitting*. This has been drawn on freely in compiling the section above.

Use of large pits

Use of larger pits than the standard 30 cm cubed has been tried for a number of fodder trees, such as *Artocarpus* and *Ficus*. These have often considerably increased early growth, for instance in Nijgad, Bara District, where excellent growth of fodder trees was obtained by planting them in pits 75 cm cubed. The disadvantage of very large pits is of course their cost, and the amount of labour required, which rules them out in large-scale plantations. However farmers planting a few trees near their houses would probably find it possible to dig a few large pits, and should be encouraged to do so when planting valuable fruit and fodder trees. The use of compost in the pits would further increase growth.

Season of planting

Monsoon planting

In nearly all localities the safest time to plant to ensure good survival and height growth is as soon as possible after the onset of the monsoon, that is in June in the centre and east of Nepal, and July in the west. This ensures at least two months of heavy rain after planting, and in most localities at least five or six months growth before water supplies in the soil are exhausted. The plants can develop a good root system before the period of water stress begins, and have a better chance of surviving this period. Various factors such as shortage of labour, or a large planting programme, may prevent all planting being completed at the ideal time. However every effort should be made to finish planting before the end of July. This not only avoids the risk of an early end of the monsoon in September, but it has also been shown that early planting results in much better height growth. At Pakhribas the height increment of *Alnus nepalensis* planted at the end of June was 43 per cent greater than that of trees planted at the end of August, when measured of November in the following year; and those of *Ficus auriculata* and *Bauhinia purpurea* were 22 and 90 per cent greater respectively (P.R. Pradhan, 1982b). The main reason for trials of planting at other times of the year is that the onset of the monsoon is a season when farmers are very busy planting their crops, and hence labour is difficult to obtain for forest plantations.

Winter planting

The main reason for trials of winter planting is, as stated, shortage of labour during the monsoon. Other reasons put forward are that in winter young trees are dormant and hence less likely to suffer from transplanting shock, and that some species are commonly planted in winter in the Indian Himalaya. The fact that autumn or spring planting is a common practice in Europe and parts of North America may also have influenced thinking on the subject.

There is not a great deal of knowledge about dormancy of young trees in Nepal, in particular about what factors cause them to come out of dormancy in the spring, if indeed they are dormant or partially dormant during winter. If emergence from dormancy is triggered by temperature this is likely to occur in March or April, which is often a hot and dry period. If seedlings would remain dormant until the rains then planting dormant seedlings would give good results, but this seems rather unlikely.

In considering Indian practice it should be borne in mind that winter rainfall and snowfall increase from east to west in the Himalaya. The average precipitation in Himachal Pradesh from November to March is 264 mm (Forestry Research Institute, 1975), while in Nepal only one station out of those for which the data have been analysed, Dadeldhura, has more than 200 mm. Also a larger proportion of the winter precipitation in the Indian Himalaya falls as snow. In fact climatically in Nepal the period March to April is the least favourable for tree growth as it is characterized by generally low rainfall, high temperatures and high evapotranspiration. March and April in most stations are the months with the highest water stress.

Despite this it has been possible occasionally to plant trees successfully in February and March. At Pakhribas in 1980 there were no significant differences in survival of *Ficus auriculata* and *Bauhinia purpurea* between trees planted at the end of February, the end of April, the end of June and the end of July, but *Alnus nepalensis* survived very badly when planted in February or April (P.R. Pradhan, 1982b). However, 1980 at Pakhribas was a favourable year, with the highest March to May rainfall of the six years on record, 55 per cent above the average. Another record from Pakhribas gives rather different results. In a provenance trial survival of *Alnus* from July planting ranged from 90 to 100 per cent; from February planting, from 29 to 67 per cent (Lamichhaney, 1984). At Jiri 80 per cent survival of *Pinus patula* planted in March 1978 was recorded, but in 1979 planting of the same species in February was a complete failure, though this was attributed in part to fungus attack (Grunenfelder, 1980a). However, here again 1978 was a favourable year at Jiri with March, April and May rainfalls 40, 78 and 36 per cent above average. In 1979 March rainfall was only 44 per cent of the average, April 19 per cent, and May 53 per cent. This demonstrates that winter planting trials should be repeated for a number of years before conclusions are drawn from them.

Other records of successful winter planting are of *Pinus roxburghii* at Doti District, of *Salix* (from cuttings) and *Alnus* in a wet place in Acham District (M. Stewart, 1982) and *Alnus* on a moist site in Silgadhi, Doti District (J. Stewart, 1983a). Both these sites are in the Far Western Development Region, where winter rainfall is heavier than elsewhere in Nepal. Grunenfelder (1980a) states that *Bombax ceiba* can be planted successfully (in the IHDP project area, Dolakha District) in winter if 30-month-old seedlings, 1.5–2 m tall are used. He also states that bare-root plants of *Fraxinus* can be planted during the few rainy days in winter, and that cuttings of *Populus deltoides* subsp. *monilifera* should be planted in February–March, while still dormant, otherwise the rate of growth is considerably reduced. There was 85 per cent survival of *Juglans regia* at Megapauwa in the same district, from winter planting (Neville, 1985a). At Kharidunga, at about 2700 m in Dolakha District, *Pinus patula* and *P. pseudo-strobus* planted in February survived well until the rains began. Tokumara (1986) records that in Jani, in Baglung District at 2050 m, over 90 per cent of plants of *Pinus wallichiana*, *P. patula* and *Cryptomeria japonica* planted in winter survived until the next rains, but *Prunus cerasoides* failed.

Thus there are some records of successful winter planting. However there have also been numerous failures. It is possible that a number of the successes recorded were in unusually favourable seasons. Certainly many more trials are needed before winter planting can be recommended on a large scale, as a technique likely to succeed in most years. Planting might be possible in some years with good February and March rainfall, but the occurrence of such years cannot be predicted. Nursery work needs to be organized to produce the right size of plant at the date of planting, and if this is uncertain—for instance if planting is to be in March in years of good winter rainfall, and in July otherwise —nursery organization is difficult.

Winter planting is most likely to succeed: on wet sites, for instance near springs or streams; on north-facing slopes; at high altitudes; in the far west of Nepal, where winter rainfall is higher than in the rest of the country; in other regions of heavy rainfall with a relatively short dry season, for example, Lumle; and with species showing marked winter dormancy, especially deciduous trees such as *Salix*, *Populus*, *Juglans* and *Aesculus*. In regions with regular snow in winter, planting as the snow melts could be worth trying. At this period most of the water from the accumulated winter precipitation will be available at one time, and this would be a favourable time for planting. The risks would be of dry spells in April and May, before the monsoon. However there are not many places in Nepal with regular winter snowfall where the snow lies for long periods.

Planting in the pre-monsoon rains

Before the main monsoon breaks there is a period of gradually increasing convectional rainfall. Farmers in many places sow maize during this period. In many places trees also could be planted then, with considerably less risk of failure than from winter planting. Trees planted in mid-May would have two months longer growth in the rainy season than trees planted in July.

The main danger is from a dry spell between planting and the break of the monsoon. Plants raised in polypots should be capable of withstanding a moderately long dry spell of the order of ten days or so, provided that they are planted in moist soil. In the large plantation scheme at Sagarnath planting begins as soon as the topsoil is wet to a depth of 25 cm, usually in May (K.J. White, 1984), and this rule could well be followed elsewhere, provided that there is a reasonable assurance of sufficient rains during the succeeding month. For this the five-year low figures given in Table 5, pages 50–103, should be consulted, and compared with the monthly evapotranspiration figure. Naturally in the west of Nepal, where the monsoon breaks later, planting will also begin later, and June rather than May would be the month for pre-monsoon planting.

The earlier that seedlings are planted, the greater is their height growth during the rainy season. Hence trees planted in May will have a greater height increment in the first year than those planted in, say, July. The period of the pre-monsoon rains is the best time to plant stumps. Unfortunately this period is also one when farmers are busy in the fields, so planting at this time will not help a great deal in solving the labour problem. It may give a little more flexibility however. If pre-monsoon planting is impossible due to poor rains at this time, or other causes, holding over the plants in the nursery for a few weeks should not cause very great problems with most species.

Transport of plants

Plants may be transported from the nursery to the planting site by mechanical transport, such as trucks or tractor trailers, by bull-cart, or by porters. The last method will be the only possibility in many remote community forestry plantations in the hills. The type of plant, whether seedlings in polypots, bare-root plants, stumps or cuttings, will also affect the way that they are transported.

Seedlings in polypots

The important factor in transporting seedlings in polypots is that the core of soil around the seedlings should not be broken or damaged. The seedlings should be closely packed together so that they do not shake about during transport but they should not be crammed into trays or other containers by force. They should be kept upright during transport, and not allowed to fall over, otherwise the soil round the seedlings may be shaken out.

If mechanical transport or carts are used the seedlings should be packed in trays. A tray 30 cm x 45 cm will hold about 60 plants. These trays may be of wood, metal, or strong expanded wire mesh; the first type is easiest to make and may be cheapest, but the last is lighter to transport. A tray 36 cm x 25 cm will hold about 40 seedlings in the standard tubes (3 inch x 7 inch lay-flat) used in Nepal. As each seedling weighs about 300 g this will be a total weight of 12 kg plus the weight of the tray, which is relatively easy to handle; trays much larger than this become unwieldy. Such trays can double as nursery trays in which seed is sown to raise plants for pricking out. To make the best use of mechanical transport a temporary staging should be constructed in the vehicle. This enables more than one layer of seedlings to be transported. The floor of the top layer should be about 50 cm higher than the floor of the vehicle so that the stems of the seedlings are not bent. The total weight of seedlings plus trays should not exceed the load rating for the vehicle. Seedlings transported in vehicles should be protected from the sun and the strong currents of air produced by the moving vehicle by tarpaulins or hessian screens. The vehicles should be driven slowly, and bumping and shaking avoided as much as possible.

Where transport is by porters the traditional *doko* will generally be used. Other forms of backpack for transporting seedlings have been devised, but they are relatively expensive and unlikely to be available in hill nurseries in Nepal. The bottom of the *doko* should be filled with straw to give a firm base for the seedlings to stand on, and then seedlings carefully packed in the *doko* so that they remain upright and are not shaken about. The standard *doko* load is 25 kg, equivalent to about 80 seedlings in standard 3 inch x 7 inch lay-flat pots, but in some areas 100 seedlings are carried at a time. The standard distance a porter can carry a load in a day is 12 km. When seedlings in polypots are transported they should never be tied together in bundles by a string. Nor should they ever be handled by grasping the seedlings; only the polypots themselves should be taken hold of. If water is available near the planting area, polypot-raised seedlings can be transported to the site before the date of planting. They should be placed under a shady tree and watered regularly until needed. For preparation of nursery stock for planting see the previous chapter.

Bare-root plants

These should be transported in large plastic bags to reduce transpiration. Before the plants are put in the bags the foliage should be dry, otherwise the plants are liable to rot. They should be put into the bags immediately they are lifted from the nursery bed, and then put under shade. Wrapping the roots in damp moss or grass—damp, but not wet—before the plants are put in the bags is helpful. After the seedlings have been put into them the bags should be squeezed to expel excess air and the necks tied tightly with string. It is important that the plastic bags are shielded from the sun at all times, otherwise overheating will occur and kill the seedlings. The plastic bag should be wrapped in several layers of hessian or similar material and kept well shaded, and on arrival at the planting site it should be put under the shade of a tree, or in a cool, well-ventilated building. The roots should never be exposed to strong sunlight, even for a few minutes. Bare-root plants should be planted as soon as possible after arrival at the plantation site; if they cannot be planted immediately they should be put in a cool place under shade. If long delays are expected they should be heeled in.

Stumps

These are much less liable to dry out in transport than either polypot-raised or bare-root plants; however they should be protected as much as possible, and should not be exposed to the sun or dry winds. They can be tied in bundles and put in plastic bags for transporting. If they cannot be planted immediately they may be heeled in. A trench is dug in the ground slightly deeper than the length of the root portion of the stump, the stumps placed upright in their bundles, and the earth filled back into the trench round them, and well-firmed up. On no account should they be left open to the air between transport and planting.

Cuttings

Small unrooted cuttings should be treated like stumps. Rooted cuttings should be treated like bare-root plants if they are not in polypots, and similar to other polypot-raised plants if they are grown in plastic bags.

Planting methods

Different techniques are needed for plants raised in polypots, stumps, and bare-root seedlings, and for planting in previously prepared pits or in unpitted sites.

Plants in polypots

If plants in polypots are to be planted in previously dug pits into which the soil has been refilled, the first step is to use a hoe to make a hole in the soil deep enough to take the plant or slightly deeper. Then about two centimetres are sliced from the bottom of the container, to remove any curled up roots, and the container is placed in the hole so that the root collar is at the level of the soil in the pit. If the hole is too shallow it will need to be deepened; if too deep a little soil is refilled back into it.

Then the plastic container is slit using a sharp knife or razor blade and removed from the seedling, taking great care not to disturb the cylinder of soil round the roots of the plant. The plant is held in an upright position and then the soil refilled round it, a little at a time, and as each amount of soil is added it is pressed firmly round the plant with the fingers. When the hole is completely full the whole plant is further firmed up by treading round it with the feet. When the work is completed the soil round the plant should be level with the surrounding soil surfaces, and it should be impossible to move the plant by pulling it gently with the hands. The following important points should be noted.

- The polypot must be removed.
- The cylinder of soil round the plant must be intact.
- The root collar of the plant must be level with the soil, and certainly not higher.
- After planting the seedlings should be really firm in the ground.

Where pits have not been prepared before planting, holes should be dug slightly larger than the cylinder of soil in the polypot. To make this sort of hole a special tool is useful. It consists of a steel blade about 20 cm long by 8 cm wide, sharpened at the bottom end, and fixed vertically to a handle. The hole is dug by driving the tool down vertically and removing the soil by hand until the hole is deep enough. More sophisticated tools are available for making this type of hole, such as the Schlich spade, which has a semicircular blade and lifts out a core of soil, but these are considerably more expensive. It is best to dig the holes (not pits) and plant the seedlings on the same day. Sometimes holes are dug a considerable time before the seedlings are planted, but this carries the risk that the soil on the inside of the hole will dry out and produce a less favourable environment for roots to develop after the seedlings have been planted.

After the hole is dug the bottom is sliced off the polypot, the remaining plastic removed, and the plant placed in the hole. It is held upright, and soil filled in round it, and finally firmed up as before by trampling. If special tools are not available ordinary holes can be dug with a hoe or mattock; the type of hoe in which the blade is fixed at right angles to the handle is more efficient than the traditional *kodali*. It is important that the hole should be dug deeply enough. On sloping ground the root collar of the seedling after planting, and the soil after it has been refilled into the hole, should be level with the downhill edge of the hole, otherwise soil is likely to be washed away from the seedling, exposing the roots. Other techniques are similar to those used for seedlings planted in pits.

Other types

When bare-root seedlings are to be planted, a few seedlings at a time should be removed from the plastic bag in which they have been transported from the nursery (and which should be kept in a shady place) and put in smaller plastic bags to be carried by the individual planters. Holes should be dug large enough to contain the whole root system of the plant without bending the roots. The plant should be held upright in the hole and the lower roots covered with soil, then further small quantities of soil added, taking care to spread out the side roots at each stage. The soil round the roots should be continually firmed up with the fingers, and after planting is complete, by trampling with the feet. For planting stumps smaller holes can be dug, though they must be deep enough to take the whole length of the root. Sometimes crowbars are used for this purpose, making a hole just big enough to take the stump.

Weeding

Second to the use of poor planting stock, neglect of weeding is an important factor causing plantation failure in Nepal. Weeding is needed to reduce competition for water, nutrients and light. It is especially important in regions with a pronounced dry season, where the trees are competing with other vegetation for the reserves of water stored in the soil after the rains. The less water that is used by weeds and grasses, the more there is available for the planted trees. The maximum growth of planted trees is obtained when all competing vegetation is removed; that is to say, when the area is clean weeded. However this is often impracticable, since clean weeding by manual labour is very expensive. On steeply sloping sites it is also undesirable, as it increases soil erosion. Usually a compromise is reached, either to weed in strips along the lines of trees, or to weed in patches around the individual trees. In Nepal the latter method is nearly always used.

In Nepal it is customary to weed in a circle 60 cm in diameter round the trees, but this should be regarded as an absolute minimum. Increasing the diameter of the circle to one metre would be very desirable. In parts of the Terai and Bhabar Terai zones where there is a dense growth of perennial grasses weeding 60-cm circles is certainly inadequate, especially if *Imperata* is present; here clean weeding is very desirable for most species and the very high costs of this can only be avoided by growing the trees together with agricultural crops, or by mechanization.

Weeding should be done by hoe, to expose the bare soil round the trees. Light digging with the hoe is beneficial. Cutting the grass at ground level round the trees is not enough to prevent competition for water, but very tall grasses and bushes overshadowing the trees should be cut back. The first weeding should be at the time of planting or a few days later. Often when pits are prepared the digging will leave a clear area round the trees, which may only need to be slightly enlarged. The dates of subsequent weeding will depend on the grass and weed regrowth; sometimes a good weeding in the early rains at the time of planting will carry the plants through to the end of the rains. It is very important however that the trees should be well weeded at the end of the rains, before the dry season has set in, so that during the dry season, when the effects of competition for water are most serious, the trees should be as free as possible from grass and weed competition.

The number of years during which weeding is needed will depend on the vigour of the weeds and the rate of growth of the trees. Two years can be regarded as the minimum on most sites and for most species. When the rate of growth of the trees is slow, as in *Abies* species, weeding for several years may be needed. Different species of trees vary in their susceptibility to weed competition. The growth of eucalypts, *Leucaena* and some exotic pines is very severely affected by weed competition; teak and *Pinus roxburghii* will withstand weed competition to some extent, but always at the expense of the rate of growth.

Another reason for thorough weeding is that the trees in a plantation which has been well weeded are less likely to suffer severe damage from fire, than those in an area which is full of grass. Even if the trees are only spot weeded the flames will not approach as close to their stems as they will in unweeded areas.

Agricultural tractors and disc harrows are used to cultivate between the rows of trees in some countries. These methods are only suitable for use in large-scale industrial plantations on flat or gently sloping land, and require that the ground is free from stumps before it is cultivated. Chemical herbicides are being increasingly used in weed control in forest plantations in various parts of the world, and in some circumstances are the cheapest and most effective method. Purchase of herbicides, however, needs foreign exchange, and their application requires considerable skill and the wearing of protective clothing, often including gloves and face shields, by the operator. Indeed certain herbicides are so dangerous to human health that their use has been banned or severely restricted in a number of countries. For these reasons the large-scale use of herbicides in forest plantations is unlikely in Nepal in the near future. For further information see Chapman and Allan (1978), and the references they quote.

Replacement of dead plants

If good nursery stock is used and the trees are planted well and weeded well, it should be possible to obtain a well-stocked plantation in the year of planting; this should certainly be the aim. However, casualties are liable to occur, in which case the dead trees should be replaced by healthy ones as soon as possible. If possible, trees which die within a few weeks of their having been planted should be replaced in the year of planting, but this will only be successful if the original planting was early in the rainy season, so that the plants used for replacement still have a long enough period of rainy weather in which to establish themselves. In Sagarnath, where planting begins in May, replacement of casualties takes place in June and July. Rather than attempting to plant replacements late in the rainy season it is better to wait until the next year.

As most casualties occur quite late in the year replacements will usually be made in the year after planting. However, if casualties are few, say less than 20 per cent, and are scattered throughout the plantation area, replacement is not worth while. This is assuming that the original spacing between the trees was reasonably close, such as 2.5 m x 2.5 m. If wide spacing such as 4 m x 4 m has been used it will be necessary to replace all casualties. The reason why it is not worth while to replace single, dead trees in a row at 2.5 m spacing is that the replacement trees, being a year younger than their neighbours, will be permanently outgrown by them, and will remain suppressed or severely dominated.

Where casualties are more than 20 per cent, or if the dead trees are in groups and so likely to produce permanent gaps in the plantation, replacement will be needed. Replacement of casualties should be the first task undertaken in the new planting season, and should take priority over planting new areas. All too often replacement is delayed until all the new area has been planted and is done late in the rainy season with the worst plants in the nursery. This means that the replacement plants in turn die, and further replacement plantings will need to be made in the next year, and so on. The result will be a poor, gappy plantation which will have cost more in time and labour than if replacements had been made at the proper time.

Plantation establishment by direct sowing

Direct sowing was at one time widely used in India and is still used there to some extent. One of the reasons for this is that certain species were very difficult to raise in nurseries until the use of plastic containers became widespread some thirty years or so ago. Other advantages of direct sowing are that the expense and labour involved in raising nursery stock is avoided, and that seeds are considerably easier to transport to the plantation site than plants, especially plants raised in containers. Against this direct sowing has a number of serious disadvantages including the following.

- Large quantities of seed are required, though these are reduced if the sowing is in pits or small patches.
- The seed of some species is liable to be eaten by rodents and other animals.
- The young seedlings are much more liable to damage by external agents such as drought and insect attack than if they are raised in a nursery where

they can be tended continuously. Very small seedlings also suffer much more damage from weed competition than do well-grown nursery stock.
- The seed bed in the forest needs careful preparation if even germination and good survival are to be obtained. (Sowing on recently burnt patches, however, often gives good results.)
- It is unusual for the crop to be completely established by direct sowing, and very frequently gaps have to be resown, or planted up with nursery-raised stock, or with seedlings taken from areas where dense regeneration has been obtained.
- At some time after the seedlings have germinated they will need to be thinned out to a suitable distance between the plants.
- There is usually some loss in growth in the first year.

For these reasons direct sowing should only be used when conditions are particularly favourable to it. It cannot be recommended as a routine method for plantation establishment for most species in Nepal.

Methods of direct sowing

Broadcast sowing

In this method the seeds are merely scattered over the surface of the soil. It is only likely to succeed where the mineral soil has been exposed and there is little weed competition, as on landslips and recently burnt areas. *Alnus nepalensis* has been successfully established along the Lamosangu–Charikot road by broadcasting it on soil exposed when the road was built, and it has also been sown successfully in some places to stabilize landslips. Some failures in using this method have also been recorded. It needs an abundant supply of cheap seed.

Line sowing

This technique is commonly used in India. Usually strips 30–45 cm wide are cleared, and hoed to a depth of 15 cm or more. Sometimes a more elaborate method is used, in which trenches from 30 cm to 45 cm square in cross section are dug, and the seed sown in the replaced soil. Line sowing is often combined with cultivation of agricultural crops. It commonly requires 15–20 times as much seed per hectare as would be needed if the same quantity of seed was used to raise plants in the nursery.

Patch sowing, and sowing in pits

In patch sowing the patches are cleared at a spacing equivalent to that of the trees required in the plantation, e.g. 2.5 m x 2.5 m or 3 m x 3 m. The patches are from 30 to 45 cm square, and are hoed to a depth of 15–20 cm and the soil well pulverized. Usually about ten seeds are sown in each patch, but this number may vary according to the percentage germination expected. Seed may also be sown directly into pits similar to those used for planting seedlings, with the soil replaced. This technique has been successfully used for *Acacia catechu* in the Pokhara Valley. The development of the roots of the seedlings should be better in pits than in patches, but of course the costs of pitting are higher than those of preparing patches. Sowing in pits or patches will need about five times more seed per hectare of plantation than using the same amount of seed to raise plants in a nursery.

Tending of seedlings after direct sowing

Newly germinated seedlings from direct sowing will need more thorough weeding than the much sturdier plants raised in nurseries. For this reason direct sowing is often combined with taungya. However, if trees are raised in conjunction with agricultural crops it is important that the seedlings continue to be weeded after the crops are harvested. In the years after direct sowing it will be necessary to thin out the surviving seedlings. In line sowings with 3 m between the lines thinning out to leave one plant per metre would be suitable in most cases; in patch or pit sowings the seedlings should be thinned out to one per pit, or if there are doubts about subsequent survival, to two per pit.

Time for direct sowing

The optimum time for sowing on most sites is during the pre-monsoon rains, as soon as the soil has been sufficiently moistened. In areas where snow can be relied on, sowing before the first snowfall often gives good results; the seed will germinate after the snow melts. However, areas in Nepal where snow can be relied on are few.

Agroforestry

The combined cultivation of trees with agricultural crops or pasture plants has received a great deal of attention in recent years, under the general term agroforestry. When interpreted broadly, this covers a very wide range of activities, ranging from large plantation schemes to a farmer planting fodder trees on terrace risers. Only some aspects have been considered here.

Classical taungya

The practice of raising agricultural crops between trees in forest plantations is an old one. It appears to have first been introduced on an organized basis for raising teak plantations in Burma about 1870, and hence is widely known by the Burmese word taungya which literally means shifting cultivation. Since then it has spread to many parts of the world. The main objective of classical taungya is to reduce weeding costs, and hence the cost of establishing plantations, by allowing cultivators to grow crops between the trees. Although the cultivators benefit, taungya schemes tend to be evaluated from the point of view of the forest owner or tree planter. Taungya often enables much more intensive cultivation to be done than otherwise would be economically possible; the trees are better protected against fire and grazing animals; and it can provide the basis for establishing a settled and relatively prosperous labour force. Its disadvantage to the tree grower is that competition from crops sometimes reduces the rate of growth of the trees as compared with clean cultivation, though this is by no means always the case. Often a slight decrease in the first year's growth is followed by an increase in subsequent years, as is shown in Sagarnath, for *Eucalyptus camaldulensis* (Table 12). In any case clean cultivation is often impossible for reasons of cost, and the comparison should be made between growth under taungya and growth under less intensive methods of cultivation, such as patch cultivation.

Table 12—Effect of crops on growth of *Eucalyptus camaldulensis*

Crop	Tree height as percentage of control height (%)	
	at 3 months	at 12 months
Control, no crops	100	100
Groundnuts	104	111
Upland rice	89	113
Maize	85	111
Sesame	43	—

Note: From K.J. White (1984); the control was weeded.

Later on in the life of the trees the effect of intercropping is even more striking; B.K. Pokharel (1990) gives an example of a *Eucalyptus* plantation 3.6 years old, where the mean annual increment was 23.5 m^3 ha^{-1} with intercropping, against only 2.0 m^3 ha^{-1} without it; an increase of nearly 12 times.

Advantages to the cultivators are that they have areas of new and hence fertile soils for their crops; depending how the work is organized, clearing and preparation of the land may be done for them; and they usually have the opportunity of working as labourers in forest activities to supplement the income from their crops. Well-organized taungya can be used as a method for increasing the standard of living of the local people. A general advantage is that full use is made of the land, which produces both wood and food.

The main difficulties in introducing large-scale taungya systems are that a successful scheme requires considerable organization and a good understanding with the cultivators. Also taungya will only be successful where the soil is fertile enough to grow healthy agricultural crops; this rules out its application in many communal forestry plantations in the hills of Nepal where the least fertile soils are usually allotted for plantations. The most important application of taungya practices in Nepal has been in the Sagarnath Project, in the Terai of Sarlahi District; more details of this and other projects are included later.

Organization of taungya

Before local farmers are allowed into plantation areas to grow crops between the trees it is essential that a clear statement is drawn up, preferably in writing, defining the mutual responsibilities of the cultivators and the plantation authorities, and that these prescriptions should be formally agreed to. In drawing up such agreements the interest of both the forest owner and the cultivators should be considered carefully. The prescriptions should include among other things, details of the area of land to be allocated to each family, the crops that may be grown, how close to the trees they should plant the crops, and how long they may continue to cultivate; also the sanctions which the plantation authorities may apply if these conditions are breached. The cultivators, on the other hand, must be convinced that if they adhere to the conditions of the agreement they will have unencumbered rights to the crops they produce, and the right to continue to cultivate the area for the period specified in the agreement. It should be made clear however, that in growing crops on the land they do not acquire any permanent legal rights to the land.

It is very important that individual cultivators should not be allocated larger areas than they can easily cultivate, otherwise parts of the plantation will remain uncultivated, and weeds will need to be controlled by hand. In the Bhabar Terai and Terai zones of Nepal it is estimated that a family can cultivate from between 0.12 and 1.0 ha each year, the lower figure being for new, uncultivated forest land, and the higher for land which has been previously cleared and disced, and in which bullock ploughs are used in cultivation. The area cultivated will also depend on the size of the family unit and the age of its members. Assuming an average cultivated area of 0.3 ha per family, three active members per family unit, and three years cultivation, the number of people required to cultivate in an afforestation scheme with an annual planting programme of 1000 ha is 9000 (K.J. White, 1984). This is a very large number of people, and there may be difficulties in recruiting so many from within a reasonable walking distance of the plantation area.

One solution to this is the establishment of forest villages. A scheme on these lines has been set up by the Forest Industries Organization of Thailand, to establish teak plantations. The organization provides schools, health services, temples, water and in some cases electricity, together with a plot of ground on which each cultivator can build his house. It also guarantees a certain number of days of paid labour per year to each cultivator, together, of course, with an area of land within the plantation area to cultivate. Such an organization could also include the establishment of co-operatives to purchase seeds and fertilizers, and to help market the products. To establish village communities on the scale suggested is no simple task, and an alternative has been suggested of renting out the land to larger operators, to cultivate in blocks of 12 ha and upwards. This is less desirable socially, but it may possibly be the only practicable solution in some cases. However in the Sagarnath Project larger operators showed no interest in such schemes.

Of course the introduction of taungya in smaller units such as are likely to be planted in community forestry projects would not give rise to these difficulties of labour supply. There are a great number of possible variations in the organization of taungya plantations; some of those used in India are described in Champion and Seth (1968b).

Crops to be grown

The ideal is a low-growing, nitrogen-fixing crop such as groundnuts or beans (gram, mung, etc.). However, a large range of crops give satisfactory results, including, in the Nepal Terai, maize, soya beans, upland rice, chillies, wheat, oil-seed mustard (tori), chick pea (chana), garden pea (kerau), mash, linseed, groundnuts, buckwheat, millet (kodo) and a wide range of vegetables—in fact, almost any crop apart from, when the trees are young, twining plants which climb up the young trees. In India sugar cane, plantains, jute, cotton and sorghum are not allowed in taungya plantation (Ghosh, 1977), but some of these are considered acceptable in Sagarnath. Sesame also has been found to be harmful to one-year-old seedlings, but can be used once the trees have reached at least 2 m in height. Tall crops such as maize and sorghum should not be sown closer than 50 cm from the young trees. Shorter crops can be grown up to 25 cm from the trees. The choice of crops to be grown should be left to the cultivators, apart from a few, such as those mentioned above, that are known to harm the trees. Table 13 gives the crops grown at Sagarnath (B.K. Pokharel, 1990).

Table 13—Crops grown at Sagarnath

	Summer	Winter
Preplantation year	Maize, upland rice	Mustard, lentils
First year	Maize	Mustard, lentils, millet (*Eleusine*), tobacco, wheat
Second year	Maize, sesame	Mustard, pigeon pea, turmeric

According to K.J. White (1988b) an alternative for a summer crop, on sandy soil, would be groundnuts. *Guizotia* (jhuse til) and linseed could be added to the winter crops. In Tamagadhi, Bara District, by far the most common pattern was maize as the summer crop and mustard in the winter. Maize was sown in April–May and mustard in October–November. The third commonest crop was upland rice (P.T. Evans, 1990a).

Generally after the second year in the plantation competition from the trees is so high that cultivation of agricultural crops becomes uneconomic. According to Evans yields drop by 25 per cent in one-year-old plantations, and 35 per cent in two-year-old. Trials have been made of shade-tolerant crops for cultivation after this stage; these include pineapples, ginger, bananas, roselle (*Hibiscus sabdariffa*) and medicinal plants such as *Rauwolfia*. No firm results have as yet been obtained from these trials. In irrigated poplar plantations it is anticipated that it will be possible to grow crops under the trees for the whole rotation (eight years). As the trees are deciduous a full range of winter crops can be grown, but in summer only shade-bearing crops such as turmeric and ginger will be possible (Arendt and Lindgren, 1990). Some success has also been reported from growing essential oil plants, such as *Cymbopogon* species (lemon grass, palmarosa and citronella) and mint between the trees (Adkins, 1988; G. Amatya, 1990). For essential oil production this is especially interesting when the crops are planted under eucalypts, particularly such species as *E. citriodora*, which also produce essential oils.

Spacing of the trees

The spacing between the trees in taungya plantations will be affected by their rate of growth and the length of the period of cultivation of the agricultural crops. In plantations of *Eucalyptus camaldulensis* in which the trees are expected to reach a height of 10 m in a little over two years the estimated period of cropping at different spacings is given in Table 14. The original spacing at Sagarnath was 3 m x 2 m, but it is now being increased to 4 m x 1.7 m for eucalypts, and 4 m x 2 m for *Dalbergia sissoo*, and an increase to 5 m x 2 m is considered possible. For poplar plantations a spacing of 5 m x 5 m, or wider, is recommended. This will allow intercropping throughout the life of the plantation.

Table 14—Length of cropping period under different tree spacings

Spacing	Trees ha^{-1}	Years under agricultural crops
1 m x 1 m	10,000	1
3 m x 2 m	1667	2
4 m x 1.7 m	1500	3
4 m x 2 m	1250	3
5 m x 2 m	1000	4–5

Note: Adapted from K.J. White (1984)

Trees having slower height growth would permit longer periods under agricultural crops, but cultivation of annual crops for long periods without fallow is likely to cause a fall in soil fertility to an unacceptably low level, unless this is overcome by the use of fertilizers or rotating the crops. This, rather than competition by the trees, could be a reason for shorter cropping periods.

Agroforestry aspects of the Sagarnath Project

The information in this section has been extracted from K.J. White (1984; 1988a; 1988b). The Sagarnath Project was designed to establish 10,000 ha of high-yielding industrial plantations, primarily for fuel. Planting began in 1980 when 170 ha were planted; by 1984 the annual planting area had reached 1000 ha and the total area of 10,000 ha was expected to be planted by 1991. The rotation was expected to be ten years, and planned yields were 80,000 to 100,000 m^3 of fuelwood per annum. However if the existing rate of growth is maintained, especially that of the eucalypts, the planned yields will be considerably exceeded. The soils are typical Bhabar Terai to Terai soils ranging in texture from sandy loam to silty clay loams; in parts of the area there is a high gravel content. The depth of the permanent water table ranges from 4 m to more than 80 m. No precise rainfall data are available, but it is probably about 1500–1600 mm, with more than 85 per cent falling in May–September. Before the plantations were made the land was occupied by exploited *Shorea robusta* forest. The altitude is less than 200 m.

The two main tree species planted were *Eucalyptus camaldulensis*, Petford provenance (actually from Emu Creek), and *Dalbergia sissoo*. Other species have been planted on a smaller scale. Before establishing the plantations the remaining *Shorea robusta* forest was felled and any commercially usable timber and fuelwood collected for transport and sale. This work was normally done by contractors, though difficulties were experienced in getting the work completed in time for subsequent land preparation and planting. After commercially valuable timber had been harvested, the local people were allowed to remove any of the remainder, such as small fuelwood, that they could use. Felling and harvesting should begin in September; felling should be completed by January and harvesting by February. After harvesting was complete the residue was cleared up and small stumps removed manually. The few large stumps which remained were ignored, and were dealt with by including them in the planting line, deliberately bending it to include them if necessary. Stumping should have been completed by March. Some difficulties were found in removing stumps efficiently. When stumping was complete the whole area was disced using heavy equipment. The main purpose of this was to make the growing of agricultural crops between the trees easier. Discing should have been completed by April.

The land was allocated to cultivators, beginning in September and ending in April. The choice of crop and its management were left to the cultivator, except that after the trees were planted certain crops definitely injurious to them were prohibited, for example, sesame when the trees are small. Crops must not be planted closer to the tree seedlings than 25 cm for low crops such as mustard and 50 cm for tall crops such as maize. The commonest crops grown by cultivators were maize during the rains and oil-seed mustard (tori) in the dry season; groundnuts gave better returns but could not be grown on all sites, and in addition the cost of the seed was more than many poor farmers could afford. At the original spacing between the trees of 2 m x 3 m agricultural crops could be grown for two years after planting but this was later increased to to 4 m between the rows which would enable crops to be grown for three years, though crops in the third year would have low growth rates; maize, for instance, could only be used for fodder. It was thought that increasing the distance between the rows to 5 m would enable commercial crops to be grown in the third year also. Cultivation for three years would provide protection against fire for four to five years. Cultivators were allowed to grow crops, without restriction, for up to a year before the trees are planted. It was found possible to plant the trees as soon as the pre-monsoon rains had wetted the top 25 cm of the soil, usually in May.

Planting should be finished in July. Trials are under way on crops which can be grown at later stages in the cycle. It is hoped that eventually the whole ten-year rotation of the plantations can be in the form of a combination of trees and agricultural, horticultural or pasture crops.

Other taungya schemes

At Tamagadhi in Bara District a taungya scheme was begun in 1976, which by 1989 involved 51 families. The main tree species in 1989 were *Dalbergia sissoo* and *Eucalyptus camaldulensis*, but there were also teak, *Leucaena*, *Acacia auriculiformis*, *Cassia siamea*, *Ceiba pentandra* and *Acacia catechu*. Before the rains the area was cleared of shrubs, and the debris disposed of by controlled burning. Planting was at 2.5 m x 2.5 m spacing, in pits 45 cm x 45 cm. All maintenance after planting was the responsibility of the cultivators, who were also expected to water the tree seedlings when necessary. The project supplied fertilizer at the rate of 32 kg nitrogen and 32 kg phosphate per hectare, applied in a ring round the young trees. The project was considered to have succeeded quite well silviculturally, but crop yields were relatively low and the cultivators were also dissatisfied with their social and economic conditions (P.T. Evans, 1990a; 1990b; B. Shrestha and Pandey, 1989).

In Dang District cultivators were given one *bigha* (0.66 ha) to cultivate, with the intention that after three years they would be given a new plot of the same area. They could continue to grow shade-resistant crops on the first area, while they would cultivate their normal crops on the new area. A similar move would take place after another three years, so eventually they would have three *bigha*. In the tenth year the trees on the first plot would be harvested, and the cycle begun again. Trees planted were *Melia azedarach*, *Eucalyptus camaldulensis* and *Dalbergia sissoo*; it was intended to suspend plantation of eucalypts in favour of leguminous trees. Original tree growth and crop yields were high (Demanski and Bashyal, 1990). It seems that in this scheme there might be difficulties caused by the varying amount of shading of the crops in different years; for instance in the first year the farmer would have all his crops under full light, in the second all under one-year shade, and in the third all under two-year shade, before returning to full light in the fourth year; thus yields would fluctuate considerably. Taungya in poplar plantations, and using essential oil plants, has already been mentioned.

Agroforestry at the farmers' level

Certain forms of agroforestry are traditional in Nepal. The prevalent farming system in the hills, in which tree fodder is fed to cattle which provide dung to manure the farm crops, is agroforestry in a broad sense, although trees and crops are not necessarily on the same area of land. A more intimate association of crops with trees is found when farmers plant trees on their terrace risers. This is also a traditional practice, although in some areas it has considerably increased in recent years as a result of population pressure and reduced availability of fodder from communal sources, among other factors (Carter and Gilmour, 1989). For planting on farm land farmers prefer trees which will eventually produce narrow crowns with most of the leaves on epicormic branches. Species preferred include *Litsea monopetala*, *Artocarpus lakoocha* and *Bauhinia purpurea*, though this varies in different parts of the country (Upadhyay, 1991). Another traditional form of agroforestry is the cultivation of large cardamom under a forest canopy, particularly of *Alnus* in eastern Nepal. Small *Alnus* plantations are often made for this purpose.

A more recent development has been alley or hedge-cropping. This method was introduced to farmers in Bahunipati in Sindhupalchok District (Arens, 1984; Baidya, 1990). In this method *Leucaena* was sown 2–4 m apart in rows along the contour in farmers' fields, and the resulting hedge cut periodically to 15–30 cm above ground level to provide fodder and green manure. *Leucaena* was also planted at one metre spacing along terrace risers. The method was very successful and contributed to a considerable expansion of livestock production in the area. Unfortunately the arrival of the *Leucaena* psyllid has severely affected the scheme, and until either resistant varieties of *Leucaena*, or an acceptable substitute, are found, future prospects are uncertain.

Combination of trees and pasture crops

Most plantations in the hills also provide grass fodder, in that local villagers are allowed to cut the natural grasses for stall feeding to their animals and may be allowed to graze their animals once the trees are large enough to permit this to be done without their suffering damage. The use of sown or planted fodder crops between the trees is however much rarer. An example of where the combination of trees and fodder crops could be useful is when the trees themselves are being grown mainly for fodder. Most fodder trees need to be planted on relatively fertile soil, and at a wide spacing to allow good branch development; one way of utilizing the ground between them would be to establish improved pastures. The introduction of pasture legumes is also being tried during the later stages of the rotation in *Eucalyptus* plantations at Sagarnath.

It should be borne in mind that establishing improved pastures on previously uncultivated land is neither simple or cheap. The seed of fodder legumes needs to be sown on clean cultivated soil, and the seedlings weeded until they are well established. Merely broadcasting seed of fodder plants on the surface of uncultivated soil is rarely successful. Some grasses which can be propagated by stem cuttings (such as napier grass, *Pennisetum purpureum*) or offsets (such as kikuyu grass, *Pennisetum clandestinum*) may be easier to establish. Fodder legumes at present commonly cultivated fairly widely in Nepal include white *Trifolium repens* (clover) which is suitable for altitudes over about 1300 m; while greenleaf (*Desmodium intortum*), silverleaf (*D. uncinnatum*), perennial stylos, such as Schofield and Cook (*Stylosanthes guianensis*), siratro (*Macroptilium atropurpureum*) and cowpea (*Vigna unguiculata*) can be grown from the Terai to the frost line. Perennial stylos, in particular, have shown promise in some localities such as Adabhar. Once well established they form a dense mass of foliage which suppresses competing grasses, and persists for a number of years.

Grasses commonly used include *Setaria anceps* (Nandi setaria and other cultivars), napier grass (*Pennisetum purpureum*) and for altitudes above about 1500 m kikuyu grass (*Pennisetum clandestinum*). At Palpa, *Melinis minutiflora* (molasses grass) was found to be the best species for dry, poor soils on north-facing slopes (Fonzen, 1986b). This list is far from exhaustive and for more details standard works on tropical pasture plants, such as Bogdan (1977), should be consulted. For growing between rows of young trees twining legumes should be avoided; also very tall grasses, such as napier grass, should not be planted close to young trees, unless they are kept closely cut back to not more than a metre high.

The main difficulty in introducing herbaceous fodder plants into the later stages of plantations is that very little information is available on the shade tolerance of such plants. In rubber plantations in Malaysia the legumes *Centrosema pubescens* (centro), *Pueraria phaseoloides* (tropical kudzu), and *Calopogonium mucunioides* are used as cover crops, but of these only *Centrosema* can readily withstand a long dry season (during which it dies back, to sprout again in the rains). Grasses which will tolerate some shade include *Axonopus compressus* (carpet grass), *Paspalum conjugatum*, *Brachiaria brizantha* (signal grass) and *B. miliiformis*. *Axonopus* and *Paspalum conjugatum* are rather inferior fodders. Relatively little study has been made of growing fodder crops under shade in Nepal, or indeed generally of combining trees and herbaceous fodder plants. More such studies are needed before firm recommendations can be made.

Use of fertilizers in plantations

Sometimes a species of tree cannot be grown satisfactorily in plantations on certain types of soil because of a deficiency in one or more plant nutrients. In Nepal poor and stunted growth of eucalypts and some pines, particularly *Pinus* *patula*, on some soils, may be due to boron deficiency, but this has yet to be confirmed experimentally. It can be remedied by applying borate to the soil near the plants (but not in contact with them) at or soon after the time of planting; foliar application of borate salts is less effective. It often happens, however, that trees are apparently healthy, but will grow faster and give higher yields if they are given fertilizers. Use of fertilizers in these circumstances is essentially a matter of economics, i.e. of whether the discounted value of the cost of applying fertilizers is exceeded by the extra value of the final crop. Use of fertilizers may also increase early growth of trees and so reduce weeding costs, as weeding does not have to be carried on for so long.

In Nepal the use of fertilizers to increase yields of species which will grow fairly satisfactorily without them has only been tried in a few experiments. In community forestry plantations, for which very limited funds for buying materials are available, it is rarely likely to be feasible, especially in the hills where transport is difficult and expensive. It might however be economically sound in larger-scale plantations, especially in the Terai. The type and amount of fertilizers to be applied will vary with the species of tree, the soil, and the climate, and sound prescriptions can only be made as the result of field trials and observations. Soil and foliar analyses can give indications of which plant nutrients are likely to be deficient, but the results of such analyses always need to be checked and calibrated by field trials.

In general in Nepal the most important major nutrient deficiencies are likely to be in nitrogen and phosphate; in many soils there are adequate supplies of potassium. Thus the use of compound fertilizers containing nitrogen, phosphorous, potassium, is likely to be unnecessary on many sites. It is unlikely that the addition of extra quantities of potassium would do any harm, but it is wasteful to pay for a nutrient which is not needed. The fertilizers available in Nepal are listed in Table 10 in the previous chapter (page 196). The form in which fertilizers are applied may be important. In Nigeria urea was found to be harmful to *Pinus caribaea* (J.K. Jackson, 1970) but ammonium sulphate was not. Urea did not harm eucalypts. Addition of large quantities of ammonium sulphate tends to make soils more acid. For forestry plantations rock phosphate often gives better results than the more soluble phosphatic fertilizers, especially on acid soils, and is usually considerably cheaper. Phosphate rock may occur in west Nepal and in the Muktinath area (C.K. Sharma, 1977), but so far has not been exploited.

In forestry plantation work it is usual to apply the fertilizer at about the time of planting only, though for very intensive plantations repeat doses may be given during the life of the trees. Mineral fertilizers, especially boron, should not be put in the planting holes, nor should they be allowed to come in contact with the leaves. A satisfactory way of applying fertilizers is to dig one or two very shallow pits 10–15 cm from the base of the seedlings, put the fertilizer in them, and lightly cover it with soil. This is best done within two or three weeks after planting. Fertilizers will not be very effective unless the plantations are well weeded, otherwise most of the nutrients go to stimulate weed growth rather than tree growth. Growth of fodder trees on farmers' land can often be improved by adding well-composted manure to the soil in the planting pits. This is the regular practice when *Leucaena* is planted by farmers in Bahunipati, Sindupalchowk (Arens, 1984), and is recommended for the successful plantation of such species such as *Artocarpus lakoocha*.

Pruning

A form of pruning which may be needed in very young plantations is the removal of multiple stems from some species of trees, especially if they have been planted as stumps. In general the stems should be reduced to one per tree though for fodder and fruit trees this is less essential; indeed in some species there may be a higher fodder or fruit yield from trees which have a number of stems, provided these are not too crowded. This singling out of multiple stems should be done in the dry season after the trees have been planted, and can usefully be combined with inspection of the plantation to note where there are casualties to be replaced. Otherwise pruning is usually done in older stands to remove the branches which, if left on the stems, will produce knots in the timber. It is unnecessary in trees which are to be used mainly for fuelwood, and in species which are naturally self-pruning, such as most eucalypts. It is mainly used in plantations of conifers, especially pines, and is also needed in poplar plantations to produce high-quality logs for peeling. In Nepal another reason for pruning is to provide small fuelwood and cattle bedding at an early stage in the life of plantations.

In pines the first pruning should take place when the trees are 4–5 m tall, when they should be pruned to a height of 2 m. In addition to producing knot-free timber in the lower bole this makes access to the plantation easier. The timing of subsequent prunings and the height to which they are made will depend on the rate of growth of the trees and on economic factors, such as how much the higher value of knot-free timber compensates for pruning costs, which increase as pruning goes higher in the tree.

Removal of green branches in pruning reduces the increment of the tree, and in general pruning should not go above two thirds of the total height of the tree. Because of the high costs of high pruning it is frequently confined to a relatively small number of selected trees which are expected to form the final crop of the plantation, while the remainder are gradually removed in thinnings. It is very important that side branches should be pruned level with the bark of the tree stem. If this is not done and snags remain these will eventually produce bad knots in the timber. In most countries branches are pruned with a special curved saw which cuts on the downward stroke, but in Nepal pruning by *khukri* has been found to be quite satisfactory, provided that the first cut is made on the underside of the branch so that strips of bark are not torn away when the branch is removed.

A factor affecting the economics of pruning in Nepal is the strong local demand for the branches for fuelwood and litter. This justifies more intensive pruning than would be economically sound in some other countries. Pruning, especially its economics, is a large subject which has been dealt with very briefly here. For further information see J. Evans (1982), and the references he quotes.

Thinning

The main objective of thinning is to concentrate the increment of the stand on a comparatively small number of selected trees which will then reach timber size more quickly. It also enables trees to be utilized which would eventually become suppressed and die as the result of competition, and may provide some financial return during the early period of the rotation; this can be important if plantation profitability is calculated using compound interest rates. Badly shaped trees can be removed to favour straighter trees, and in mixed plantations the more valuable species can be preferred. In addition heavy thinning of fodder and fruit trees may be needed to encourage branch development. Trees grown on a short rotation for fuelwood production will generally not need to be thinned unless the initial spacing was very close. On the other hand, plantations for saw-timber will need a number of thinnings during the course of their life.

A number of different types and grades of thinning have been distinguished and prescriptions for these can be found in standard text books. It is sufficient here to say that very light thinnings, such as the removal of only dead, dying, diseased and suppressed trees, have very little effect on the growth of the remaining stand, while very heavy thinnings will cause a loss of increment in addition to promoting heavy branching in the trees that are left. To a very large extent the timing and intensity of thinnings is governed by the objects of management of the plantation and the demand for different types of produce. K.J. White (1983) suggests the following thinning schedule (Table 15, page 240) for pine plantations in the hills of Nepal. Note that the original stocking of 2000 trees ha^{-1} implies a planting distance of 2.2 m x 2.2 m, with no casualties, or 80 per cent survival of trees planted at 2 m x 2 m. At 2.5 m x 2.5 m initial spacing only 1600 trees ha^{-1} would be planted, and the thinning at the height of

5 m would be unnecessary. The heavy thinning at the height of 15 m would have as one of its objectives the encouragement of natural regeneration. White also envisages the establishment of improved pastures and the cultivation of horticultural and medicinal crops between the trees. The thinning schedule described should be regarded as one possibility, and not as a rigid prescription; in particular, the rotation appears to be very short. Actual schedules used will depend on local silvicultural and social conditions.

Table 15—Suggested thinning regime for pines

Height of trees (m)	Age (yr)	Trees per hectare	
		Initially	After thinning
5	—	2000	1500
9	10	1500	900
15	15	900	250
25	25	250	Clearfell

An interesting situation has arisen in some parts of the hills of Nepal where pine plantations have been invaded by natural regeneration of other species. These colonizing species may be of greater value to the local people, for fodder and fuelwood production, than the pines originally planted. During thinnings a decision has to be made on which species to favour. In the Chautara area where a nine-year-old *Pinus roxburghii* plantation had been heavily invaded by broad-leaved species, principally *Schima wallichii*, a number of management plots were laid down in 1983 by the staff of the Nepal–Australia Forestry Project, with the following treatments (Nepal–Australia Forestry Project, 1983).

- Pruning to 2 m and reduction of multi-stem clumps to the best single stem, but no other thinning (Treatment 1).
- Treatment 1 plus thinning to favour the pine.
- Treatment 1 plus thinning to favour the broadleaved species.
- Treatment 1 plus thinning to favour the dominant individuals regardless of species.
- Coppice with standards, retaining the best 300 stems ha^{-1} as standards, and removing the rest. After this treatment the broadleaved trees are expected to coppice.

These trials should produce very interesting results which will need to be assessed not only on factors such as volume production, but also on how the resulting stand best meets the needs of the local people. Much more could be written about thinning, and more details can be found in standard texts. In Nepal relatively few plantations have reached the thinning stage and more detailed prescriptions will have to be based on the results of trials under local conditions.

Chapter 11

PROTECTION OF TREES AGAINST INJURIES

Frost and winter cold

In most of Nepal annual frosts may be expected above 1800–2000 m depending on slope and exposure. In valleys surrounded by hills, frosts may be expected at lower altitudes; the Kathmandu Valley is a good example. Even at Trisuli, at 595 m, light frosts have been recorded in some years. Exceptionally, frosts may occur at much lower altitudes, particular in the west; for instance frost has been recorded at Nepalganj (190 m). Such frosts are, however, very rare, averaging one frosty day in ten years at most, and can be disregarded in planning routine afforestation activities.

Local topography has a great influence on the occurrence of frost. During calm, cold nights the cold air flows down the hill slopes and collects in the valleys, and thus small enclosed valleys and depressions are particularly liable to frost. Flat shelves on hillsides and flat-topped hills may accumulate moderate amounts of cold air, but steeper slopes tend to be frost free. Even a dense belt of trees, a hedge, or a wall, if sited across a valley, can cause accumulation of cold air above it and hence frost. On the other hand a belt of trees can reduce the effect of frost below it. Shade of trees and shrubs, even if it is quite open, reduces the radiation of heat from the ground and hence the dangers of frost damage. A thick grass mat, on the other hand, prevents conduction of heat from the soil below and hence may intensify cold damage. The effect of snow is to protect anything covered by it, but it may increase damage to the parts of trees and particularly young seedlings which are exposed above it.

Different species of trees vary in their resistance to frost, and in addition certain provenances of the same species may be more resistant than others. Frost resistance of the same species often varies within the season. It is low at the beginning of the cold season, then rises to a maximum which continues through most of the winter, and then falls again as spring approaches. It is for this reason that abnormally early and late frosts do more damage than mid-winter frosts even though the actual temperature in midwinter may be lower than during the autumn or spring frosts. Heavy fertilizing with nitrogen increases susceptibility to frost damage if it increases the growth of plants during a season of frost danger.

Frost causes damage not only directly by injuring the tissues of plants, but it may also cause drought injury, as the trees are unable to draw water from frozen ground. Even if the ground is not frozen low temperatures can reduce the rate at which water can be absorbed from it. Thus on an exposed windy slope tree seedlings may suffer damage from excessive transpiration in cold weather even if temperatures do not drop to the freezing point. In addition some tropical trees suffer harm at temperatures considerably above freezing point. Rapid thawing can increase the damage done by frost, and repeated freezing and thawing cause even more damage. Thus trees on slopes with an easterly aspect which catch the first rays of the morning sun can be expected to suffer more severe frost injury than those on other aspects. The very great contrast in Nepal between night and day temperatures may also increase the damage from frost.

Another form of damage is caused by frost lift or frost heave. When the water in the soil freezes it expands and thus the soil surface is raised. Subsequent thawing causes it to fall back again, but in the meantime young seedlings may be partially forced out of the ground and their roots exposed. Frost lift is a particular problem in bare-root nurseries, especially if they are on soils with a high clay content; it has also occasionally been observed in plantations in Nepal. Seedlings with well-developed root systems are less liable to suffer from frost lift than those with weaker root systems; mulching the seedlings with grass also reduces the danger.

In nurseries seedlings can be protected against frost by providing low shade over them at night. This reduces radiation from the ground and hence tends to increase the temperature near the ground surface. Nurseries should also be carefully sited to avoid particularly frosty areas. In plantations the most effective way of preventing frost and cold damage is not to plant susceptible species on cold or frosty sites. Which species are frost-tolerant can only be found by experience, but before planting a new species on a large-scale, small-scale trials should be made first. This is especially important if a species is planted at altitudes higher than its normal range, and with exotic species. An exotic species may tolerate freezing temperatures during part of the winter in its homeland but may still suffer from frost damage if planted under slightly different climatic conditions elsewhere, especially if frosts occur earlier or later than they do in the native country. The dangers of frost can in some cases also be reduced by planting the seedlings under an open cover of trees or shrubs.

Reference: Peace (1962).

Snow

Heavy snow can damage trees by breaking off their branches or by pushing them over. This is not normally a problem at most altitudes at which trees are planted in Nepal. Trees with downward sloping branches such as *Abies* species shed their snow load more easily than those with horizontal or ascending branches. A cover of snow will protect young seedlings beneath it but the parts of the trees above the snow are liable to frost and drought injury. This is in part because extremely low temperatures often occur over snow, which acts like a blanket and prevents heat radiating from the ground. In addition the air over snow often has a very low relative humidity which increases transpiration and damage by drought. An unusual snowstorm in the winter of January 1984 at Tistung, Makawanpur District, at about 1900 m, caused considerable damage to trials of exotic conifers in this way. Some species and provenances, however, were little affected and this gives guidance on the species which should be planted where such conditions are likely to occur.

Hail

Heavy hailstorms can damage trees by stripping off their leaves and damaging young twigs. They may also severely reduce seed production by stripping off the flowers; this has been observed, for instance in *Litsea cubeba* in the Pokhara area. The wounds caused by hail may serve as the entry points for fungus diseases. Little can be done to protect plantations against hail. In nurseries where hail is a danger the seedlings should be protected by shades during periods of hail risk, the shades being dense and solid enough to prevent hail penetrating them.

High winds

Strong winds can uproot trees or snap their stems. Strong, dry winds can also cause excessive transpiration and damage to leaves and succulent twigs. Over most of Nepal the strongest winds occur in gusty squalls at the beginning of the monsoon. Damage to forests and plantations caused by gales is rare, and little can be done about it apart from seeing that the trees are planted properly, and in particular that the roots do not curl round and strangle each other (Bohora and Basnet, 1983). The very strong, drying winds which blow regularly along some of the inland valleys of Nepal, such as at Jomsom, cause considerable problems by their desiccating effect on the vegetation. A possible way of mitigating this damage would be to first establish a shelter belt of some resistant species at the windward side of the proposed plantation, and planting to the leeward of this, so that the plantation gradually moved downwind.

Drought

Drought is normal in most parts of Nepal between October and May–June, and is one of the main factors governing plantation techniques, including the choice of species, planting early in the monsoon, the use of container-raised plants, and reduction of competition by grasses and weeds. Apart from the very arid zone north of the Himalaya these techniques will enable successful plantations to be raised in all but the most unfavourable years. Provided that the rains continue into September the planted trees should be capable of withstanding the subsequent period of drought.

Grazing and browsing by domestic animals

Grazing, browsing and trampling by domestic animals causes considerable damage to young plantations; as is shown by the figures from the Community Forestry Development Project, set out in Table 16.

Table 16—Percentage of seedling mortality caused by domestic livestock

	Planting year	
	1981 and 1982	1983
CFD plantations		
main cause	10.2	15.0
secondary cause	32.1	48.6
Private plantings		
livestock damage	33.0	35.0

Sources: J.G. Campbell and Bhattarai (1983b); Community Forestry Development Project (1984).

The most effective way to reduce grazing damage is to persuade the local people not to graze their animals in young plantations. There has been considerable success in achieving this in some areas. According to Gilmour (1983) in the Nepal–Australia Forestry Project in Chautara the concept of forests without fences has become a reality and this is also true of a number of other areas. To achieve this, close involvement of the local people in forestry activities and planning is necessary, so that they will voluntarily keep their animals out of newly planted areas. As a back-up to this it is customary to appoint village forest watchers to put straying animals in pounds, to warn offenders and if necessary to bring them before the village authorities for trial. (The employment of forest watchers (*heralu*) is a traditional practice in Nepal.) Various village development committees have drawn up schedules of fines (which can often be commuted into so many days labour) for offences: see, for example M. Stewart (1984). However for such sanctions to work they must be accepted and considered reasonable by the community as a whole.

If people are not allowed to graze their animals in young plantations provision must be made for them to obtain the fodder needed by their animals from other sources. For instance, villagers are generally allowed to cut grass and carry it to their homes for stall feeding. This has the additional advantage of reducing fire hazard in the plantations. Areas where grazing is less likely to cause damage can be set aside for this purpose, and the growing of fodder trees and in some cases the planting of improved fodder grasses and legumes can be encouraged. Domestic animals differ in the damage they do to young trees. Cattle and sheep generally prefer grass to trees unless they are very hungry and the tree leaves are especially palatable; cattle, however, can do a fair amount of damage by trampling on young trees, and very heavy grazing can result in soil compaction and increased erosion. Buffaloes and horses are more likely than cattle and sheep to bite off the tops of young tree seedlings. Goats prefer browsing woody plants to grazing and are the most injurious animals in plantations.

Grazing damage can be reduced to some extent by silvicultural techniques. Large well-developed seedlings with lignified stems are less likely to suffer severe damage from grazing than are small soft-stemmed seedlings. Species also vary in their palatability; *Alnus nepalensis* is little damaged by grazing animals once the plants are over 50 cm tall. It is therefore possible to reduce grazing damage by choosing unpalatable species. However if growing trees for fodder is one of the main aims of the plantation it is obvious that the trees planted must be palatable to grazing animals.

Fence construction

While the most desirable way of preventing grazing damage in plantations is to persuade people to keep their animals out of the plantation voluntarily, there are places where this is impracticable, and it will be necessary to construct artificial barriers such as fences, walls or hedges. Such barriers are expensive and indeed often account for half or more than half of the plantation costs, especially if the areas planted and protected are small. The cost of fencing per unit area of square plantations is proportional to the square root of the total area, so that to protect one hectare of plantation by itself costs ten times as much per hectare as the cost of protecting one hectare in a hundred-hectare block. Table 17 gives the length of fence needed for square blocks of different sizes.

Table 17—Length of fence per unit area for square plantations

Area (ha)	Length of fence (m)	Length of fence per ha (m)
1	400	400
2	566	283
3	683	231
4	800	200
5	895	179
6	980	163
7	1058	151
8	1131	141
9	1200	133
10	1265	126
20	1789	89
30	2191	73
40	2529	63
50	2828	57
100	4000	40

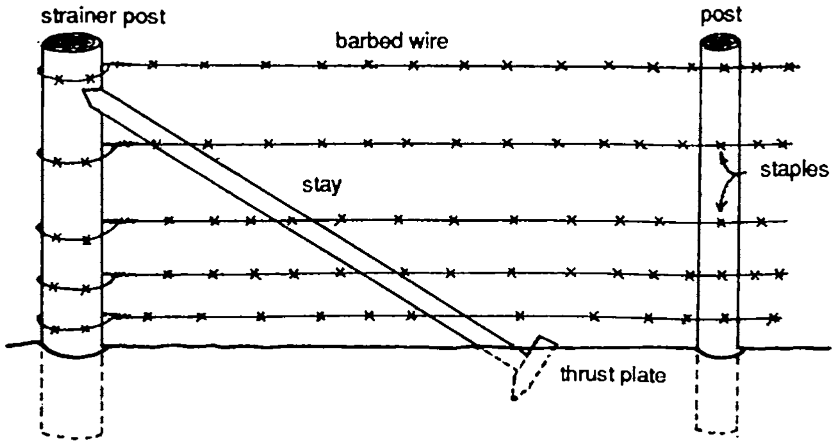
For rectangular blocks, with the long side twice as long as the short side, the length of fence per unit area must be increased by approximately six per cent; if the long side is four times as long as the short side, the length of fence per unit area is 25 per cent more than for a square plantation. Thus fencing is cheapest if the area protected is as near square as possible; however small deviations from squareness are not very important. For instance a 144-ha square plantation would need 4800 m of fence; the same area if 900 m by 1600 m would need 5000 m. Re-entrants and sharp angles should however be avoided.

The cheapest reasonably permanent form of barrier is the barbed wire fence; it is not as efficient as a well-built stone wall, but in general walls cost something like three or four times as much to build as fences, depending on the availability of stone. The construction of barbed wire fences is described in detail by Fearnside and Drew (1977) and their paper should be consulted for further information. For plantation protection five strands of barbed wire are recommended. The lower strands should be closer together than the upper ones. A suitable arrangement would be to have the lowest strand about 18 cm above ground level, and then strands at 18 cm intervals until third one above ground level, and 30 cm between strands above this. The total height of the top strand from the ground would then be 114 cm. Posts should be 3 m apart with stouter posts (strainers) at the corners and say every hundred metres on straight lines. At corners the strainer posts need to be supported by diagonal stays which are notched in to the strainer near the top, while their base rests against a thrust plate. The angle between the stay and the strainer should not be greater than 40° and the angle between the thrust plate and the stay should be slightly less than 90° (see Figure 6). The stays should follow the fence line where there is a right-angled corner, but on wide-angled corners they should bisect the internal angle and point into the plantation.

If sawn timber fence posts are used the standard specification is *Shorea robusta* timber 6 ft x 4 inch x 3 inch (180 cm x 10 cm x 7.5 cm); these posts can be used both for strainers and intermediate posts. However such posts are expensive and difficult to transport, and in many areas it will be necessary to rely on round posts from the local forest. They should be 1.8–2 m long and about 15 cm in diameter for the strainers and 10 cm for intermediate posts. Durable timber should be selected for fence posts. Charring the ends before putting them in the ground will reduce the danger of rot. Posts should be set 45–60 cm in the ground. If the ground is fairly soft the posts can be sharpened at the end and driven in with a large wooden mallet. If the ground is too hard for this, holes will need to be dug first, using a crowbar. The holes should be only slightly larger than the diameter of the posts, and the soil should be rammed firmly round the base of the pole up to ground level, using the blunt end of a crowbar or similar instrument.

It is very important that the wire should be strained tightly and not allowed to sag between the fence posts. The end of the wire is fixed to the first strainer by tying it to the post and fixing it firmly with staples, and then the wire is rolled out to the next strainer post and strained tightly to it. Special tools exist for this purpose, such as the Donalds wire strainer, but if these are not available a crowbar (*gal*) with a good deep notch between the prongs at the curved end can be used. A labourer takes the end of the barbed wire between the prongs of the crowbar, just behind the barb, and using the strainer post as a fulcrum pulls the wire round the strainer post as hard as he can. When he can strain it no tighter another labourer on the opposite side of the post hammers in a staple, preferably just behind one of the barbs of the wire, to anchor the wire and stop it slipping back. This method does not give as good a result as the use of a proper

Figure 6—The components of a barbed wire fence



wire-straining tool but is adequate for most purposes. After the wire has been firmly stretched between the strainer posts it should be fixed to the intermediate posts by staples. The staples should be at an angle, not vertical, and their points should point downwards, except when the fence is going across a hollow, when the points should point upwards against the pull of the wire.

Care should be taken on uneven land that gaps are not left between the bottom wire and hollows in the ground. This can often be avoided by the arrangement of the fencing posts. Gullies beneath the fence can sometimes be blocked by fixing saplings horizontally across them. Provision should be made for access to the plantation by building stiles (for humans only) or making gates if animals or vehicles need to enter the area (which will not usually be the case).

The type of fence described above will be enough to keep domestic animals out of the plantation area provided their owners do not make deliberate efforts to let them in. To keep people from climbing through a fence it is necessary to increase the number of strands to six, and to put additional strands cross-wise diagonally between the fence posts. Even if this is done, really determined people will find a way to get through a fence, so the extra expense in making this type of fence is rarely justified. In areas where there is reasonable co-operation from the local people it may be sufficient to fence only particularly vulnerable areas, such as those running along well-used cattle trails, while the remaining sides of the plantation from which there is less danger are left open. Even a well-constructed fence will not keep out domestic animals if their owners are determined to allow them to enter the plantation; they will cut the wire, or twist wires together to make gaps large enough for animals to pass through. The appointment of guards or watchers is essential. They should be responsible for regularly inspecting the fence and repairing it when necessary, and also for removing animals which have entered the plantation illegally.

Considerable economies in fencing can be achieved if the wire, and the posts if they are still sound, are removed and used elsewhere when the fence is no longer needed, such as when the trees are large enough to be immune to grazing damage. Also where there is a regular planting programme the fence forming one side of the first area planted can be moved to form part of the boundary of the extended area, and this can be continued in subsequent years. It is sometimes more economical to fence areas for several years' planting in advance, rather than to move fences and extend them each year over comparatively small areas. The agreement of the local people to this should first be obtained. Table 18 gives the materials and labour required for fencing. It may need to be modified to suit local conditions.

Table 18—Materials and labour per 100 m of barbed wire fence

	Five lines of wire with no diagonals	Six lines of wire with diagonals
Strainer posts	1	1
Intermediate posts	33	33
Stays	2	2
Thrust plates	2	2
Barbed wire	500 m (50 kg)	820 m (80 kg)
Staples	3 kg	4.5 kg
Digging holes for posts	5–7 man-days	5–7 man-days
Stretching and fixing wire	10–15 man-days	11.25–18 man-days

Notes: Modified from Ministry of Forests and Soil Conservation, 2040-2041 (1983). These figures assume 100 m between the strainer posts, and 3 m between intermediate posts. It is assumed that 14-gauge barbed wire (weight 1 kg 10 m^{-1}) is used; if 12-gauge wire, weighing 1 kg 7 m^{-1}, is used, the weights will need to be adjusted.

In some areas it may be possible to use live fence posts. These are made from large cuttings, about 2 m long and a minimum of 7.5 cm in diameter, of species which can be propagated in this way. These include *Erythrina* and some *Ficus* species. It is better to try to root the cuttings round the plantation area a year before planting and fixing the wire, so that casualties can be replaced before the wire is fixed. The distance between live fencing posts should be closer than between ordinary posts, say 2 m or less. Where the live posts have not rooted it may be necessary to substitute cut posts for them, and it will probably be necessary to use cut posts for the strainers.

Walls

Stone walls are more durable than barbed wire fences and are much more difficult to make temporary gaps in; they are, however, considerably more expensive to erect, though they do have the advantage of using only local labour and materials. The art of constructing stone walls is well known to Nepalese in the hills, and does not need to be enlarged on here. Walls should generally be 45 cm wide and about 180 cm high, of which 60 cm is below ground level. The height above the ground should be at least 120 cm, when measured at the outside of the wall. Thorny shrubs planted on the top of the wall may help to keep goats out; a species often used for this purpose is the crown of thorns, *Euphorbia milii* (labre khada phul), but others might be tried. Sometimes lower walls, about 60 cm high, with thorns planted above them, have been found enough to keep grazing animals out of the plantation, though in this case they are probably more a symbolic boundary than an efficient physical obstacle. On steeply sloping ground it has been found possible in some places to keep animals out by digging a sort of terrace across the slope with a vertical face about a metre high. The efficiency is improved if the spoil is stacked above the vertical face. Such methods should only be used on stable slopes where the subsoil is consolidated enough to maintain a vertical face; they should certainly not be used where there is any possibility of landslides.

Hedges

The substitution of living hedges for barbed wire fences or other artificial barriers is sometimes possible, but hedges have a number of limitations. They need to be established several years before the plantation work, or else must themselves be protected by barbed wire or other means until they have grown to a suitable size. They need frequent tending and trimming. The soils round the perimeter of a plantation may not all be suitable for the best hedge species, and gaps may form where the plants have died or failed to grow vigorously. They need quite a lot of planting material. In general the care and effort needed to establish a good hedge is at least as much as is needed to make a good plantation.

Against this hedges if well cared for are more permanent than barbed wire fences. They provide shelter, and if strategically sited round nurseries can reduce the flow of cold air in winter and hence the danger of frost; however care must be taken not to create artificial frost hollows by planting hedges across the mouths of valleys. They can also act as shelter belts against desiccating winds. Trimmings from hedges can provide a certain amount of fodder and small fuelwood. Hedges can also be ornamental and are more attractive to look at than wire fences. Hedges round plantations will generally be more useful in demarcating the boundary and providing a mild deterrent to grazing animals, than in forming stock-proof barriers, though it is possible by using the right species, and with careful maintenance, to make a stock-proof hedge.

The best species for hedges are tough, thorny plants which produce plenty of side branches, and which do not grow to a great height, though their initial rate of growth should be as fast as possible. To keep out stock hedges need to be quite strong; a full-grown buffalo can exert a good deal of power. Some Nepali trees and shrubs which could, if well-tended, be expected to form fairly stock-proof hedges are *Pyracantha crenulata* (ghangaru), *Berberis* spp. (chutro), *Mahonia acanthifolia*, *Prinsepia utilis* (dhatela) and *Elaeagnus infundibularis* (mahonia). For lower altitudes *Pithecellobium dulce* (jalebi) makes quite a good hedge, though it is not as sturdy as the species mentioned above. Other species which might be useful in the Terai are *Ziziphus* spp. (bayer) and thorny acacias (*Acacia nilotica*, *A. farnesiana*). Some succulents also make good hedges if they are planted at close spacing; these include prickly pear, *Opuntia monacantha* and other species (hathi kane), *Agave* spp. (kettuke), and *Euphorbia royleana* (sihundi). Other species are listed in M.W. Campbell (1983a) and K.K. Shrestha (1982), though many of these are mainly ornamental. Macmillan (1956) also lists a number of species suitable for hedges in tropical countries.

Hedges can be raised from seed, seedlings or cuttings. If they are to be raised from seed a strip along the line of the hedge about 50 cm wide should be thoroughly cultivated and the seed sown along it about 10 cm apart. Seedlings and cuttings of most species should be planted about 25 cm apart, though *Agave* can be planted at a wider distance, say 50–60 cm. It will be seen that unless seed is used quite large numbers of plants will be needed. A ten-hectare plantation, 400 m x 250 m, would need 5200 seedlings or cuttings to make a hedge round it. Hedges will need to be weeded regularly until the plants are well established. Once the hedge has reached the required height it will need to be trimmed and cut back regularly, otherwise the hedge plants will become leggy with gaps between them. In England thorn hedges used to be laid regularly, by cutting half way through the stems of the shrubs, bending them over more or less parallel to the ground, and fixing them in this position by tying or with pegs. If this is done regularly, and the hedges well-trimmed, a stock-proof hedge can be established.

Fire

Forest fires in Nepal, though possibly less severe than in some other tropical countries, are still quite prevalent and are capable of doing considerable damage, especially to young plantations. Many of the natural forest species have developed some resistance to fire, by such means as thick bark, capability of sprouting from the roots after burning, and (in young pine trees) developing a dense mass of foliage to protect the leading shoot. Thus natural forests in the Terai and Middle Hills can withstand some degree of burning. There are areas in the plains of India where protection against fire tends to convert, for instance, *Shorea robusta* forest into a wetter, less commercially valuable type. However if such areas are found in Nepal at all they are of relatively small extent. Against this many species in the high mountains, such as *Abies*, are very sensitive to fire and are easily destroyed by it. In Nepal generally the policy should be one of complete protection against uncontrolled fire. This is especially important in plantations where even if young trees are not completely killed by fire, their growth will suffer while damage to the stems will increase the danger of fungus and borer attack.

The most effective way of protection against fire is to stop fires being lit. Very few, if any, fires in Nepal are caused by natural causes; man starts the fires, either by accident or design. Karkee (1991) found in the areas of the Middle Hills that he studied 40 per cent of fires were caused by accident and 60 per cent deliberately. He includes as accidental causes carelessness in the use of cigarettes and matches, escape of fire from land being cleared for cultivation, and smouldering charcoal left by charcoal burners. Elsewhere honey collectors who use fire to smoke out wild bees are a frequent source of accidental fires. Fires were started deliberately to kill trees so that the dead wood could be used for fuelwood, to induce new grass growth for cattle grazing, to clear forest for farming, to make fuelwood and fodder easier to collect, and for hunting. Fires are also sometimes started maliciously by people with a grudge or complaint against the forest owner or manager. Thus the main task is to persuade people not to burn the forest deliberately, and to be careful to prevent spread of fire into the forest from other activities. As more forest comes under the control of user groups it is to be hoped that they will see that it is in their interest to prevent fires, and that the force of public opinion will deter fire-raisers. Publicity and extension activities on the danger of fires should be increased.

Plantations and sensitive areas of natural forest should be protected by firebreaks. Ideally these should be 6 m wide and cleared of all vegetation so that the bare soil is exposed. However in hilly country such wide firebreaks would be liable to cause erosion, and 2 m breaks may be all that is possible. In large plantation schemes in the plains firebreaks can be combined with a system of roads, as has been done in the Sagarnath scheme (K.J. White, 1988d). If plantations are well weeded, or intercropped, the fire hazard will be very considerably reduced; in some circumstances cattle grazing can reduce fire hazard, provided this is done after the young trees are big enough not to be in danger from the animals. If fires break out they will need to be put out as soon as possible. In a large plantation scheme this will require the provision of fire towers or other look-out posts and trained fire crews. The towers should be equipped with radios (such as walkie-talkies), to communicate with a central fire control point, which can direct fire crews to the source of the outbreak. An alternative is to station fire crews at the look-out posts themselves. Fire crews should be equipped with back pumps, axes, and rakehoes (a combined hoe and rake, used to clear up and isolate smouldering debris), and should have mechanical transport. Mechanized trailer pumps and water tankers are an advantage.

Naturally all this sort of thing will be impossible for the protection of village forests in the hills. Watchers should have as part of their duty reporting outbreaks of fire, and calling on the local people for help in putting them out. Light fires can be extinguished by using green branches to beat out the flames; rural people are quite familiar with the techniques needed. The important thing, again, is to mobilize public opinion against fire, and to demonstrate to the local people that it is in their own interest to prevent and control forest fires. Once a fire has been extinguished it is important that a watch should be kept on the burnt area, to ensure that smouldering debris does not again burst into flame, and start the fire again.

Injuries caused by wild mammals

Deer such as chital (*Axis axis*) and sambar or jarayo (*Cervus unicolor*) can cause considerable damage to young trees both by browsing and by injuring the bark by rubbing it with their horns. To keep deer out of a plantation a fence 2–2.5 m high is needed, with the wires closely spaced. Wire mesh with squares about 12 cm x 12 cm has also been found to be effective. The cost of such fences, however, prevents their use except under very special circumstances and if plantations are established where deer are prevalent the best solution is to plant unpalatable species.

Wild pig (*Sus scrofa*, bandel) cause some damage by rooting up the ground in plantations, during which they may damage the trees, but this damage is relatively slight. They also cause damage to the bases of trees by stripping off their bark. Porcupines (*Hystrix indica*, dumsi) also damage trees by tearing off the bark. Langur monkeys (*Presbytis entellus*, bander) sometimes do considerable damage by eating young shoots of some species, particularly *Dalbergia sissoo*. A troop will work systematically throughout a plantation, eating all the young shoots as they go.

Bamboo rats (*Cannomys badius*), which superficially resemble moles but have two very prominent incisor teeth, make underground runs along which they sometimes bite off the roots of young seedlings. Mole-rats or bandicoots (*Bandicota* spp.) have similar habits. Other rodents which damage young seedlings are rats and mice of various species. In nurseries the damage may be so serious as to justify the enclosure of seed beds by wire mesh cages. Rodents may be controlled by the use of poison baits; zinc phosphide is one such material, but is dangerous to humans and domestic animals and should only be used under the most careful supervision. Warfarin is less toxic to humans, but is not readily available in Nepal. Damage by rats and mice in plantations can be reduced by planting large, well-lignified seedlings, the stems of which are not so easily bitten through. In some countries damage has been reduced by keeping the ground between the trees free of vegetation in which the rats and mice can hide, and thus making it easier for predatory birds, such as hawks and owls, to catch them.

Hares (*Lepus nigricollis*, kharayo) also cause damage to young trees in plantations; again planting larger seedlings can reduce the damage. Apart from rats and mice, and in some places hares, wild animals do relatively little damage in plantations other than in some rather restricted localities, e.g. near the boundaries of national parks. If plantations have to be established in such areas the use of unpalatable species, and also species which readily shoot from the roots if the stems are damaged, is usually the only practicable way of minimizing the damage.

Diseases and insect pests

In plantations in Nepal, in contrast to nurseries, it is rarely practicable to try to control plant diseases and insect pests by chemical means. Such control is expensive, and also often involves the release of large quantities of harmful chemicals into the environment which in addition to killing the pests may also kill useful insects, as well as birds and other wildlife. More satisfactory and feasible means of reducing the danger of attacks by diseases and insects are to plant species or provenances which are less susceptible to injury, and to modify silvicultural practices.

With regard to the choice of species, it is not generally correct that exotic trees are more liable to insect and disease damage than are indigenous trees. Of course if exotic trees are planted in areas which have soils and climates that are unsuitable for them, their growth will be weak and stunted. Such trees are more liable to damage by disease and insects than well-growing, vigorous trees, but this will also apply to indigenous trees grown on unsuitable sites. There are, however, no hard and fast rules. Sometimes an exotic tree when transferred to a new locality will leave its pests behind; this has largely happened with eucalypts. However it can also happen that the pests eventually catch up, as happened with the *Leucaena* psyllid. Against this, some of the most devastating epidemics have been caused by an exotic pest or pathogen attacking an indigenous species; examples are the destruction of indigenous elms in Europe, and of chestnuts in the United States.

The first steps to reduce damage by insects and fungi are by prevention. This begins at the frontier of the country, where plant quarantine regulations are intended to prevent the importing of diseased material and harmful insects. Plant quarantine is not the responsibility of the Department of Forests, but forest officers returning from outside Nepal should observe the quarantine regulations and not attempt to bring in plant material which is likely to be the source of disease. Diseased plants should never be taken from the nursery to the plantation, but should be burnt. It is better to fall short of a plantation target than to run the risk of bringing in a disease which may kill large numbers of trees. Within the plantation, trees seen to be diseased should be cut down and burnt. This may not always be completely effective as the disease may have become established before the first symptoms are seen, but is likely to reduce the damage. Dead trees and felling debris should be removed from the plantation—in Nepal there is often a demand for such material for fuelwood—or otherwise burnt in or near the plantation. Insects and diseases are often able to enter the stems of trees through injuries to the bark. Thus care should be taken in forest operations such as thinning not to damage the bark of the trees left behind. When branches are pruned off the cut should be level with the stem of the trees and care should be taken not to tear off strips of bark during pruning.

As previously mentioned the best way of reducing disease and insect damage is to plant resistant species or provenances. Different provenances within a species may show considerable variation in their susceptibility to disease; for instance different clones of the euramerican poplar hybrids vary greatly in their susceptibility to bacterial canker, and it is likely that susceptibility to brown needle disease in pines may vary with the provenance. Also some species of trees may be more susceptible to a given disease if planted on certain sites, while on different sites the degree of damage may be much less. Insect damage to some species may be reduced if they are planted in mixed plantations, or as an understorey. Trees of the Meliaceae, such as *Toona ciliata* are reported to suffer less damage from the shoot borer, *Hypsipyla robusta*, if they are planted in mixed plantations or under shade. In India, *Michelia champaca* is often planted in mixed plantations because of the danger of attack by the champ bug, *Urostylis punctigera*, but serious damage from this insect has not been recorded from Nepal.

Termite damage to certain susceptible species may be controlled by mixing insecticide with the seedling potting mixture. The only important species planted in Nepal for which this may be necessary are eucalypts, and even with these damage is rare. Insecticidal treatment of the potting mixture should only be used where there is a real danger of serious termite damage, as it involves the use of persistent insecticides which may be harmful to the environment.

The more important diseases and insect pests of trees in Nepal are dealt with under the individual species, but no attempt has been made to list all the defoliators and minor diseases which have been recorded from various species, partly because they do relatively little damage, and partly because little can be done in practice to control them. A list of some papers on fungus diseases in Nepal can be found in the References to this chapter. At the present time in Nepal there are two potentially serious diseases of pines, brown needle disease caused by *Cercoseptoria pini-densiflorae* and a needle rust caused by *Coleosporium campanulae*. Both of these need to be kept under very careful observation, as they could reach epidemic proportions. The two most potentially harmful insects are the toon stem borer and the champ bug, referred to above. Neither has so far been recorded as causing appreciable damage in Nepal, but it would be surprising if pure plantations of *Toona ciliata* escaped borer attack.

Crickets and grasshoppers cause considerable damage in young plantations by biting through the stems of young seedlings, but this damage could be greatly reduced by planting well-grown nursery seedlings.

While up to the present few really serious diseases and pests have been recorded on plantation trees in Nepal it is necessary to be vigilant in watching for signs of disease or insect damage, and reporting them to a responsible authority as soon as possible. This may enable steps to be taken to eliminate a dangerous disease or insect pest before it becomes a serious problem. Diseases and insect pests in nurseries, and their control, are dealt with in Chapter 9 on page 197.

References: For general information on fungal diseases in Nepal see M. Karki (1992) and Pawsey (1989); other references on Nepal fungi are Adhikari (1988); Adhikari and Manandhar (1989; 1990); Adhikari *et al.* (1987); Bhatt (1966); Cotter and Adhikari (1987); Durrieu (1980; 1987); Ivory (1990); Pandey (1976); S.C. Singh (1968); Singh and Joshi (1977); M. Thapa (1990a; 1990b; 1990c). For general information on insects and fungi see Browne (1968); Gibson (1975; 1979); Peace (1962).

Chapter 12

MANAGEMENT OF NATURAL FORESTS

Introduction

This book is a manual of afforestation, and hence is primarily concerned with the establishment of forest plantations. However plantations are not the only way of providing needs in forest produce, nor necessarily always the best. In many places management of the natural forest will be a better solution. Plantations should, if properly managed and cared for, give a considerably higher yield than natural forest; they can introduce valuable species which are not present in the natural forest; and they are a means of establishing forests on bare unproductive ground. However they are relatively expensive to establish, and their success depends on a number of factors, not only silvicultural—choosing the right species, raising good nursery stock, planting at the right time, preventing competition from weeds—but also administrative, such as release of the funds for a nursery in time to raise plants of the size needed for planting, supplying materials, and so on. In short many things can go wrong in establishing plantations, and the results may be an expensive failure. There is no need for such mishaps to occur, and good plantations can be, and have been, established. But there also, sadly, many cases of failed plantations.

In managing natural forests there are far fewer things that can go wrong, and if errors are made they are rarely irremediable. Costs are relatively low, and large external inputs unnecessary. Simple techniques which can be used by local communities can be devised. Thus, if suitable areas of natural forest are available, consideration should be given whether it would be better to manage these areas to provide for the needs of the community, rather than to establish plantations. In this chapter no attempt will be made to deal with large-scale management of natural forests on a commercial basis, such as managing *Shorea robusta* and pine forests for timber. Information on these subjects can be found in standard textbooks, such as Troup's *Silvicultural Systems* (1952), or his *Silviculture of Indian Trees* (1921) together with the revised edition currently being produced by the Forestry Research Institute, Dehra Dun. What follows is confined to describing some techniques which have been used in natural forest management in Nepal, with some general observations and examples. Emphasis is on possible techniques which could be used by local communities to manage natural forest for their own needs. The discussion will be confined to silvicultural aspects of forest management. It is appreciated that human factors are possibly of even greater importance; more failures are caused by poor human relations than by bad silviculture. Such matters as the formation of truly representative user groups, thoroughly involving them with the planning (ideally they should do this themselves, with only technical advice from the Forest Department), equitable distribution of forest products, are extremely important, but cannot be discussed here.

There is a long-standing tradition in Nepal of local communities managing their own forests. This was disrupted to some extent by the nationalization of all forests in 1957 but it continued in an informal way in a number of localities, and is often responsible for the preservation of what natural forest continues to exist today. Control was by such methods as specifying the type of produce that could be removed, and sometimes the amount, for instance dead wood only, or so many basket loads of litter per family; the area from which it could be removed; the type of tool to be used, for instance only sickles and not axes; the time when it could be taken, for instance the forest might be open for one week twice a year for fodder collection; and the people who could collect it, for instance the inhabitants of a certain village or ward. More details can be found in Tamang (1990). In many places watchers (*heralu*) were employed by the villagers, and paid for by them, sometimes in cash but often by collecting a certain amount of rice from each user household (*manapathi*). Sometimes each household took it in turn to provide a *heralu* from its family members.

In many places the management practices adopted were very conservative, for instance confining exploitation to the removal of dead wood, grass and leaf litter. This has had the effect of preserving much forest which otherwise might have been destroyed, but this conservative tradition has sometimes made it difficult to persuade local people that it is possible to combine preservation with making greater use of the forest. As Karmacharya (1987) writes 'Cutting trees is not bad in itself; a forest is a resource which should be utilized regularly in a managed way'. It is not always easy to get this idea across.

General principles

Most management of natural forest will be undertaken by local user groups, with some help and guidance from forestry officials. Thus it is essential that plans for forest management should be simple, easy to understand, and capable of being undertaken by villagers. They should aim at sustainable forestry through measures that, over a period, will ensure that yields of forest produce will not decrease, and if possible will increase, and the protective aspects of the forest will be preserved. In many cases this can be done without an inventory first being made. If, for instance, it is decided to manage a *Shorea robusta* forest on an eight-year rotation, the area can be divided into eight parts and one part cut each year. There may well be annual variations in the quantities produced, but these are relatively unimportant; yields of agricultural crops also vary from year to year. Plans must however be flexible, particularly when they are first introduced, as this should be a time when much is being learnt by experience. For instance in the crude example mentioned above the local people might find that six years was long enough to produce the size of wood they needed, and should be able to modify the plan to meet this.

Local people 'require a plan based on a description of which trees to cut or leave, rather than on quantities' (Chand and Wilson, 1987). The first step in preparing a management plan should be to decide what is wanted from the forest—the sorts and sizes of forest produce. Is the main local need for fuelwood? If so, what is the preferred size? (In considering this it should be borne in mind that most fuelwood is collected by women, who should have the main say in deciding this.) Is there a demand for small poles or for larger timber to be sawn up for house building? Should provision of fodder for animals take priority? After these decisions have been made—and there may need to be a compromise between the different goals—a plan for the management of the forest can be drawn up.

Management methods

Most natural forest managed for local use, except areas set aside exclusively for fodder production, will be managed under some form of coppice or coppice with standards system. The exceptions are conifer forests—pine forests at lower altitudes and species such as *Abies* and *Tsuga* at high altitudes—as these species will not coppice. Forests for fodder production could be managed by pollarding or some form of controlled lopping.

Coppice consists of felling the trees at or near ground level, usually when they are relatively small, so that they regenerate from shoots from the cut stumps. All the trees may be cut simultaneously on a given area, which is clearfelling, or only some of them cut at one time. One method is to cut half the trees in a given year, and half in the next year, which avoids complete exposure of the soil and can be expected to reduce soil erosion. It is also possible to work a system of selection coppice in which only a few trees are cut in a given area in each year, and this is repeated every year, the trees to be cut usually being selected on the basis of size, the largest being cut each year. This can become rather complicated and is not dealt with further here. As much of the demand in

Nepal is for relatively small sizes of wood for fuelwood, coppice rotations will generally tend to be short, of the order of five to ten years, though this will of course depend on species and growth rates.

Other operations which may be needed under coppice systems are pruning, singling and thinning. Pruning is largely to provide fodder, and will generally be done when the forest is about to close canopy; it should not exceed half the height of the tree in general purpose coppice. (This would not necessarily apply to forest managed primarily for fodder production.) Singling in the strict sense consists of removing all but a single stem from each stool, but can also be used more loosely for reducing the number of shoots to two, three, four, etc. This produces fodder and some fuelwood, and also increases the rate of growth of the shoots left. The shoot or shoots to be left should be selected for their vigour, and if pole production is one of the objects of management, for straightness. One very important aspect of singling is that it allows some yield from the forest before it is mature enough for clear cutting, while at the same time minimizing any potential damage to the forest from overcutting.

Thinning is when some of the trees are removed to favour the growth of those left behind. The intention is that the trees felled in thinning will be removed permanently, though in practice they will shoot from the stumps like other cut trees. The shoots arising can be cut each year, until the rest of the trees are coppiced. Like singling, removal of shoots from thinned coppice stumps will provide some fodder and fuelwood. Thinning can be directed towards favouring the most valuable species, which will often be multipurpose species or those which yield good fodder, or the best-shaped and most vigorous trees. After thinning the remaining trees should be, as far as possible, evenly spaced through the area.

In coppice with standards some trees are kept as standards when the remainder are coppiced. The standards are expected to live through several coppice cycles, to provide large poles and timber; valuable fodder or fruit trees can also be retained as standards. The management of the coppice between the standards is similar to that of simple coppice, described above.

Management of different forest types

Among the most important types of forest to be managed under some sort of coppice system are *Schima-Castanopsis* forest in the Middle Hills, and *Shorea robusta* forest in the Terai and at lower altitudes in the hills. Fortunately in both these types of forest the useful species coppice very readily, and both have a great capacity of recovery after quite severe degradation.

Schima-Castanopsis forest

Degraded forest in which *Schima wallichii* and species of *Castanopsis* are characteristic species is very common in the Middle Hills. It is often reduced to a scrubland of coppice shoots, sometimes with a few larger trees scattered among it. However, if protected, much forest of this type can recover quite rapidly. If the forest is very degraded the first step may have to be protection, in which all cutting and grazing is excluded for a number of years, until the trees begin to close canopy. Thereafter controlled exploitation can begin.

Experiments in different management practices for this type of forest have been laid down near Nagarkot, Bhaktapur District (1700–1800 m), and in Khalti, Sarangot, Kaski District (950–1120 m) (Forest Research Division, 1991; Tamrakar, 1992; Thompson, 1986; 1988a; 1990a; 1990b; Thompson *et al.*, 1990). Tamrakar's paper gives details of the yields from the Nagarkot plots. In these plots six treatments were applied.

- (1) Simple coppice; clearfelled after canopy closure (five years old in this case). At three years old, this was singled to 2-4 shoots per stump and at four years to one shoot per stump, when it was also pruned to half tree height. Singling to one shoot per stump continued in the two years after felling.
- (2) Phased coppice; half felled at canopy closure, half in the following year. Singling took place at four and one year before felling, and continued in the years after felling. The trees left after the first felling were pruned to half height.
- (3) Coppice with standards regular. Coppice felled after canopy closure, leaving 35 per cent of the canopy as regularly spaced standards, irrespective of species. Singling took place five, two, and one year before felling, and in the coppice after felling. In the year before felling the trees were pruned to half height.
- (4) Coppice with standards irregular. As in (3), but multipurpose species favoured as standards, and regular spacing not essential.
- (5) High forest. Thinned to maintain the crown cover at about 75 per cent, the thinning to release selected trees from crown competition. Understorey singled. Thinning began five years after the plots were established, and thereafter continued annually, together with singling the understorey.
- (6) Control. No treatment.

Yields from the simple coppice (1), on clearfelling at the age of five years were 12 t ha^{-1} of foliage and 16 t ha^{-1} of wood less than 4 cm in diameter. Phased coppice (2) yielded 13.5 t ha^{-1} foliage and 14 t ha^{-1} of wood at the first cut, and 12.7 t ha^{-1} of foliage and 20.5 t ha^{-1} of wood at the second cut. Coppice with standards (3) and (4) yielded about 10 t ha^{-1} of foliage and the same amount of wood at the time of coppicing. To this must be added the yields from singling and pruning, and thinnings in treatment (5) high forest. Altogether over a five-year period, and including the standing timber left, the mean annual increments were as shown in Table 19.

Table 19—Yields from natural forest at Nagarkot (green t ha^{-1} yr^{-1})

Treatment	Foliage	Branchwood	Stemwood	Total
Simple coppice	6.8	7.3	—	14.1
Phased coppice	6.7	10.0	—	15.7
Coppice with standards, regular	5.8	5.1	3.0	13.9
Coppice with standards, irregular	6.1	5.7	2.0	13.8
High forest	4.9	3.4	2.8	11.1
Control	1.7	1.7	7.0	10.4

Note: Branchwood includes all wood less than 4 cm diameter.

Thus it will be seen that managing of this type of forest under different forms of coppice system produced a mean annual yield of green biomass of between 13.8 and 16.7 t of which 40–48 per cent was foliage and the rest wood. These figures are given to illustrate the general magnitude of the yields likely to be obtained; they will of course vary greatly in different localities. The treatments applied are also only some of the many different treatment combinations which could be used. In practice it would be necessary to lay out a series of plots. For instance in the simple coppice treatment in this particular experiment almost 50 per cent of the total yield, and over 60 per cent of the yield in wood, was obtained in the year of coppicing, when the trees were five years old. To roughly equalize the annual yield there should be a series of five plots, with one plot being coppiced annually. Plots not ready for coppicing could be singled annually.

Operations for improvement of shrubland have also been described by H.B. Pradhan and Rautianen (1990) but in some ways these are rather too rigid; for instance they prescribe that the stocking after harvesting should be at least 10,000 stems ha^{-1} (average 1 m between the stems). It is doubtful if such stocking is appropriate in all types of shrubland. *Thinning Guide* (Anon., n.d.) has some useful guidelines for thinning natural forest.

Shorea robusta forest

No yield data have been seen from management of *Shorea robusta* forest for local needs, but some management proposals have been put forward by Mathema (1991a). The first step should be to protect the area against grazing by fencing. On favourable sites, after a year abundant regeneration will establish itself from stumps, and particularly from seedlings which have been cut back annually by fire or grazing, but of which the living roots persist for many years. This regeneration should be singled out to two or three shoots per stool; if there are many shoots between the stools these could be thinned out to say 1 m x 1 m spacing. Less valuable species should be removed to favour the *S. robusta*. The yield at this stage will be mainly fodder plus some small fuelwood. In the next year the shoots should again be singled out, this time to one per stool. Once the trees have reached a diameter of about 4 cm, and a height of 2–3 m, they can then be left until the canopy closes, when a thinning can be done, if it is desired to manage the forest for timber or large poles. For short rotation fuelwood production little thinning, as opposed to singling, should be needed.

Lallich *et al.* (1990) describe a management plan for an area of cut-over *S. robusta* forest in Dang District, with dense regeneration 1–3 m tall. They proposed a broadly similar procedure, with progressive singlings in the first three years combined with removing vegetation competing with *S. robusta*. In the eighth year *S. robusta* would be thinned to 3 m x 3 m, and selection harvesting with the primary goal of stand improvement would take place in year 20, with the proviso that all harvesting would be timed to coincide with good seed years. It would appear that timber production was one objective here. Another possibility in *S. robusta* forest is taungya, by growing agricultural crops between the young shoots. At Tamagadhi, Bara District, this has been done on a small scale; the best *S. robusta* stems are singled and kept at 3 m spacing, with crops between them. This type of management would be orientated towards timber production.

Some growth data are available for *S. robusta* forest regeneration in the Bhabar Terai from K.J. White (1988b). One plot of 33-month-old regeneration of *S. robusta* forest had a total of 6325 stems ha^{-1}, of which 4575 (72 per cent) were *S. robusta*. The mean height of *Shorea robusta* was 3.5 m, with mean diameter 3.4 cm; the best 400 *S. robusta* ha^{-1} had a mean height of 4.6 m and a mean diameter of 5.9 cm. A second plot in regrowth 14 years old in the same general locality had 1639 stems ha^{-1} of which 928 (57 per cent) were *S. robusta*. They had a mean height of 8.5 m and a mean diameter of 9.1 cm. The best 400 stems *S. robusta* ha^{-1} had a mean height of 11.4 m and a mean diameter of 11.7 cm. These figures suggest a coppice rotation of five years or less to provide small fuelwood, and 10–15 years for pole production, depending on the size of material needed. A coppice with standards system to produce both types of produce would of course be possible. Growth rates in hill *S. robusta* forest are likely to be slower than these.

Other forest types

Regeneration of pine forest is by seed, and as pines are strong light-demanders, to ensure regeneration wide gaps, probably at least 10 m in diameter, will need to be made in the canopy, or a shelterwood system used. Much pine forest especially in the Far Western Development Region is very degraded and the first step in management will need to be protection against grazing, and where there is young regeneration, against fire. See also Raeside (1986). The selection system is appropriate for shade-bearing conifers such as *Abies* and *Tsuga.* Management of forest for leaf fodder production probably would be best done by traditional methods, such as by opening the forest for limited periods and specifying how many loads of fodder could be removed, but methods such as rotational pollarding might also have a place. Managing trees to produce the highest yields of fodder, when it is needed, is a complicated question, and it is not possible to go into more details here.

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APPENDIX 1

Miscellaneous data

(1) Plants per hectare at different spacings

Spacing (m)	No. of plants	Spacing (feet)	No. of plants
1 x 1	10000	3 x 3	11960
1.5 x 1.5	4444	4 x 4	6728
2 x 2	2500	5 x 5	4306
2.5 x 2.5	1600	6 x 6	2990
3 x 3	1100	7 x 7	2197
4 x 4	625	8 x 8	1682
5 x 5	400	9 x 9	1329
6 x 6	278	10 x 10	1076
8 x 8	156	15 x 15	478
10 x 10	100	20 x 20	269
2 x 1	5000	30 x 30	120
2 x 3	1667	3 x 4	8970
2 x 4	1250	3 x 6	5980
2 x 5	1000	6 x 9	1993
3 x 4	833	6 x 12	1495
3 x 5	667	6 x 15	11963

(2) Nursery

- 1 filled polypot 3 inch x 7 inch (7.5 cm x 18 cm) lay-flat weighs 300 g and has a volume of about 300 ml of soil. The diameter of the filled pot = 5 cm (2 inch).
- 1 filled polypot 4 inch x 7 inch (10 cm x 18 cm) lay-flat weighs 530 g.
- 1 stand-out bed 10 m x 1 m can hold about 4300 seedlings in 3 inch x 7 inch lay-flat pots.
- 1 *doko* load of soil (25 kg) can fill about eighty 3 inch x 7 inch pots.

(3) Transport by *doko*

- Standard load 25 kg (30 kg in some localities).
- Daily walking distance 12 km.
- Volume of *doko* load of soil 0.6 cubic feet = 17 litres = approximately one kerosene tin.
- One *doko* can hold 80–100 seedlings in 3 inch x 7 inch lay-flat pots.

(4) Labour requirements (man-days)

Adapted from standard norms (Ministry of Forests and Soil Conservation, 1984).

(a) Nursery (per 10,000 plants)

Germination bed preparation	10
Seedling bed preparation	10
Sowing seed in bed	1
Sieving and mixing soil	10
Filling pots	40
Direct sowing into pots	5
Pricking out seedlings into pots	40
Weeding in beds and bags,	
—including insecticide spraying	4
Grading and shifting seedlings	2
Root pruning	2
Stump preparation	40

(b) Planting per hectare (2.5 m x 2.5 m = 1600 plants ha^{-1})

Site clearance—open grassland	4
—25% covered with small bushes	10
—50% covered with small bushes	20
Pitting (30 cm x 30 cm x 30 cm pits)	
—soft loamy soil	19
—sandy soil	26
—sandy soil with gravel	32
—hard soil with gravel	38
Planting	25
Weeding—dense	20
—fairly dense	18
—fairly open	15

(5) Conversion factors

Imperial/US	Metric	Metric	Imperial/US
1 inch	= 2.54 cm	1 cm	= 0.3937 inch
1 yard	= 91.44 cm	1 m	= 1.094 yard
1 mile	= 1.609 km	1 km	= 0.6214 miles
1 sq. inch	= 6.452 cm^2	1 cm^2	= 0.1560 sq. inch
1 sq. ft	= 0.0929 m^2	1 m^2	= 10.76 sq. ft
1 sq. yd	= 0.8361 m^2	1 m^2	= 1.196 sq. yd
1 acre	= 0.4047 ha	1 ha	= 2.471 acres
1 sq. mile	= 2.590 km^2	1 km^2	= 0.3861 sq. mile
1 sq. ft/acre	= 0.2296 $m^2\ ha^{-1}$	1 $m^2\ ha^{-1}$	= 4.356 ft^2/acre
1 cu. ft	= 0.02832 m^3	1 m^3	= 35.32 cu. ft
1 cu. ft/acre	= 0.06998 $m^3\ ha^{-1}$	1 $m^3\ ha^{-1}$	= 14.29 cu.ft/acre
1 pint	= 0.5683 litre	1 litre	= 1.760 pint
1 gal (imperial)	= 4.546 litres	1 litre	= 0.220 gal (imperial)
1 gal (US)	= 3.785 litres	1 litre	= 0.2642 gal (US)
1 ounce (oz)	= 28.35 g	1 g	= 0.03527 oz
1 oz/sq. yd	= 33.91 $g\ m^{-2}$	1 $g\ m^{-2}$	= 0.02949 oz/sq. yd
1 pound (lb)	= 0.4536 kg	1 kg	= 2.205 lb
1 ton (2240 lb)	= 1.016 tonnes (t)	1 tonne	= 0.9842 tons

Nepali measures

1 *ropani* = 0.052 ha (approx. 1/20 ha, or 1/8 acre)
1 *bigha* = 0.68 ha (approx. 13 *ropani*, 2/3 ha, or 1.7 acres)
10 *muthi* (handfuls) = 1 *mana* = about 0.56 litre
1 *pathi* = 8 *mana* = about 4.5 litres = about 1 gallon
1 *muri* = 20 *pathi* = about 90 litres
1 *maund* = 36 kg approx.

(6) Nepalese Calendar

The lengths of Nepalese months vary between 29 and 32 days and are not constant from one year to the next. The following are their approximate equivalents in the western calendar

Baisakh	mid-April to mid-May
Jesth, Jeth	mid-May to mid-June
Asadh	mid-June to mid-July
Saaun, Srawan	mid-July to mid-August
Bhadra, Bhadau	mid-August to mid-September
Ashwin, Asauj	mid-September to mid-October
Kartik	mid-October to mid-November
Marga, Mangsir	mid-November to mid-December
Paush	mid-December to mid-January
Magha	mid-January to mid-February
Phalgun	mid-February to mid-March
Chaitra	mid-March to mid-April

The official era in Nepal is the Vikram Samvat, (V.S.) of which the new year begins on the first of Baisakh. The Vikram Samvat is 57 years ahead of the western calendar; thus the year beginning in mid-April 1994 A.D. is 2051 V.S.

APPENDIX 2

List of Nepali words used in text apart from names of trees

achar	A sort of pickle made from various fruits and vegetables, with spices and mustard oil.
alainchi	The large cardamom, *Amomum subulatum.*
amp	The mango, *Mangifera indica.*
Baisakh	The first month of the Nepali year, from mid-April to mid-May approximately.
ban mara	Introduced weedy shrubs, which during the last few decades have colonized large areas of Nepal. The lowland species is *Eupatorium odoratum*, and the highland species *E. adenophora.*
besar	Turmeric, *Curcuma domestica,* a spice used in curries, etc.
betel	The fruit of the palm, *Areca catechu,* chewed with 'pan'.
bhabar	The outwash zone at the base of the Siwalik Hills, often with very bouldery soils, in which many streams disappear underground.
bhitra madesh	The 'inner Terai' or duns, consisting of broad flat-bottomed valleys between the Siwalik Hills and the Mahabharat range, or between branches of the Siwalik Hills.
bigha	A measure of area used in the Terai, 0.68 ha.
Chaitra	The 12th month of the Nepali year, from mid-March to mid-April approximately.
chanda	*Hibiscus sabdariffa,* a herb with red calyces used in preparation of food and drinks.
chandra garuwa	*Rauwolfia serpentina,* a valuable medicinal plant the roots of which are the source of reserpine, used to treat high blood pressure.

chautara	A raised platform surrounded by a stone wall on which trees are usually planted, as a meeting place and a resting place for travellers.
chital	The spotted deer, *Axis axis*.
choya	A sort of string prepared from bamboos.
chuchche	A pointed pick-like implement, with a short handle, used as a hoe.
chutro	*Berberis* spp.
cutch	A tanning material extracted from the wood of *Acacia catechu*.
dasai, dasain	The most important festival in the Nepali Hindu year, occurring in the month of aswin (September–October).
dharni	A measure of weight, approximately 2.5 kg.
dhatela	The shrub, *Prinsepia utilis*.
dhungro	A cylindrical container made from a section of bamboo culm.
doko	A tapering basket made of bamboo and carried on the back —the usual way of transporting materials in the hills.
dun	A broad flat valley between the Siwalik Hills and the Mahabharat Range, or between branches of the Siwalik Hills.
gal	A crowbar.
ghangaru	*Pyracantha crenulata*, a spiny shrub used for hedging.
hathi kane	The prickly pear, *Opuntia* spp.
heralu	A forest watchman.
jalebi	*Pithecellobium dulce*, a shrub or small tree used for hedging.
jarayo	The sambhar deer, *Cervus unicolor*.
Jesth	The second month of the Nepali year, approximately mid-May to mid-June.
Kartik	The seventh month of the Nepali year, approximately mid-October to mid-November.
katha	A form of catechin, from *Acacia catechu*, used for chewing with betel and pan.

kettuke	*Agave* spp., (sisal), used for hedging, erosion control, and a source of fibre.
khet	Unirrigated crop land.
khukuri, khukri	A heavy knife carried by many Nepalese farmers and Gurkha soldiers.
khurpi	A sickle.
kodali	A hoe with a very broad blade and a short handle. Also used for a spade.
kodalo	A hoe with a smaller blade and longer handle than a kodali.
labra khada phul	*Euphorbia milii*, a small succulent spiny plant planted on the tops of walls to prevent goats climbing them.
madilo	*Eleagnus infundibuliformis*, a hedge plant.
Magh, Magha	The tenth month of the Nepali year, approximately mid-February to mid-March.
magel jhari	Light rains falling in winter.
mana	A Nepali measure of volume, about 0.56 litres.
Mangsir	The eighth month of the Nepali year, approximately mid-November to mid-December.
Marga	See Mangsir.
naike	A foreman, especially one in charge of a forest nursery.
namlo	The band over the head used to support a doko.
nanglo	A round tray made of bamboo.
pan	The leaf of *Piper betle*, chewed with betel nut.
panchayat	A group of villages administered by a council (*panch*).
pathi	A Nepali measure of volume, equivalent to eight *mana* or about 4.5 litres.
Paush	The ninth month of the Nepali year, approximately mid-December to mid-January.
Poush	See Paush.
rato mata	Deep red soil, very liable to erosion.
ropani	A measure of area in the hills of Nepal, about 1/20 hectare.
sambar	A large deer, *Cervus unicolor*.