Chapter 16*

ECOLOGY AND BIOTECHNICAL STABILIZATIONS

16.1 ECOLOGICAL CONCERNS OF ROADSIDE PLANTATIONS

16.1.1 *Introduction*

Roadside plantation is a form of land use system which is assuming increasing significance. The new roles being ascribed to this activity are partly the outcome of knowledge development, e.g., bioengineering techniques for the stabilization of slopes alongside roads. The other factors contributing to the significance of the roadside land have emanated from increasing pressure on land use and its resources. It is being realised that to meet the needs of the growing human population every bit of land has to be brought under proper land use with as much benefit as possible. In this respect, in recent times, roadside plantations have been seen to complement forestry in most developing countries. Therefore, roadside plantation is helping to provide an economic benefit in addition to the benefits of solving the ecological problems of the restoration and maintenance of ecosystems.

Under mountain conditions, the **plantations on roadsides** have different objectives. So far most efforts have been concentrated on using vegetation to stabilize slopes made vulnerable to erosion as a result of road construction. This objective focuses on plantations only in vulnerable areas and the rest of the roadside land has been rarely used for populations. In most cases, a second priority in roadside plantations was given to the aesthetic aspect, i.e., planting flowering trees and other species on land not covered under the first objective. Even in the case of the first objective, use of vegetation is a recent phenomenon. It is assumed, therefore, that most of the roadside land falling under different categories of roads is yet to be brought under proper land use planning. Also, the focus of plantations may vary with the available width of land on the sides of roads, and this varies with road type. On a particular mountain road, the vegetation variation is a function of varying climatic regimes, farming systems, and ecosystems. As such, it depends on the characteristics of locations through which the road passes, e.g., **forest ecosystems**, pastures or range lands, and horticulture or crop-dominated farming systems' areas; or **detritus ecosystems**, i.e., industrial dominated areas, pure habitations like urban areas, valleys, low, and high mountain areas.

This chapter discusses roadside plantations under an ecosystemic framework. The overall objective is to develop concepts whereby roadside vegetation makes a meaningful contribution to the ecosystem's health and stability.

The possible contributions of plantation practice fall within three broad categories:

a. contributions to restoration, conservation, and maintenance of ecosystems,
b. contributions supporting sustainability of agro-ecosystems, and
c. contributions to maintain the quality of physical health of ecosystems.

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* Tables and Figures in this Chapter that have not been credited to any source have been compiled by the author.

The degree of contribution under each of these categories depends upon two factors. One, how much land width is available on the roadside? and two, what efforts are made to realise full use of all the available land for plantations, taking all aspects into consideration ? Land availability for plantations on roadsides depends upon the amount of land acquired along different categories of roads. Regulations in this regard may differ among regions and countries. For example, in India there are three main categories of road; national highways, state highways, and district/village roads. Under the first category, the usable combined width of roadside area is 45m in the plains and 24m in the mountains; for State highways it is 45m for the plains and 24 m for the hills; and for district level roads it is 25m for the plains and 15-18m for the mountains (Table 16.1) Village link roads are generally 9 m wide with 9-12m of combined open area on the sides.

Whenever a road passes through an agricultural area, there may be situations where the planned width of the roadside land strip is not available or where it has been encroached upon by farmers. It may permit only one row of plantation and even the choice of species may be decided upon by the person whose agricultural fields were acquired for construction of the road. Such instances arise where roads have been built under special programmes without paying compensation to the people whose lands were acquired. There is yet another situation where land available for roadside plantations is much more than the acquired width. Such situations are commonly met on mountain roads passing through slopy areas. These areas generally come under wasteland, grassland, forests, etc. and many of them are either already well vegetated or they may be degrading due to climatic harshness or excessive use.

Table 16.1 Available widths of roadside land along different categories of mountain roads: case of India as an example

Category of roads	Width of total land recommended to be acquired for constructing road				Main road width	Land normally available for roadside plantations[1]	
	Mountainous areas, slopy lands		Valley plains, least slopy plains			Mountainous areas	Valley plains
	Normal (m)	Range (m)	Normal (m)	Range (m)		(m)	(m)
National highways	30	30-60	45	30-60	12.0	18	33
State highways[2]	30	30-60	45	30-60	12.0	18	33
District roads	20	15-25	25	30-60	9.0	11	16
Village roads	10	15-20	12	15-20	7.5	3	4.5

Source: Information developed through personal communications with road engineers and the Secretariat of the Indian Roads' Congress, 1988.

Note:

1. The actual available area differs because of the range. It may increase or decrease because of the range of acquired land, common encroachment problems, and steep slopes in rocky mountain areas.
2. In practice State highways are less wide than national highways.

16.1.2 *Contributions for Restoration, Maintenance, and Conservation of Ecosystems*

The micro-ecosystems of mountain areas along the alignment of roads will be affected in terms of vegetation disturbances because of the clearing of the area for construction and also because of the uncontrolled throwing of debris. After a road is built there are always general accusations that the road accelerates deforestation in an area. Moreover, with increasing accessibility several valuable plant species are overexploited to the extent that fears of their becoming extinct become imminent. Efforts have been made here to conceptualize an approach to make use of plantations to repair the damage to the best possible extent.

i) *Plantations as Part of Restoration Ecology*

Areas exposed because of road construction activity or made vulnerable by it can be partly or fully restored to the original condition of vegetation cover if it existed previously. This will mean restoring the ecological system back to normal. In using plantations for restoration and maintenance, the aim is to alter conditions on **failed slope surfaces** to induce stability through a variety of functions, catching material moving downslope, armouring the slope and protecting the surface, draining the slope, and supporting the slope by reinforcement.

Incorporating plantations, for the restoration and maintenance of roadside areas, is a relatively recent endeavor. It was first attempted on a considerable scale during the 1960s (Greenway 1987). This endeavor has grown steadily in the last 20 years and the influence that grass, shrubs, and trees may have on **slope stability** is now emerging as a successful experience.

Although the technique is discussed in detail in Section 16.2 of this chapter, the point emphasized here is its value as an approach to **restoration ecology**. If by restoration we imply that the components affected, i.e., the kinds of plant species, are to be restored then it does mean that species used as tools of restoration should necessarily be among the flora of the local ecosystem. The point advocates giving preference to local plant species, rather than using introductions, as far as possible. Introductions may help restore the physical environment but they also bring changes in the phytosociological structure of plant communities which might sometimes lead to unaccountable transformations in ecosystemic structure and function. In such cases they help restoration only partially.

ii) *Contributions to the Conservation of Plant Resources*

The present day accusations against road development are that it is a cause of accelerating deforestation and erosion of plant resources. Wherever road development takes place a similar scenario develops. There are instances within the Hindu Kush-Himalayan Region where, within a short time of road development, the areas have been subjected to complete loss of their tree cover. Roads by themselves are not the agents of destruction. Destruction is also a result of population pressure, scarce land resources, and lack of alternatives to sustenance. Both forest resources and forest land for agriculture become economically very important with access.

Under such circumstances, threat of the extinction of vegetation becomes imminent. In the first instance, economically important plant resources are overexploited and their conservation becomes a necessity. They cannot survive in their natural habitat due to its loss or management control limitations. Roadside land provides an excellent, unconventional **alternative habitat** for **conservation plantations** of such plant species. The management of the conservation plantations on roadside sites is relatively easy and more effective in control. Representatives of all threatened life forms, i.e., trees, shrubs, and herbs, can be conserved this way. In a way such efforts can turn these sites into replicas of botanical gardens. Nevertheless, the conservation effort herein means that it could be one of the criteria used for choice of species for maintaining roadside stabilization and using unmanaged land areas. The concept is an ideal example of combining development with conservation and conservation with development.

On priorities regarding the conservation of species, the World Conservation Strategy (IUCN 1980) has outlined the following criteria which might prove helpful in species' selection for plantations in the present context. It outlines that priorities should be given to these categories:

i. species that are endangered throughout their range, and
ii. species that are the sole representatives of their family or genus.

The formulation is illustrated in Table 16.2.

Table 16.2: Formulation for determining conservation priority of threatened species

Size of loss	Imminence of loss		
	Rare	*Vulnerable*	*Endangered*
Family	4	2	1
Genus	7	5	3
Species	9	8	6

Source: IUCN 1980

Note:
1 - 9 = suggested order of priority
1,2,3 = highest priority
4,5,6 = intermediate priority
7,8,9 = Lower priority

Further priority should be given to those plant species that are most threatened and most needed. As pointed out, such a conservation effort assumes that there is institutional and public concern for conservation but the felt constraint is habitat, because of the ongoing expansion of land use transformation in the original habitat or because there is a lack of infrastructural facilities to preserve distant plantations *in situ*. The advantages of using roadsides for plant conservation efforts lie in better management through accessibility and through the status of land, i.e., protected under more strict regulations and the convenience of forcing regulations.

Such a conservation strategy, however, calls for the multidisciplinary efforts of several institutional agencies, such as the department of roads, to make land available, and the department of forests and environment, for the resources and research institutions to prepare priority lists of threatened species for an area. Given the national awareness and international concerns and funding assistance for the conservation of natural resources (World Bank 1986), the execution of this unconventional method of plant resources' conservation seems possible for some areas.

iii) *Plantations to Maintain Natural Ecological Systems*

Natural ecological systems or ecosystems consist of several components or **trophic levels** that provide channels for energy flow. Groups of components performing a similar function make one trophic level. For example, rats eating grain crops form one trophic level of herbivors. Snakes, cats, and birds together form another trophic level. They form a web of **food chains** through which ecosystemic energy flows. The sustainability of an ecosystem depends upon the diversity of components within trophic levels as well as the diversity of trophic levels within an ecosystem. The more diverse a system the more stable and self sustaining will it be.

Existence of these trophic levels, however, depends heavily upon the amount of available plant resources within an area. In the absence of diverse plant forms these components will be eliminated for want of a suitable habitat or 'niche'. Take, for instance, the case of agricultural land spread over a vast area without much natural vegetation, trees, or shrubs. The crops in-this area will have more chances of insect infestations, and additional efforts will be needed for the control of insect pests to minimize crop losses. For effective **biological control**, creating a suitable habitat for insect predators, birds may provide an answer. In addition, because the birds eat insects at a particular time of year, they contribute to biological control and should be provided with resting places, nesting places, and food for lean periods by providing wild fruits from trees and shrubs. This would further add to their comfortable stay in the area.

Plantations on roads passing through such crop-land dominated valleys can play a very special role in restoring ecological systems or the natural ecosystemic functioning impaired by over-simplification of the agro-ecosystems. The choice of species in this respect can be further linked to other development efforts; for example, noting the slack period for bee flora in the area and choosing species that compensate for it.

16.1.3 *Contributions Supporting the Sustaibability of Agroecosystems*

i) *Increasing Role of Roadside Land as Common Property Resources for the Local Populations*

Common property resources are still an important form of natural resource endowment in the rural mountain areas of the developing countries. Broadly defined, **common property resources** (CPR) are those used by an entire community without any exclusive individual ownership or access rights (Jodha 1985). CPRs have been the backbone of subsistence mountain farming and have fulfilled various kinds of subsistence needs: green and dry fodder, fuel, grazing land, etc. The land is categorized as community lands, waste lands, degraded forests, shelter belts, panchayat land, etc.

In the absence of regulatory institutions and because of rapid population growth, exerting tremendous pressure on land for cultivation, the trend is towards the gradual depletion of common property resources. The profitability of, rather than the upkeep of, CPRs has become the guiding force behind the choice of enterprises and usage patterns of CPRs. Privatization of these resources through legal processes, illegal seizure, and overexploitation are contributing in a major way to their depletion. This process of change deprives a region of its comparative advantage in a key subsistence or economic activity (Jodha 1985).

The future of CPRs should be considered according to their several advantages, for example, such as promoting the economic activity best suited to the natural resource base of a region, sustaining the rural poor, and assuring the use of land according to its capability.

Apart from several measures suggested for saving CPR lands (Jodha 1985) to ensure sustainable benefits, there is yet another alternative. This lies in strengthening the role of roadside land as CPRs. Although legally they are government lands, used for raising revenues, *de facto* they have been increasingly used as CPRs. Under mountain conditions, several roads, both highways and feeder roads, pass through subsistence mountain farming areas where people depend upon plant resources from the non-agricultural land of CPRs. Curiously, while traditional forms of CPR are depleting with the increasing road network, the new version of CPRs in roadside land is increasing. In several areas it can be seen to be taking over the role of CPRs almost completely.

To derive maximum benefits, an institutional strategy on the following lines might help : recognize the significance of roadside land for CPR use, establish effective regulations to create and maintain it, and ensure the cooperation of the local people for the systematic management of its productive resources, for example, social forestry systems and technological support for selecting productive, environmentally suitable plant species and managing a healthy plant community on this land resource.

ii) *Farming Needs of Communities Living along the Road and the Contribution of Roadside Plantations*

Probably the most serious deforestation and conservation problems faced by mountain areas are caused by the lack of rural development. In their struggle for food and fuel, growing numbers of desperately poor people find themselves with little choice but to strip available vegetation, resulting in harmful consequences such as soil erosion.

This is also the general scenario encountered near roadside habitations in several mountain areas. Often the rural mountain communities responsible for this destruction do not need to be told that it is a mistake. What such communities need is to be equipped to win their livelihoods in sustainable ways. Therefore, there is a need to develop the means to help these rural communities to conserve plant resources as an essential basis for the development they so sorely need.

Plants growing on the roadside could be important and renewable resources, particularly for rural mountain communities. The food and nutritional importance of these plants or their products, *per se*, for the local people, are generally underestimated and ignored.

One recalls a situation in which village school children were picking wild fruits (*Zizyphus*, *Rubus*, Currants, Indian gooseberry, peaches, apricots, pears, and *Hyppophae* from roadside plantations while going to school and on returning home in the afternoon. One can visualize roadside plantations becoming a source of fruits for cowherds and shepherds. It is useful to know that *Aesculus*, a tree recommended for roadside plantations (Tiwari and Singh 1984) in high altitude areas, is a source of food during hunger gaps. Families in several areas of the Himalayan Region, whose grains are exhausted early before the next crop is harvested, process the kernels of the bitter fruits of *Aesculus* to yield a kind of flour. As the fruit production per tree is in quintals, it is a viable proposition. *Aesculus* fruits also provide nutritious fodder for cattle and this is generally saved for the snowy, winter period. *Hyppophae*, a roadside plant of the high mountain *Trans-Himalaya* yields juicy berries, a rich source of Vitamin C, even if taken in small quantities. More important, this rich Vitamin C source is available to those who can otherwise not afford to purchase Vitamin C to contain deficiency. Plantations of *Hyppophae* managed on roadsides may help improve the nutritional status of the remote high mountain people on a sustainable basis rather than conducting crash programmes of child nutrition improvement over a short period. Besides, large-scale plantations of this species will also help improve soil fertility and provide cash benefits from the sale of berries or their products.

The Indian gooseberry (*Phyllanthus amblica*) is another rich source of Vitamin C and it is a plant of the lower hills. In Himachal Pradesh, a Himalayan State of the Indian Union, the Roads' Department raises *Phyllanthus* plantations on several roads. Both the department and the local public make good use of its fruits; the former to raise revenue and the latter to use as food.

Prinsepia, a thorny shrub, is a good plant for slope stabilization and relatively less palatable for livestock. Its fruits have been in use as a source of edible oil by subsistence farming communities in the mountains. Dried twigs are used for fuel. Planted on roadsides, it may serve as a multipurpose species.

Sapindus is a tree whose fruit wall is a source of natural soap. Subsistence communities use it for washing clothes. A farming family's needs are met by a tree or two. The excess is always sold in local markets. In Himachal Pradesh, this species has been planted on roadsides in the lower hills. *De jure* the property belongs to the Government but *de facto* nearby farming families collect the produce from these trees.

Likewise, there are an unaccountable number of economic plant species for roadside plantations.

iii) *Role of Roadside Plantations in Off-farm Income and Employment Generation: The Case of Apiculture*

Roadside plantations, established as bee forage, particularly for forage scarcity periods, enhance the scope of beekeeping which, in turn, increases the possibility for farmers to earn additional income from honey. This also increases crop yields through the pollination services of bees. Recent experiences gained from using roadside plantations for large-scale apiculture, as a form of off-farm activity, have been described in Pakistan. The United Nations' High Commission for Refugees and the Government of Pakistan have provided bee colonies to Afghan refugees, who move them along the road lengths for the whole year. Hundreds of tents and bee colonies can be seen on the sides of all the roads in the Northwest Frontier Province (NWFP). This activity has provided subsistence to several hundred people.

But why do we need roadside plantations for apiculture ? Populations of most pollinating insects are declining because of the vast clearance of waste lands for cultivation. The extensive practise of agriculture and monoculture is reducing their hibernating and nesting places. Indiscriminate pesticidal/insecticidal sprays are killing them continuously. Under the present state of affairs we have to depend upon domesticated honey bees for the pollination of crops. To sustain bees and encourage apiculture, varieties of bee flora are required which provide subsistence rewards during some parts of the year and surplus during the others. Some agricultural and horticultural crops serve as useful and plentiful forage but the availability is restricted to short durations only. This means that agricultural and horticultural crops provide honeybees with nectar and pollen for a short period in the year only, restricting the scope of beekeeping. Therefore, apart from crops, other kinds of plantation that flower for long periods in a year, or a combination of several tree species that blossom during different months, so that nectar and pollen are almost continuously available to honey bees, are needed. The exercise carried out along the roadsides would involve the whole mountain road length, passing through different climatic regions, and this would provide the advantage of diversity in terms of species and their blossom calendars. To ensure variations in the efficient use of roadside flora throughout the year, the bee colonies need constant movement along the road length, for example, summer in the high mountains, winter in the foothills, and spring in the mid-hills. Table 16.3 lists species which are important as honey plants, in addition to other uses. Plant species can be selected out of the whole list for roadside plantation, keeping other needs in mind.

iv) *Aesthetics, Comfort, and the Role of Plantations*

Historically, the role of roadside plantations was perceived as a means of comfort for travellers. Although much has changed with time, the concept of the provision of comfort to travellers is still followed. In most parts of the sub-tropical hill terrain, the provision of shade during hot summer months assumes the highest importance. In the present age of automobiles, planting tree groves to provide shade and a good environment at some selected places, where travellers may stop and rest, is considered necessary. While the avenue may provide shade to the travellers, it should not be so dense as to obstruct the view of the landscape. Also it should not trap exhaust gases and mist under the canopy to adversely affect visibility. The aim of comfort for travellers should be integrated with other imperatives of roadside plantations. Wherever species are planted to serve the aforementioned imperatives, but the plantations clash with the above interests of the travellers, the solution lies in creating rows of plantations. The first row should provide the traveller with comfort and rest and the rows behind it should contain some species of choice to serve other imperatives.

16.1.4 *Contributions to Maintain the Quality of Physical Health of Ecosystems*

Although roads add to the well-being of human beings, and the intentions in road development are always for overall improvements in quality and sustainability of ecosystems, the physical environment of an area is adversely affected by road development in the following ways:

(a) erosion of soil due to exposure of bare surface and debris;

(b) atmospheric pollution created by emissions from vehicles plying on the road, as well as from material used to construct the road; and

(c) noise pollution created by vehicles.

i) *Erosion*

Much of the soil surface becomes exposed during road construction. In mountain areas, this is further compounded by the downward dumping of debris and the destruction of vegetation cover for a considerable distance. This adversely affects the habitat quality of the surrounding area. In the high mountains, where vegetation cover takes a long time to develop because of harsh climatic conditions, such an exercise proves disastrous. Restoration efforts mostly prove ineffective because they are inadequate. Long-term impacts include further enlargement in erosion areas and effects on local water quality.

Plantations can create an effective vegetation cover on the exposed parts and save the area from erosion. More discussion on the topic is given under biotechnical stabilization in Section 16.2.

ii) *Atmospheric Pollution*

Dust stirred up from the road surface, especially during dry weather, carbon smoke from automobiles, and other activities such as crushers on roadsides, all add to atmospheric pollution around roadsides. Large-scale use of the road by heavy vehicles helps to increase the ground temperature and lower atmospheric humidity locally. This, in turn, interferes with plant establishment (in the initial stages), soil, micro-flora, and fauna.

The sulphur and nitrogen compounds from burning fossil fuel are causes of acid rain. The bitumen used as the wearing coat in all roads is hydrocarbon and starts melting at 38°C and is converted into molecular form through the traction of moving vehicles. From all these sources the atmosphere in and around roads contains the following pollutants:

a. carbon dioxide (CO_2)
b. carbon monoxide (CO)
c. lead and other metal compounds, and
d. unburnt petrol and oils.

Among the heavy metals, lead, copper, cadmium, and asbestos dust are released by vehicles along with smoke.

Therefore, the sides of roads polluted by the presence of solid, gaseous, and liquid substances in the atmosphere are injurious to human beings, agriculture, and animals. Clinically, several disorders and diseases are ascribed to this kind of air pollution. Sulphur dioxide affects the respiratory tract and causes chronic nasal pharyngitis and nitrous oxides are injurious to eyes and nose. Lead poisoning causes abdominal pain, headaches, weakness, and several other diseases and discomforts. Carbon monoxide impairs oxygen intake by the blood and has disastrous effects on human beings. A study on lead, cadmium, and copper contamination, due to vehicular emission, has established that the effect is noticeable in the biological chains and results in the toxicity of some of the foods eaten by man (Panda 1988).

All these factors contribute to the disastrous effect on the health of road users as well as those living near roads. Sometimes the impacts of excess pollution are even visible on plants. It induces mortality in some species or impairs their growth. Pollution of water along the roadside by these agents kills one form of plant species and helps the growth of plants such as Parthenium and Water Haycinth. While Parthenium causes allergies, Water Hyacinth chokes waterways, helps spread malaria, and kills other useful aquatic flora and fauna by shutting out oxygen.

Systematic roadside plantations with combinations of herbs, green shrub barriers, and trees with appropriate architecture, wherein all this vegetation makes a green belt, can effectively control atmospheric pollution. The poisonous elements are taken up by plants on the roadsides; they partly absorb the gases and partly help in raising them high into the atmosphere for possible dilution. This saves roadside habitations from harmful concentrated exposures to a large extent.

iii) *Noise Pollution*

Excessive noise from vehicular traffic is a form of environmental pollution. Vehicular traffic on a busy road generates a sound intensity which becomes irritable. The sound of horns is harmful to the health of those living near the roads. Sound levels above 50 decibels are irritable and those in excess of 150 decibels become harmful to human beings (Odum 1971). Trees and shrubs planted on roadsides are an effective noise-reducing medium. Each 30m width of trees can absorb 6 to 8 decibels of sound intensity (Tiwari and Singh 1984). However, the effectiveness of a belt of trees and shrubs as a noise-reducing medium depends upon the height of the tree, width, and overall density of planting and foliage distribution. The width of the belt of trees being limited by the space available for the purpose, the trees and shrubs producing denser belts will prove more effective in noise abatement. To reduce the noise generated by high speed traffic on highways to tolerable limits, belts of trees and shrubs are necessary. The reports reveal that, to reduce the noise generated by a moderately speeding car, a 7 to 15m wide green belt works as an effective measure of noise control (Tiwari and Singh 1984). Evergreen trees are better for noise abatement than deciduous trees which do not afford a barrier to sound when leafless. In the hills, trees planted uphill from a road provide maximum sound control (Tiwari and Singh 1984). Detailed criteria for the choice of species for noise pollution control are described by Cook and Haverbecke (1971).

16.1.5 *Pattern of Changes in Roadside Plantation Approaches*

Trees were planted along the roads, as a first concept, mainly to provide shade and shelter to the traveller (Malik 1973). Avenue planting was carried out for travellers' comfort rather than slope stabilization, economic returns, or social benefits. Later, the emphasis shifted to economic returns (Singh 1973; Ladwa 1976) particularly in areas where the area under forest declined or where it was already very small. In such circumstances, the acute shortage of forest products provided support to the view point that the strip plantations along roads should be managed primarily to meet the requirements of local people and that the considerations of comfort to travellers and aesthetics should receive only secondary consideration (Gandhi 1976). For example, in India, the National Commission on Agriculture (NCA 1976) recommended the proper planning of roadside land use for planting beneficial plant species. It stressed that the activity of raising roadside plantations should be treated as a commercial investment. It brought a change in the objectives of the management of roadside plantations. Roadside land thus came to be recognized as a potential site for the production of various forest species. The institutional management systems became busy planning for maximum revenue realization from these plantations. The maximization of social benefits from these plantations is a developing approach. This new concept is developing with a view to meeting the growing shortage of fuelwood and small timber from roadside plantations that have better locations and site conditions.

16.1.6 *Engineering Angles on the Orientation of Plantation*

Because of the past focus, primarily on traveller and economic benefits, only trees and shrubs have been so far considered in planting designs. The planting systems usually followed are of the following types: viz. balanced line, unbalanced continuous line, unbalanced discontinuous line, sporadic system, and parkway system. Of these, the first two are widely practised wherever possible. The **balanced line system** produces a continuous green wall of trees that are uniform in size, as in the case of long stretches of eucalyptus avenues, and is not always considered to be aesthetically desirable. An **unbalanced continuous line**, produced as a result of alternating avenues of different species, interspersed by different kinds of trees, is preferred to the former option. A plantation is expected to be such that it does not shut out the view of landscape, scenic beauty, places of interest, and beautiful hill and country features.

The position of the first row of trees and the number of rows to be planted, on either side of the road, will depend upon the category of the road, the recommended width of the land acquired, and the width of the roadway for different categories of roads.

Single row planting is normally possible along village roads and other district roads, while more than one row can be planted in the case of the remaining three categories of road. In the case of **multiple row planting**, the first row is generally for shade and ornamental value and the remaining rows may be planted with plant species to meet the farming and other needs of local people. The spacing between the trees in the first row of shade or ornamental trees will have to be wider than that between the trees in the remaining rows. The crown spread of the species to be planted determines the spacing. While too wide spacing may defeat the very objective, too close spacing may increase costs and impair visibility. Excessively dense avenues may also cause clouds of dust and smoke to linger. It is also desirable to keep the initial planting closer in order to provide for mortality and to keep a selection of better plants for final retention. Too close spacing on hill roads, particularly on the curves, is dangerous. It may be desirable to miss a tree or two in such places. The trees should also not obstruct the view in places where the pedestrians or domestic animals might be crossing the road near the villages.

The general practice followed is to plant the first row 7.5 - 9m away from the centre, according to the type of road. The remaining could be spaced, keeping the landscape in mind. In India spacing between trees in the first row is 7.5m and in the remaining rows it is kept at 3m (Tiwari and Singh 1984). The spacing, however, should not be a fixed criteria and needs to be adjusted according to species and objectives. The above criteria are developed keeping in mind the trees alone. What about shrubs and herbaceous vegetation? Similarly, criteria need to be developed for each location in the case of slope stabilization and social plantations. The spacing between species should differ depending upon the species being planted. It could be 10m for shade trees, 5m for commercial species, and 2m for fuelwood and fodder species. Spacing for slope stabilization on mountains needs entirely different considerations, however.

The choice of species is broadly determined by the climate, site conditions, and object of planting. The mountain areas have several major and micro-climatic zones through which the roads cross. On the basis of temperature alone, the following major climatic zones are classified in the Hindu Kush-Himalayan Region, viz., subtropical low hills and a mid-hill temperate zone, representing the high hills, and a cold arid zone comprising the trans-Himalayan high mountain areas. Besides temperature, the annual rainfall varies widely in geographic terms. Equally variable could be the site conditions, depending upon soil and other modifications brought about in the course of road construction. Removal of top soil during road construction, or the dumping of debris creating a new soil profile, will add to the transformation in soil structure and the creation of specific micro-habitat conditions.

Choice of species, therefore, has to be made, keeping in mind the suitability of the available micro-climatic and edaphic environment to species that are to be planted.

Other considerations, in the selection of species, include species with small, thin leaves which, after falling on the ground, will soon decay and be converted into humus to help the growth of ground grass cover on slopes. This will help prevent the cutting action of rain down the slopes. Thicker leaves take a longer time to decay and also become fire hazards on roads. The needle-type leaves of conifers make the road slippery, enhancing chances of accidents. The rooting of trees planted because of other considerations should have deeper roots to avoid damage to either the roads or to the pavements. Plants having leaves with hair follicles on them, and a large foliage volume ratio, are especially recommended for areas prone to noise pollution.

16.1.7 *Choice of Species for Planting*

The selection of appropriate plant species for each locality depends upon the purpose for which the plants in that locality are required and the physical and climatic characteristics of the site. In the roadside plantations of mountain areas, stabilization of mountain slopes to maintain road worthiness all the year round is the primary aim. However, on sites where stabilization is not a problem of primary concern, plantations aimed at location-specific purposes, described earlier in the text, can be kept in mind. As no single species will meet all requirements, it becomes necessary to select a combination of species that will meet all or almost all the requirements.

The great diversity in physical and climatic conditions within the Hindu Kush-Himalayan Region is represented on one extreme by the hot and humid foothill regions, which can sustain a luxuriant growth of vegetation, and on the other by the rugged tracts of the high Himalayan windy cold deserts which nurse the hardiest plants only with difficulty. This poses both enormous opportunities and problems to plantation choice. Unless care is taken to select suitable species, efforts are likely to go to waste.

In the cold deserts of the high Trans-Himalayan Region only trees with moisture conservation mechanisms will grow. In water-logged areas only those species that allow copious water transpiration will stay and on steep slopes and windy areas only plants with special adaptations for firm rooting will survive. There are species with wide ecological amplitudes which can be successfully planted over a wide range of climatic conditions (Table 16.4). However, species also exist that have narrow ecological amplitude and can be grown only in specific micro-climates of their preference.

Shrubs, although generally neglected when laying plantations, have great value for slope stabilization and for other purposes. Several shrub species are capable of fixing nitrogen, are good soil binders, provide good surface cover, and could be significant as fodder, food, and fuel plants. They are important noise abetters in green belt plantations (Cook and Haverbecke 1971). The role of grasses is secondary to other forms. The list of species in Tables 16.3 and 16.4, recommended for plantations, contains mostly trees with broad ecological amplitude. The listing is incomplete, however, in the sense that it leaves scope for shrubs and herbs to be included.

Table 16.3: List of honey plants of the Hindu Kush-Himalayan Region for roadside plantations from the apicultural perspective

Botanical Name	Blooming Period*	Honey Potentiality		Economic and other uses[2]	Distribution and Remarks
		Nector Rating	Pollen Rating		
Acacia auricul-aeformis A. Cunn. Ex. Benth .	VI - VII	N_3	P_3	Timber, fire-wood, shade, other uses - gums, medical	Subtropical to sub-temperate
A. catechu (Linn.) Wild.	VI - VII	N_3	P_3	Medicinal, fuel, fodder for goats & sheep	Subtropical
A. senegal (Linn.) Wild.	VII - VIII	N_3	P_3	Food-pods, fodder-pods and leaves; timber, fuel, land use-hedges, shade; other uses -gum and tannin	Grows in poor soil/sandy area, survives hot dry winds
Aesculus indica Colebr.	IV - V	N_2	P_2	Fodder-mashed seeds for cattle, fuel, timber, other uses-shade amenity and medicinal	Temperate climate concentration 29% to 69 %
Albizzia lebbek (Linn.) Benth	IV - V	N_2	P_2	Fodder, timber, and fuel; nitrogen fixer	Subtropical climate
A. chinensis (Osb.) Merr.	IV - V	N_2	P_2	Fuel and timber	- do -
Azadirachta indica A. Juss. climate	III - IV	N_1	P_1	Fodder-leaves,	Tropical to sub-fertilizer, tropical
				timber, fuel, medicinal-leaves, extract oil	grows quickly, starts flowering in 2 years, recommended for plant-ing to increase honey
Bauhinia variegata Linn.	III - IV	N_2	P_2	Fodder, food (floral buds), fuel	Tropical to sub-tropical climate
B. vahlii W. and A.	IV - VI	N_2	P_2	Fodder and fuel	- do -

Botanical Name	Blooming Period*	Honey Potentiality Nectar Rating	Pollen Rating	Economic and other uses[2]	Distribution and Remarks
Bombax ceiba Linn.	II - III	N_1	P	Food-flowers, fodder-seeds for livestock feed, other uses cotton for stuffing & seeds for oil/soap, and used for timber	Subtropical, nectar sugar concentration approx. 6%
Butea monosperma (Lam.) Taub. (B. fronodosa) Koenig	- II	N_1	P	Timber, fuel & other uses-food for lac insect, red dye from flowers and bark as medicinal	Subtropical
Cassia fistula Linn.	IV - V	N_2	P_1	Fuel and medicinal	Tropical to subtropical climate, recommended for planting to increase honey production
Delonix regia (Boj.) Rafin	VI - VIII	N_2	P_2	Fuel, shade, ornamental tree	Subtropical, quick growing plant with profuse flowering
Emblica officinalis Gtn.	III - VI	N_2	P	Food-fruits, fuel, medicinal	Lowhills with subtropical climate
Eribotrya japonica (thumb) Lindl.	XI - I	N_2	P	Food-fruits, land use amenity, liquor from fruits	Tropical to sub-tropical climate; nectar sugar concentration 30.5% to 65.0% %
Eucalyptus spp.	XII - IV	N_1	P_1	Paper and pulp, timber, oil from leaves	Wide ecological amplitude, nectar sugar concentration up to 30 %
Grevillea robusta A. Cunn.	XI - VII (in some areas during III - IV)	N_1	P	Timber, fuel, land use-shade, amenity and windbreak	Wide ecological amplitude, nectar secretes from flower for 3 days, nectar sugar concentration 15% to 79%, recommended to increase honey production

Botanical Name	Blooming Period*	Honey Potentiality Nector Rating	Pollen Rating	Economic and other uses[2]	Distribution and Remarks
Grewia oppositifolia Buch-Ham ex Roxb	IV-VI	N_1	P	Fodder, fibre, and fuel	Subtropical climate Good source of nectar if allowed to flower
Lagerstroemia indica Linn.	VI - VIII	-	P	Ornamental	Fairly wide ecological amplitude
Leucaena leucocephala (Lam.) de Wit	IV - V	N_1	P_1	Fodder, fuel, and timber	low to mid-hills with subtropical climate
Litchi chinensis (Gaert.) Sonner	IV - V	N_1 N	P	Food-fruits and timber	Nectar sugar concentration up to 76.2 %
Mangifera indica Linn.	III - IV	N_2	P	Food-fruits, fuel, timber, land use	Subtropical, nectar secretion amenity
Melia azadirachta Linn.	III - IV	N_1	P_1	Medicinal leaves, seeds with insecticidal use	Tropical climate, foothills
Moringa oleifera Lamk.	I - III	N_1	P_1	Food-leaves, roots, flowers, and pods, land use - hedges, amenity; other uses - medicinal oil from seeds for perfumery and lubrication	Visited by bees in swarming number
Pongamia pinnata (Linn.) Pierre	III - IV	N_1	P_1	Fodder-leaves, pressed cake for poultry feed, fuel, land use-afforestation, amenity, soil benefit erosion control, green manure, other uses-roots & medicinal-oil, twig & bark	Fairly wide ecological amplitude, subtropical

Botanical Name	Blooming Period*	Honey Potentiality Nector Rating	Pollen Rating	Economic and other uses[2]	Distribution and Remarks
Prunus puddu, Roxb.	IX - XII	N_1	P	Fuel	Wide ecological amplitude. Nectar sugar concentration from 12 to 18 %. Good source of nectar in hills during autumn
Punica granatum Linn.	IV - V	-	P	Food-seeds, fuel, and medicinal seeds	Wide ecological amplitudes. Subtropical to sub-temperate
Robinia pseudacacia Linn.	IV - V	N_1	-	Timber, fuel, land use-soil conservation	Nectar sugar concentration varies from 30% to 62 %, wide ecological amplitude
Salix spp.	III - IV	N_2	P_2	Wood for cricket bats, land use-soil conservation	Fairly widespread, nectar sugar concentration varies from 15% to 79 %
Sapindus emarginatus Vahl	X - XII	N_1	P_1	Land use-shade amenity, fruits use as substitute for soap	Subtropical, recommended for plantation to increase honey production
S. mukorissi Gaertn.	V - VI	N_1	P	- do -	- do -
Sapium sebiferum Roxb.	VI - VIII	N_1	-	- do -	Nectar sugar concentration from 23 to 31 %.
Syzgium cuminii Skeels	II - IV	N_1	P_1	Food-fruits; vinegar, vine, & fruit juice, fodder-leaves, timber, fuel, land use-shade, windbreak, amenity, other uses-tannin from bark, seeds, kernel of the fruit is specific for diabetes	Nectar secretion erratic, nectar sugar concentration varies from 9-72 %, flowers within 3-5 years

Botanical Name	Blooming Period*	Honey Potentiality Nector Rating	Pollen Rating	Economic and other uses[2]	Distribution and Remarks
S. heyneanum L.	II - III	N_1	P_2	Fodder, timber, fuel, land use-shade and wind-break	Subtropical and sub-temperate
Terminalia arjuna (Roxb.) W. & A	IV - V	N_1	P	Timber, fuel land use, medicinal fruits	Foothills and low hill areas with subtropical climate
Herbs					
Artemisia spp (21 spp)	V - VII	N_2	P_3	Good for slope stabilization and soil erosion control	Sub-temperate
Impatiens spp (20 spp)	VII - IX	N_2	P_3	Pioneer plant species for roadside soil debris	Temperate
Iris spp	III - VI	N_2	P_2	Due to extensive rhizome spread a good soil kinder for slopy areas, pioneer plant	Sub-temperate to temperate
Plectranthus spp	VIII - XI	N_1	P_2	A plant suitable for bare surface cover, pioneer for new, disturbed areas	Tropical to temperate
Medicago	VII - XI	N_2	P_2	A plant suitable for bare surface cover, pioneer for new, disturbed areas	Tropical to temperate
Trifolium spp (18 spp)	IV - VIII	N_1	P_1	Pioneer for surface cover of bare lands	widespread distribution
Fragaria spp	IV - VI	N_2	P_2	Provides surface cover through horizontal spread	Temperate

Botanical Name	Blooming Period*	Honey Potentiality Nector Rating	Pollen Rating	Economic and other uses[2]	Distribution and Remarks
Shrubs					
Adhatoda vesca	IV - V	N_1	P_2	Good for slope stabilization and soil conservation	Subtropical to temperate
Berberis lycium	III - V	N_2	P_1	Thorny shrubs-fuel, fencing medicinal/ commercial value and good for growing on slopy sites	- do -
Prinsepia utilis	IX - X	N_1	R_1	Fuel, fodder, fruit, oil seed, suitable for slope stabilization	Temperate to sub-temperate
Rosa brunonii *R. macrophylla*	IV - XI	N_1	P_1	Fodder, fuel, suitable for slopes	Sub-temperate to temperate

Source: Verma 1988 unpublished.

1. January - December months indicated as I - XII

2. Information developed by author.

N1 -	Major honey source	P1 -	Major pollen source
N2 -	Medium honey source	P2 -	Medium pollen source
N3 -	Minor honey source	P3 -	Minor pollen source
N -	Importance unrated	P -	Importance unrated

Table 16.4: Some common plant species of different climatic regimes of the Hindu Kush-Himalayan Region to facilitate selection of appropriate roadside plantations

	Species	Uses	Remarks
	(1)	(2)	(3)
A.	**TEMPERATE REGION COMPRISING MOSTLY OF HIGH MOUNTAIN AREAS**		
1.	*Aluns nepalensis* (*piak, newn, kunis, utis*)	Timber, fuel, nitrogen fixing	Large trees suitable for growing on river banks, ravines, and newly-formed soils, useful for soil conservation in landslide areas, more common in Eastern Himalayan Region grown by direct sowing or by transplanting, entirely good for slope stabilization
2.	*Alnus nitida* (*kunsh, hunis, utis*)	Timber, fuel, nitrogen fixing	Similar to above; more common in Western Himalayan Region on riversides and ravines, good for slope stabilization
3.	*Betula alnoides* (*kath bhuj*)	Plywood, furniture, and tool handles	A medium-sized tree, suitable for broken marginal lands, can be grown by transplanting entirely and also by direct sowing, can be used for slope stabilization
4.	*Buxus sempervirens* (*papri*)	Carving, mathematical instruments	Slow growing small tree, suitable for shady, rocky, ravinous areas, can be grown by transplanting entirely, rare tree, much valued
5.	*Carpinus viminea* (*chamkharik*)	Timber for shuttle making, fuel, fodder	Middle-sized tree, wood used, grown by transplanting entirely
6.	*Corylus colurna* (*bhotia badam*)	Fruits, timber, fuel	Middle-sized tree edible fruit is much relished, can be grown by transplanting entirely as well as by direct sowing, can be planted on gentle slopy roadsides, middle-sized tree, grown by transplanting entirely
7.	*Eucalyptus saligna*	Timber, fuel	
8.	*Exbucklandia populnea* (*pipli*)	Timber, furniture, plywood	Large tree of Eastern Himalayan Region; useful for soil conservation, grown by transplanting entirely

Species	Uses	Remarks
(1)	(2)	(3)
9. *Fraxinus excelsa* (*angu*)	Furniture, axe, handles, sports' goods	Large tree, grown by transplanting entirely
10. *Juglans regia* (*akhrot*)	Timber, furniture and carving, gun-stock, fruits	Large tree, grown by transplanting entirely and also by direct sowing
11. *Morus serrata* (*kimu*)	Fodder, sports' goods, furniture, toys	Large tree, suitable for growing on marginal slopy lands and on roadsides passing through farmlands, can be grown by branch cuttings and direct sowing
12. *Olea ferruginea* (*kahu*)	Tool handles, walking sticks, toys, agricultural implements, fodder fatty oil	Small tree, suitable for growing on bouldery marginal lands; can be grown by direct sowing, transplanting entirely or by branch cuttings, good for slope stabilization
13. *Populus nigra*	Light timber, matchwood, pulpwood, fuel, ornamental	Large tree, suitable for dry valleys, grown by branch cuttings, important plant for roadside slope, stabilization
14. *Prunus cerasoides* (*padam*)	Timber, fuel, fodder, wood used in religious ceremonies	Medium tree, suitable for marginal lands and around villages, grown by transplanting entirely, also by branch cuttings, good for beekeeping
15. *Prunus persica* (*aru*)	Fruits, timber, fuel	Small tree, suitable for near habitation, gentle, stable slopes, and plain valley areas, grown by transplanting entirely
16. *Pyrus malus* (*sew*)	Fruits	Small trees, suitable for growing near habitations, farming areas in valleys and marginal lands, grown by transplanting entirely
17. *Quercus incana* (*banj*)	Timber for agricultural implementations, medicinal, tussah silk rearing	Large tree of Eastern Himalayan Region, suitable for marginal lands, grown by direct sowing, good for slope stabilization in high mountain areas
18. *Quercus lamellosa* (*shaishi*)	Timber for agricultural implements, fuel, fodder tussah silk rearing	Large tree of Western Himalayan Region, suitable for deep soil, moist localities on marginal lands and roads passing through commons, grown by rearing transplanting and also by direct sowing, can be used on slopes

Species	Uses	Remarks
(1)	(2)	(3)
19. *Robinia pseudoacacia*	Fuel, fodder, soil conservation	Medium tree, suitable for marginal lands and for stabilizing ravinous land, grown by transplanting, commonly planted on roadsides in lower hills; can be planted on slopes of any degree
20. *Salix alba*	Cricket bats, matchwood, tool handles, fuel, fodder	Large tree, grown by branch cuttings
21. *Salix babylonica* (*manju*)	Fodder, fuel, ornamental	Large tree, suitable for growing around water, grown by branch cuttings
22. *Salix daphnoides* (*Bhashli, bashroi*)	Basket-making, fuel, tools and implements	Small tree, suitable for inner arid tracts of the *Himalaya*, grown by branch cuttings, the dominant roadside tree of trans-Himalayan roads in India

B. SUB-TROPICAL REGION COMPRISING FOOTHILLS OF WESTERN HIMALAYAN REGION AND CENTRAL HIMALAYAN MOUNTAINS

Species	Uses	Remarks
1. *Albizia-lebbeck* (*siris*)	Timber, fuel, fodder, medicinal	Large tree, suitable for open roadside lands and along narrow pathways, grown by transplanting entirely, direct sowing and cuttings
2. *Azadirachta indica* (*neem*)	Timber, bark and seed medicinal, insecticidal, fertilizer, fodder	Large tree, suitable for open valley lands, roadside near and along roads and paths, grown by entire transplanting and direct sowing
3. *Bauhinia purpurea* (*khairwal, guiral*)	Gum, fuel, fodder	Medium tree, suitable for roads passing through farm, grown by transplanting entirely and direct sowing
4. *Bauhinia variegata* (*kachnar*)	Gum, fodder, flower buds eaten, bark yields dye and medicine	Medium tree, suitable for road passing through farm grown by entire transplanting and direct sowing
5. *Celtis australis* (*kharik*)	Timber, fuel, fodder, sports goods, utensils	Medium tree suitable for certain sites and fodder and fuel demanding farming areas, grown by transplanting entirely, direct sowing, and branch cuttings
6. *Dalbergia sissoo* (*shisham*)	Timber, furniture, plywood, fuel, fodder	Large or medium tree, suitable for growing in lower to mid-hill plantations, on village roads, grown by transplanting entirely, root and shoot cuttings and direct sowing suitable on slopy sites

	Species	Uses	Remarks
	(1)	(2)	(3)
7.	*Dendrocalamus strictus (bans)*	Paper pulp, constructional, tent poles, basket-making	Large bamboo, suitable for growing on open marginal land road sites and near homesteads, grown by transplanting entirely and from rhizomes
8.	*Emblica officinalis (sonia)*	Fruits, tannin, timber, fuel, fodder	Medium tree, suitable for roadsides near homesteads and farms, grown by transplanting entirely or direct sowing, Himachal Pradesh already using it for roadside plantations for socioeconomic value
9.	*Eucalyptus camaldulensis*	Timber, fuel, charcoal, gum, medicinal	Large tree, suitable for both dry and swampy areas, grown by transplanting entirely
10.	*Eucalyptus grandis*	Timber, paper, pulp, fuel, essential oil	Large tree, suitable for marginal land road sites, grown by transplanting entirely
11.	*Exbucklandia populnea (pipli)*	See (a) (i) (8)	
12.	*Ficus religiosa (pipal)*	Timber for packing cases, trees on roadsides	Suitable for growing as single tree or as avenues, grown by branch cuttings, significant as shade
13.	*Grevillea robusta*	Ornamental, timber	Large tree, suitable for shade or as avenues, (cabinet making, toys, grown by direct sowing, fuel, panelling), shade tree in tea gardens
14.	*Grewia optiva (bhimal)*	Timber-cot frames, fibre, fodder	Medium tree, suitable for farming need areas. good as fodder, fiber and fuel, grown by transplanting entirely
15.	*Melia azadirachta (bakain,dek)*	Box planks, fuelwood, paper pulp, fodder medicinal	Medium tree, suitable for roads going around fields and on marginal lands, grown by transplanting entirely or direct sowing
16.	*Moringa oleifera (sahjan)*	Fruits and flowers edible, medicinal, fodder, wood for pulp	Small tree, fast growing, suitable on slopy edges and on hedges near habitations, grown by branch cuttings and direct sowing
17.	*Morus alba (tut)*	Fruits - edible, timber, sports goods, fodder, leaves for silkworm feeding	Medium tree, suitable for marginal lands, grown by transplanting entirely, direct sowing, or branch cuttings
18.	*Morus laevigata (shahtut)*	Fruits - edible, timber, sports goods, fodder	Large tree, suitable for gardens, homesteads, and marginal lands

	Species	Uses	Remarks
	(1)	(2)	(3)
19.	*Populus deltoides*	Matchwood, pulpwood, light timber, fuel	Large tree, suitable for field edges and marginal lands in the Himalayan foothill areas, grown by branch cuttings
20.	*Prunus armeniaca* (*zardalu*)	Fruits, timber, fuel	Small tree near habitation, farmland roadsides, grown by branch cuttings.
21.	*Prunus persica* (*aru*)	See (A) (i) (15)	In valleys and on stable land near habitation road sites
22.	*Pyrus communis* (*ritha*)	Fruits, fuel	Small tree, suitable for homesteads and field edges, grown by grafting
23.	*Sapindus mukorossi* (*ritha*)	Fruits, soapnut, fodder	Medium tree, suitable for growing near houses and on field edges, grown by transplanting entirely or by direct sowing, provides traditional soapy material from fruits, a source of income for poor people
24.	*Toona ciliata* (*tun*)	Timber, fuel	Large tree, suitable for growing on roadsides passing through lands and village commons, grown by transplanting entirely

C. SUB-TROPICAL CLIMATE OF CENTRAL AND EASTERN HIMALAYAS:

1.	*Acrocarpus fraxinifolius*	Fuel, boxwood, boards, planks	Large tree, suitable for roadsides and marginal lands and village commons, grown by transplanting entirely or direct sowing
2.	*Ailanthus grandis* (*gogal*)	Plywood, ornamental	Large tree, suitable for growing on village commons and roadsides, grown by transplanting entirely or direct sowing
3.	*Albizia lebbeck* (*siris*)	See (b) (1)	
4.	*Albizia procera* (*safed siris, kinni*)	Timber, fuel, fodder	Large tree, suitable for growing on village commons, marginal lands, and roadsides, grown by transplanting entirely and direct sowing, good for areas requiring fuel and fodder
5.	*Bauhinta purpurea* (*khairwal, guiral*)	See (b) (3)	
6.	*Betual cylindrostachys*	Essential oil, fuel, charcoal, timber	Large tree, suitable for cut up marginal lands, grown by transplanting entirely, economic value, income generation to people

Species	Uses	Remarks
(1)	(2)	(3)
7. *Grevillea robusta*	See (b) (3)	
8. *Grewia elastica* (*dhaman*)	Ornamental, timber, toy-making, fuel, fodder	Medium tree, suitable for slopy and plain roadsides, grown by transplanting entirely
9. *Michelia champaca* (*champ*)	Decorative timber, fuel, ornamental	Large tree, suitable for valley roads - marginal lands, and village commons
10. *Melia azadirachta* (*bakain, dek*)	See (b) (15)	
11. *Morus serrata* (*kimu*)	See (a) (11)	

D. TROPICAL REGION

(i) HIGH RAINFALL AREAS OF NEPAL & NORTH EASTERN PARTS OF INDIA

1. *Ailanthus grandis* (*gogal*)	See (c) (2)	
2. *Albizia lebbeck* (*siris*)	See (b) (1)	
3. *Albizia procera* (*safed siris*)	See (c) (4)	
4. *Artocarpus integrifolia* (*kathal*)	Timber, fruits, fodder	Large tree, suitable for growing along roads passing through habitations, aesthetic value, grown by transplanting entirely and by direct sowing
5. *Azadirachta indica* (*neem*)	See (b) (2)	
6. *Bambusa balcooa*	Constructional purposes, paper pulp, cottage industry	Medium bamboo, suitable for growing on marginal lands, grown from rhizomes
7. *Casuarina equisetifolia* (*saru*)	Timber, fuel, ornamental	Tall tree, fast growing, suitable for warm sandy areas of some foothills; ideal for fuelwood lots, grown by transplanting entirely

	Species	Uses	Remarks
	(1)	(2)	(3)
8.	*Chukrasia tabularis* (*chikrasi*)	Timber, furniture, decorative plywood, fuel	Large tree, suitable for growing around village roads, grown by transplanting entirely
9.	*Cinnamomum zeylanicum* (*dalchini, lavang*)	Cinnamon, essential oil, medicinal	Medium tree, suitable for growing on village roads and near rural habitations, grown by transplanting entirely and direct sowing
10.	*Cocos nucifera* (*nariyal*)	Fruits, copra, oil coir, toddy, jaggery	Roads of foothill valleys near habitations grown by transplanting entirely, good examples seen in Sri Lanka, Dharan, Nepal, and in parts of India
11.	*Dendrocalamus hamiltonii* (*kagshi bans*)	Paper pulp, vegetables - young shoots, constructional purposes	Tall bamboo, suitable for marginal lands, grown by direct sowing and by rhizomes, meets local requirements of rural people
12.	*Dalbergia latifolia* (*shisham, biti, jitengi, iti*) rosewood	Timber, furniture, cabinet	Large tree, suitable for growing in village, on State and national highways, grown by transplanting entirely
13.	*Emblica officinalis* (*aonla*)	See (b) (8)	
14.	*Ficus elastica* (*bor attab*), India rubber tree	Ornamental, rubber, fodder	Large tree, suitable for growing on all kinds of roads, grown by transplanting entirely or by branch cuttings
15.	*Gmelina arborea* (*gamhar*)	Timber, printing block, musical instruments, cart axles, fuel, medicinal	Large tree, suitable for village roads, grown by transplanting entirely and direct sowing
16.	*Lagerstroemia speciosa* (*jarul*)	Timber - constructional purposes, furniture, agricultural implements, telegraph poles, fodder, medicinal	Large tree, suitable along pathways, grown by transplanting entirely

Species	Uses	Remarks
(1)	(2)	(3)
17. *Melia azadirachta*		See (b) (15)
18. *Melocanna baccifera*	House construction, mats, baskets, paper pulp	Medium bamboo, suitable for growing in 3rd row onwards, grown by transplanting entirely
19. *Mangifera indica* (*am*), Mango tree	Edible fruits, fatty oil, plywood, shoe heels, furniture, fuel	Large tree, suitable for growing on roadsides of all kinds of roads, more preferable for village roads, good only for valleys and stable areas. grown by transplanting entirely (grafted)
20. *Michelia champaca* (*champ*)		See (c) (9)
21. *Parkia roxburghii* (*supota*)	Fruits, fuel, ornamental, medicinal	Medium tree of Eastern parts, suitable for roadsides, grown by transplanting entirely
22. *Sesbania graniflora* (*agast, banas*)	Light timber, fodder, medicinal, flower edible.	Small tree, suitable for near habitation roads and road hedges, grown by direct sowing or transplanting entirely
23. *Syzgium cuminal* (*jamun*)	Fruit edible and medicinal timber, tools & implements, fuel, fodder	Large tree, suitable for growing along relatively less slopy areas or valleys

(ii) **MEDIUM RAINFALL AREAS OF LOW TO MID HILLS**

1. *Acacla auriculiformis* (*Akashmuni*)	Timber, fuel, ornamental	Medium trees, suitable for slopy lands, grown by transplanting entirely and direct sowing
2. *Acacia nilotica* (*babu, kikar*)	Timber, fuel, fodder, tannin, gum	Medium tree, suitable for sites of slopy lands, marginal lands and village commons, grown by direct sowing
3. *Aegl marmelos* (*bel, vilva*)	Fuel, gum, bark, and fruit, medicinal	Small tree, suitable for roadsides near rural habitations and houses, grown by transplanting entirely
4. *Ailanthus excelsa* (*arru*)	Timber, packing cases, fishing floats, and boards, bark, medicinal, fodder	Large tree, suitable for growing on roads on marginal lands and village commons, grown by transplanting entirely and by direct sowing

	Species	Uses	Remarks
	(1)	(2)	(3)
5.	*Schleichera trijuga* (*kusum*)	Timber, tools and implements, fuel, lac cultivation	Large tree, suitable for open land around village, boundaries and village commons, grown by transplanting entirely
6.	*Tectona grandis* (*sagaun*)	Timber - railway carriages and wagons, cabinet, furniture	Large tree, suitable for field edges, marginal lands, and village commons.
7.	*Terminalia arjuna* (*arjun*)	Timber, mine-props, plywood, bark, tannin, medicinal, fodder, leaves for tussah silkworm	Large tree, suitable for growing along water courses and in water-logged areas, grown by transplanting entirely
E. TRANS-HIMALAYAN, HIGH MOUNTAIN COLD ARID ZONE			
1.	*Salix spp.*		A popular tree of the *Trans-Himalaya*
2.	*Populus spp.*	See (b) 20.	Also commonly grown by mountain communities for fuel and fodder
3.	*Prunus armeniaca* (Apricot)	See (A) (1) (15)	A popular oil seed and fruit tree-wild as well as domesticated
4.	*Alnus spp.*	Nitrogen fixing See (a) (1 & 2)	Wild forms for roadside plantations
5.	*Betula utilis* (*Bhoj Patra*)	See (A) (3)	
6.	*Hyppophae spp.*	Fruits, fuel, timber, nitrogen fixation, soil fertilization.	Shrub and tree both suitable for dry sandy or rocky locations, riversides, moist areas, good for roadsides passing through farmlands
7.	*Prunus Persica*	Fruits, fuel	Wild forms for roadside plantations

Source: Author's compilation.

16.2 BIOTECHNICAL STABILIZATION

16.2.1 *Introduction*

The design of biotechnical stabilizations requires an appreciation of the mechanics that link plants and slope stability parameters (referred to as **plant mechanics** here), as well as an understanding of plant biology. Plant mechanics is essential for defining the slope stability problem vis-a-vis vegetation and evaluating a solution to that problem, while **plant biology** is needed to generate solutions to the vegetative slope stability problem.

Plant biology can readily supply information regarding the selection of species whose characteristics suit the natural conditions that sustain the plant but is often pressed to provide information regarding plant characteristics that relate to slope stability parameters.

This chapter is divided into three sections. The sections deal with three stability problems that plants can help to solve; the three problems are common in attempts to stabilize cut slopes, the influence area of a road, and a failure zone. The three problems are: (1) surface erosion, (2) increase in soil shear strength, and (3) groundwater table or moisture content reduction. The first two problems are treated with both plant mechanics and plant biology while the third problem is treated with plant biology and drainage measures.

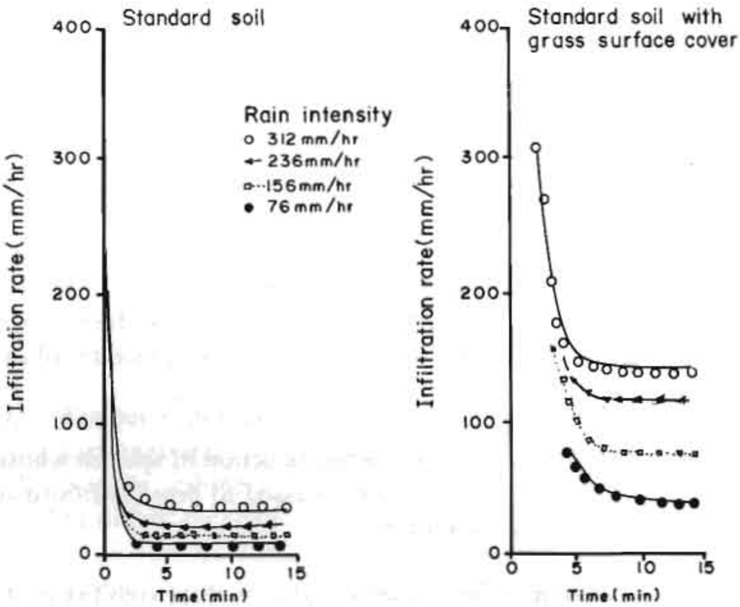
16.2.2 *Surface Erosion*

Soil loss on a given slope is determined by the interaction that erosive rainfall has with erodible soil. The interactions involve processes that are governed by characteristics of the rainfall and soil as well as by several other slope attributes. Vegetation cover is one such slope attribute. Vegetation cover reduces the erosivity of rainfall through (1) interception which armours soil and reduces the water available for infiltration or runoff (see Table 16.5), (2) an increase in infiltration caused by roots, vacant root channels, and increased surface roughness (Fig. 16.1), and, finally, (3) root binding which reduces the susceptibility of soil particles to be dislodged by splash or sheet erosion.

Table 16.5 Approximate average rainfall interception, evergreen rainforest of Brazil

Penetrating to rain gauge at 1.5a		33.0 %		
Evaporated directly from tree crowns		20.0 %		
Running down trunks 46 %	evaporated from surface	9.2 %		
	absorbed by roots	9.2 %		
	reaching by barks	27.6 %	absorbed by roots	20.7 %
			reaching water table	6.9 %

Source: Greenway 1987



Source: Nasif and Wilson

Fig 16.1 Comparative infiltration capacities from a 9° slope

The Universal Soil Loss Equation (USLE) (Wishmier and Smith 1978) provides a means to predict soil loss from sheet and rill erosion: it is a widely used method and provides the best approximation of soil loss. Its relevance here is as a vegetative cover design equation. As explained below, application of the USLE requires work to adjust input values to suit conditions in Nepal. While the USLE has been accepted as the best approximation of soil loss in other parts of the world, its validity in Nepal remains to be tested. Tests may, or may not, show that the USLE requires modification for application in Nepal. Regardless of whether the USLE is proved to require modification or not, it is the starting point in analyzing soil erosion for the design of preventive measures.

The Universal Soil Loss Equation

The USLE is defined as:

$$A = RKLSCP \qquad (1)$$

where,

A	=	soil loss in metric tons per hectare per period P,
R	=	rainfall erosivity,
	=	EI_{30},
E	=	kinetic energy of a storm in metric ton-metres per hectare,
I_{30}	=	maximum 30 minute storm intensity in cm per hour,
K	=	soil erodibility in metric tons per hectare per metric EI unit,
L	=	slope length factor (dimensionless),
S	=	slope gradient factor (dimensionless),
C	=	vegetative cover factor (dimensionless), and
P	=	soil erosion control practice factor (dimensionless).

a) Rainfall Erosivity, R

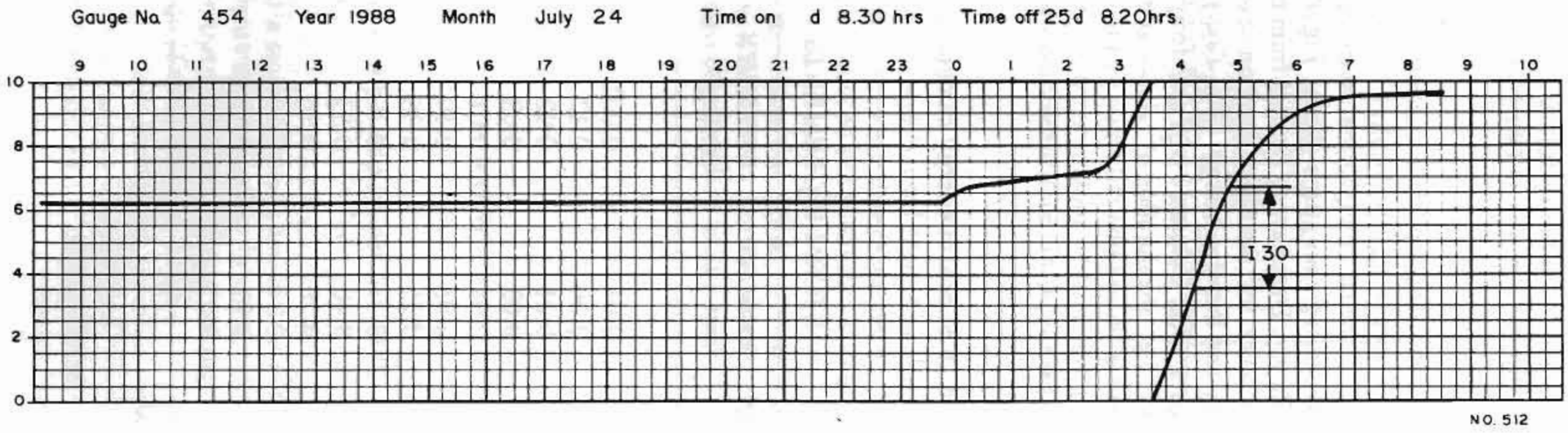
Tests have shown that the erosive power of rainfall is best measured by the product of the total energy of a storm (E) and the maximum intensity of a storm for 30 consecutive minutes (I_{30}). EI_{30} must be calculated for each storm for the period the soil loss is being calculated for (a year or 3 months, for example).

Unlike countries where past work with the USLE permits a quick calculation of R based on **isoerodent maps** (that show contours of equal R values geographically) or empirical equations that relate R to rainfall parameters, such as the average annual precipitation, work in Nepal must begin from primary data. Data must be collected from recording rain-gauge charts; Figure 16.2 shows such a chart from Kathmandu Airport Meteorological Station. Data have to be read from the chart as millimeters of rainfall in minutes of time at each inflection point for the entire duration of each storm. Every inflection point signifies a change in rainfall intensity and thereby energy. The first two columns of Table 16.6 show readings taken from the chart in Figure 16.2; Column 3 of Table 16.6 is the difference in time readings at each inflection point of Figure 16.2, i.e., the duration of rainfall at different intensities. Column 4 of Table 16.6, is the difference in amount at those same inflection points. Column 6 is the intensity during the different periods of the storm, obtained by looking up the energy for the intensities of Column 5 of Table 16.6 and in Table 16.7. Finally, Column 7 is the total energy for every intensity; it is the product of Columns 4 and 6.

Table 16.6 Storm energy calculation

CHART READINGS		STORM INCREMENTS			ENERGY	
TIME	*DEPTH (mm)*	*DURATION (min)*	*AMOUNT (cm)*	*INTENSITY (cm/hr)*	*PER CM*	*FOR INCREMENT*
18:15	6.15					
23:45	6.25	330	0.01	0.002	0	0
00:15	6.80	30	0.06	0.12	121	7
00:45	6.85	30	0.01	0.02	0	0
01:45	7.15	60	0.03	0.03	0	0
02:30	7.20	45	0.01	0.01	0	0
02:48	7.50	18	0.03	0.10	121	4
03:30	10.00	42	0.25	0.36	175	44
03:30	0.00	0	0	0	0	0
04:15	4.00	45	0.40	0.53	184	74
04:45	6.75	30	0.28	0.56	191	54
06:00	9.10	75	0.24	0.19	148	36
07:00	9.40	60	0.03	0.03	0	0
08:20	9.50	80	0.01	0.01	0	0

I_{30} = 0.33 cm/hr
Total Energy = 2.19
EI^{30} = 0.72



Source: Dept. of Meteorology, HMG, Nepal, 1988.

Fig 16.2 Recording rain gauge chart, KTM Airport, July 24, 1988

The sum of all rows, divided by 100 (a scaling convention), is E, the total kinetic energy of the storm. I_{30} is obtained by reading the maximum amount of rain falling in any consecutive 30 minutes and multiplying it by two. When the duration of a storm itself is less than 30 minutes, I_{30} is twice the amount of rain. The product EI_{30} is thus calculated for each storm over period P. The sum of EI_{3} over P is R for that period. Table 16.8, below, gives values of EI_{30} for Kathmandu Airport in 1988 and Figure 16.3 gives the cumulative frequency of EI_{30m} at Kathmandu Airport in 1988.

Table 16.7 Kinetic energy of rainfall: expressed in metric ton-metres per hectare per centimetre of rain[1]

Intensity cm/h	.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0	121	148	163	175	184	191	197	202	206
1	210	214	217	220	223	226	228	231	233	235
2	237	239	241	242	244	246	247	249	250	251
3	253	254	255	256	258	259	260	261	263	264
4	264	265	266	267	268	268	269	270	271	272
5	273	273	274	275	275	276	277	278	278	279
6	280	280	281	281	282	283	283	284	284	285
7	286	286	287	287	288	288	289[2]			

1 Computed by the equation E = 210 + 89 log10'

where,

E = kinetic energy in metric-ton metres per hectare per centimetre of rain and
I = rainfall intensity in centimetre per hour.

2 The 289 value also applies for all intensities greater than 7.6 cm/h.

Table 16.8 EI_{30} at Kathmandu Airport in 1988

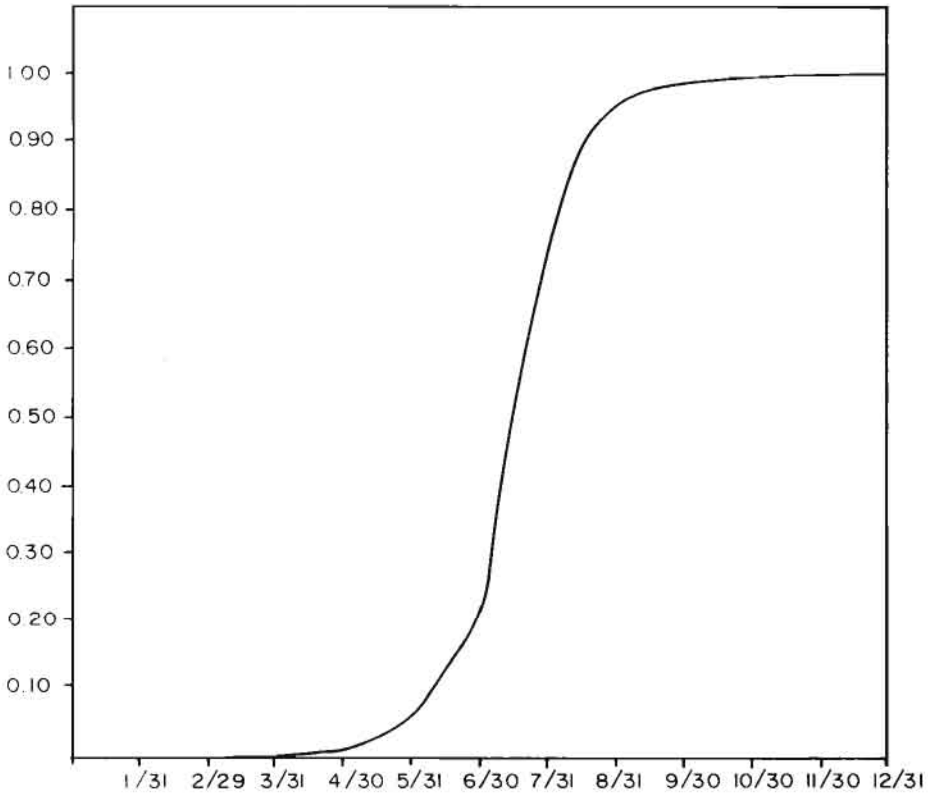
Date		EI_{30}*
January	1-15	0.01
January	16-31	0.00
February	1-15	0.04
February	16-29	1.68
March	1-15	2.90
March	16-31	0.14
April	1-15	0.28
April	16-30	0.22
May	1-15	4.06
May	16-31	14.68
June	1-15	27.88
June	16-30	38.03
July	1-15	196.62
July	16-31	36.04
August	1-15	65.36
August	16-31	16.08
September	1-15	11.24
September	16-30	5.11
October	1-15	1.61
October	1-15	0.00
November	1-15	0.66
November	16-30	0.00
December	1-15	0.00
December	16-31	0.07
		EI_{30} = 423

Source: Department of Meterology, HMG, Nepal, 1988.

* Missing storms in recording rain gauge charts have not been included. Although the mean EI_{30} for a given month is a bad proxy of EI_{30} for missing storms, the inclusion of those values for all missing storms results in an annual EI_{30} of 502.

The Department of Meteorology, HMG, has 8 operating recording rain-gauge stations in the country. Their names and the years for which data exist are as follows:

Surkhet:	May 1988 onwards,	Dhankuta:	1986 onwards,
Bhairawa:	1986 onwards,	Biratnagar:	1986 onwards,
Pokhara:	March 1988 onwards,	Taplejung:	1986, and
Okhaldunga:	1986 onwards,	Kathmandu:	1986 onwards.



Source: Dept. of Meteorology, HMG, Nepal, 1988

Fig. 16.3 Cumulative frequency of EI_{30m} at Kathmandu Airport, 1988

b) Soil Erodibility, K

The soil erodibility, factor K, is the rate of soil loss for a given soil type as experimentally determined on a standard unit plot. K represents the inherent susceptibility of a given soil to erode.

Direct measurements of K require experiments that need to cover not only the range of soil property combinations that are relevant but also need to account for all possible storm sizes and antecedent soil conditions. Such experiments will clearly be costly and time consuming; fortunately they are not necessary. Nomographs have been developed from empirical relationships derived from experiments of soil erodibility. Figure 16.4 shows a nomograph (Wischmeier and Smith 1978) that requires only five properties of the soil for use. These properties are: (1) per cent silt and very fine sand (0.002 - 0.10 mm), (2) per cent sand (0.10 - 2.0 mm), (3) per cent organic matter, (4) structure, and (5) permeability. Furthermore, only the first three properties are needed to make a first approximation of K_E. To use the chart, enter the per cent of silt and very fine sand in the left chart. Proceed to the curve that matches the per cent of sand of the slope soil. Turn upwards to intersect the appropriate curve for the per cent of organic matter. Continue along the ordinate axis to obtain a first approximation of K_E. Then continue with the right chart as indicated by the dotted line. Linear interpolations are to be used between curves on the nomograph. Figure 16.4 gives K_E in units of tons per acre per unit R. Since (1) is in metric units, the reading from Figure 16.4, K_E, has to be converted to its metric equivalent, K as $K = 1.292\ K_E$.

c) Topographic Factor, LS

The topographic factor, LS, is the ratio of expected soil loss per unit area to soil loss on a standard plot, for different values of the slope length, L, and the slope steepness, S. The LS factor will be substantially over unity, therefore particular attention is required in choosing an appropriate LS value.

As in the case of K, experimentally derived values of LS exist. However, these were developed for use in the plains' area and do not extend beyond slope angles of 45°. Table 16.9 shows experimentally verified LS factors for slopes up to a length of 305 m and 100 per cent (the equation at the bottom can be used to estimate LS for slopes steeper than 100 per cent but it should be borne in mind that the resulting LS factors have not been experimentally verified). Verified estimates of LS for slopes steeper than 100 per cent can only be obtained by experimentally verifying the validity of LS calculated from the equation in Table 16.9.

In a case where the gradient of the slope changes along its length without causing soil deposition, the following equation is used to calculate LS:

$$LS = \{[(L_{\lambda} S_{s_1})\lambda_1 - (L_{\lambda_o} S_{s_1})\lambda_o] + [(L_{\lambda_2} S_{s_2})\lambda_2 - (L_{\lambda_1} S_{s_2})\lambda_1] + [(L_{\lambda_3} S_{s_3})\lambda_3 - (L_{\lambda_2} S_{s_3})\lambda_2] + \dots [(L_{\lambda_n} S_{s_n})\lambda_n - (L_{\lambda_{n-1}} S_{s_n})\lambda_{n-1}]\}/(l_1 + l_2 + l_3 \dots l_n)$$

in which,

L_n = length factor for slope segment $\left(\frac{l_n}{72.5}\right)^m$,

l_n = length of slope segment n,

m = 0.2 for slope gradient of 0 to 1 per cent,
0.3 for slope gradient of 1 to 3 per cent,
0.4 for slope gradient of 3.5 to 4.5 per cent,
0.5 for slope gradients greater than 5 per cent,

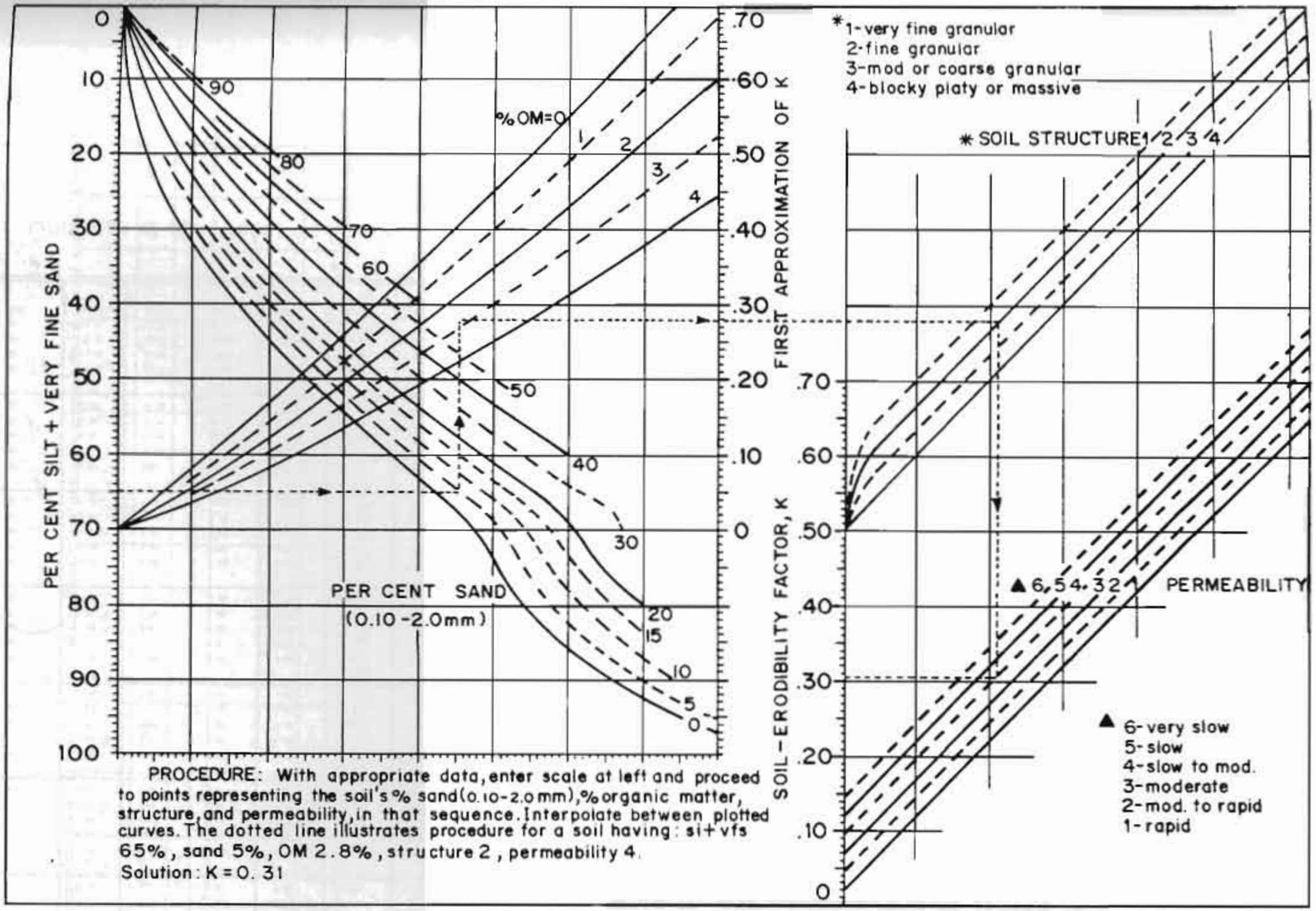
S_n = slope factor for slope segment n,

$$= \frac{65.41\ S_n^2}{S_n^2 + 10{,}000} + \frac{4.56\ S_n}{\sqrt{S_n^2 + 10{,}000}} + 0.65,$$

s_n = slope gradient in per cent of segment n, and

λ_n = the sum of the slope segment lengths from the top of the slope to the bottom of slope segment n.

The LS factors of Table 16.9 can be used to obtain LS values. A convenient tabular calculation format is illustrated for the case shown by Figure 16.5 in Table 16.10 In Table 16.10, Column 13 shows the cumulative LS values, the total being 2.21. So the equation to compute soil loss would be A = RK (33.22) CP.



Source: Wischmeier and Smith 1978

Fig. 16.4 The soil-erodibility nomograph

Where the silt fraction does not exceed 70 per cent, the equation is $100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)$

Where M = (per cent si + vfs) (100 - per cent c), a = per cent organic matter, b = structure code, and c = profile permeability class.

Table 16.9 LS Values* (10)

Slope ratio	Slope gradient s, %	LS values for following slope lengths l, ft (m): 10 (3.0)	20 (6.1)	30 (9.11)	40 (12.2)	50 (15.2)	60 (18.3)	70 (21.3)	80 (24.4)	90 (27.4)	100 (30.5)	150 (46)	200 (61)	250 (76)
100:1	0.5	0.06	0.07	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.11	0.11
	1	0.08	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.12	0.12	0.14	0.14	0.15
	2	0.10	0.12	0.14	0.15	0.16	0.17	0.18	0.19	0.19	0.20	0.23	0.25	0.26
	3	0.14	0.18	0.20	0.22	0.23	0.25	0.26	0.27	0.28	0.29	0.32	0.35	0.38
	4	0.16	0.21	0.25	0.28	0.30	0.33	0.35	0.37	0.38	0.40	0.47	0.53	0.58
20:1	5	0.17	0.24	0.29	0.34	0.38	0.41	0.45	0.48	0.51	0.53	0.66	0.76	0.85
	6	0.21	0.30	0.37	0.43	0.48	0.52	0.56	0.60	0.64	0.67	0.82	0.95	1.06
	7	0.26	0.37	0.45	0.52	0.58	0.64	0.69	0.74	0.78	0.82	1.01	1.17	1.30
	8	0.31	0.44	0.54	0.63	0.70	0.77	0.83	0.89	0.94	0.99	1.21	1.40	1.57
12½:1	9	0.37	0.52	0.64	0.74	0.83	0.91	0.98	1.05	1.11	1.17	1.44	1.66	1.85
10:1	10	0.43	0.61	0.75	0.87	0.97	1.06	1.15	1.22	1.30	1.37	1.68	1.94	2.16
	11	0.50	0.71	0.86	1.00	1.12	1.22	1.32	1.41	1.50	1.58	1.93	2.23	2.50
8:1	12.5	0.61	0.86	1.05	1.22	1.36	1.49	1.61	1.72	1.82	1.92	2.35	2.72	3.04
	15	0.81	1.14	1.40	1.62	1.81	1.98	2.14	2.29	2.43	2.56	3.13	3.62	4.05
6:1	16.7	0.96	1.36	1.67	1.92	2.15	2.36	2.54	2.72	2.88	3.04	3.72	4.30	4.81
5:1	20	1.29	1.82	2.23	2.58	2.88	3.16	3.41	3.65	3.87	4.08	5.00	5.77	6.45
4½:1	22	1.51	2.13	2.61	3.02	3.37	3.69	3.99	4.27	4.53	4.77	5.84	6.75	7.54
4:1	25	1.86	2.63	3.23	3.73	4.16	4.56	4.93	5.27	5.59	5.89	7.21	8.33	9.31
	30	2.51	3.56	4.36	5.03	5.62	6.16	6.65	7.11	7.54	7.95	9.74	11.25	12.57
3:1	33.3	2.98	4.22	5.17	5.96	6.67	7.30	7.89	8.43	8.95	9.43	11.55	13.34	14.91
	35	3.23	4.57	5.60	6.46	7.23	7.92	8.55	9.14	9.70	10.22	12.52	14.46	16.16
2½:1	40	4.00	5.66	6.93	8.00	8.95	9.80	10.59	11.32	12.00	12.65	15.50	17.89	20.01
	45	4.81	6.80	8.33	9.61	10.75	11.77	12.72	13.60	14.42	15.20	18.62	21.50	24.03
2:1	50	5.64	7.97	9.76	11.27	12.60	13.81	14.91	15.94	16.91	17.82	21.83	25.21	28.18
	55	6.48	9.16	11.22	12.96	14.48	15.87	17.14	18.32	19.43	20.48	25.09	28.97	32.39
1¾:1	57	6.82	9.64	11.80	13.63	15.24	16.69	18.03	19.28	20.45	21.55	26.40	30.48	34.08
	60	7.32	10.35	12.68	14.64	16.37	17.93	19.37	20.71	21.96	23.15	28.35	32.74	36.60
1½:1	66.7	8.44	11.93	14.61	16.88	18.87	20.67	22.32	23.87	25.31	26.68	32.68	37.74	42.19
	70	8.98	12.70	15.55	17.96	20.08	21.99	23.75	25.39	26.93	28.39	34.77	40.15	44.89
	75	9.78	13.83	16.94	19.56	21.87	23.96	25.87	27.66	29.34	30.92	37.87	43.73	48.89
1¼:1	80	10.55	14.93	18.28	21.11	23.60	25.85	27.93	29.85	31.66	33.38	40.88	47.20	52.77
	85	11.30	15.98	19.58	22.61	25.27	27.69	29.90	31.97	33.91	35.74	43.78	50.55	56.51
	90	12.02	17.00	20.82	24.04	26.88	29.44	31.80	34.00	36.06	38.01	46.55	53.76	60.10
	95	12.71	17.97	22.01	25.41	28.41	31.12	33.62	35.94	38.12	40.18	49.21	56.82	63.53
1:1	100	13.36	18.89	23.14	26.72	29.87	32.72	35.34	37.78	40.08	42.24	51.74	59.74	66.79

Slope ratio	Slope gradient s, %	LS values for following slope length l, ft (m): 300 (91)	350 (107)	400 (122)	450 (137)	500 (152)	600 (183)	700 (213)	800 (244)	900 (274)	1000 (305)
100:1	0.5	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.15
	1	0.16	0.16	0.16	0.17	0.17	0.18	0.18	0.19	0.19	0.20
	2	0.28	0.29	0.30	0.32	0.33	0.34	0.36	0.37	0.39	0.40
	3	0.40	0.42	0.43	0.45	0.46	0.49	0.51	0.54	0.55	0.57
	4	0.62	0.66	0.70	0.73	0.76	0.82	0.87	0.92	0.96	1.00
20:1	5	0.93	1.00	1.07	1.13	1.20	1.31	1.42	1.51	1.60	1.69
	6	1.16	1.26	1.34	1.43	1.50	1.65	1.78	1.90	2.02	2.13
	7	1.43	1.54	1.65	1.75	1.84	2.02	2.18	2.33	2.47	2.61
	8	1.72	1.85	1.98	2.10	2.22	2.43	2.62	2.80	2.97	3.13
12½:1	9	2.03	2.19	2.35	2.49	2.62	2.87	3.10	3.32	3.52	3.71
10:1	10	2.37	2.56	2.74	2.90	3.06	3.35	3.62	3.87	4.11	4.33
	11	2.74	2.95	3.16	3.35	3.53	3.87	4.18	4.47	4.74	4.99
8:1	12.5	3.33	3.59	3.84	4.08	4.30	4.71	5.08	5.43	5.76	6.08
	15	4.43	4.79	5.12	5.43	5.72	6.27	6.77	7.24	7.68	8.09
6:1	16.7	5.27	5.69	6.08	6.45	6.80	7.45	8.04	8.60	9.12	9.62
5:1	20	7.06	7.63	8.16	8.65	9.12	9.99	10.79	11.54	12.24	12.90
4½:1	22	8.26	8.92	9.54	10.12	10.67	11.68	12.62	13.49	14.31	15.08
4:1	25	10.20	11.02	11.78	12.49	13.17	14.43	15.58	16.66	17.67	18.63
	30	13.77	14.88	15.91	16.87	17.78	19.48	21.04	22.49	23.86	25.15
3:1	33.3	16.33	17.64	18.86	20.00	21.09	23.10	24.95	26.67	28.29	29.82
	35	17.70	19.12	20.44	21.68	22.86	25.04	27.04	28.91	30.67	32.32
2½:1	40	21.91	23.67	25.30	26.84	28.29	30.99	33.48	35.79	37.96	40.01
	45	26.33	28.44	30.40	32.24	33.99	37.23	40.22	42.99	45.60	48.07
2:1	50	30.87	33.35	35.65	37.81	39.85	43.66	47.16	50.41	53.47	56.36
	55	35.48	38.32	40.97	43.45	45.80	50.18	54.20	57.94	61.45	64.78
1¾:1	57	37.33	40.32	43.10	45.72	48.19	52.79	57.02	60.96	64.66	68.15
	60	40.10	43.31	46.30	49.11	51.77	56.71	61.25	65.48	69.45	73.21
1½:1	66.7	46.22	49.92	53.37	56.60	59.66	65.36	70.60	75.47	80.05	84.38
	70	49.17	53.11	56.78	60.23	63.48	69.54	75.12	80.30	85.17	89.78
	75	53.56	57.85	61.85	65.60	69.15	75.75	81.82	87.46	92.77	97.79
1¼:1	80	57.81	62.44	66.75	70.80	74.63	81.76	88.31	95.41	100.13	105.55
	85	61.91	66.87	71.48	75.82	79.92	87.55	94.57	101.09	107.23	113.03
	90	65.84	71.11	76.02	80.63	84.99	93.11	100.57	107.51	114.03	120.20
	95	69.59	75.17	80.36	85.23	89.84	98.42	106.30	113.64	120.54	127.06
1:1	100	73.17	79.03	84.49	89.61	94.46	103.48	111.77	119.48	126.73	133.59

Source: Goldman et al. 1986

$$LS = \left(\frac{65.41 \times s^2}{s^2+10{,}000} + \frac{45.6 \times s}{\sqrt{s^2+10{,}000}} + 0.065\right)\left(\frac{l}{72.5}\right)^m$$

where,

LS = topographic factor

l = slope length, ft (m x 0.3048)

s = slope steepness,

m = exponent dependent upon slope steepness
(0.2 for slopes < 1%, o.3 for slopes 1 to 3%
0.4 for slopes 3.5 to 4.5%, and 0.5 for slopes > 5%)

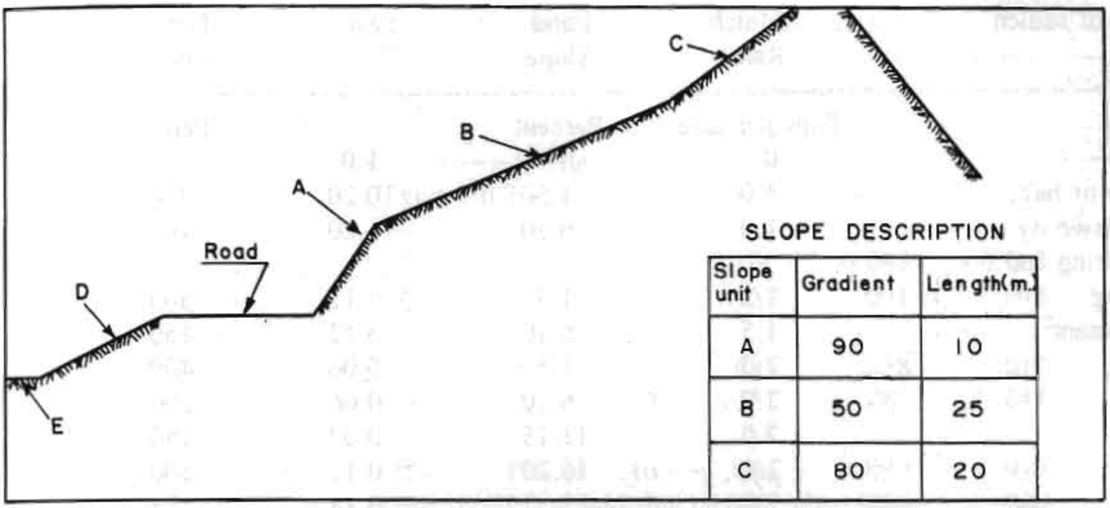


Fig 16.5 Multiple slope situation

d) Vegetative Cover Factor, C (Tables 16.11a, 16.11b, and 16.11c)

The vegetative cover factor, C, is the ratio of soil loss from a certain slope under specified cover conditions to the soil loss from a standard slope. Many factors influence C for given conditions and the estimated value of C combines all these factors.

Estimates of C vary by land use. As Nepal-specific C values are yet to be experimentally derived, approximations using C values from other areas have to be used. Judgement is crucial to choosing C values from the tables given below and it is advisable to consult a biologist in doing so; especially for C values during different periods in the year (an example problem illustrates this later on).

Table 16.11a gives C values for land use other than agricultural land. Derivation of C values for Nepalese agricultural conditions requires substantial experimental work that has not been done to date. It is recommended that Table 16.11b be used to estimate C values for agricultural land as well.

Table 16.10 LS calculation for multiple slopes

COLUMNS	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
CALCULATION SLOPE UNIT	n	s_n	l_n	λ_n	λ_{n-1}	$L\lambda_n S_{s_n}$	$L\lambda_{n-1} S_{s_n}$	(C.4)(C.6)	(C.5)(C.7)	(C.8)-(C.9)	(C.10)/(C.3)	Σ C.10	(C.12)/(C.4)
C	1	80	20	20	0	27.03	0	414.60	0	414.60	20.73	414.60	20.73
B	2	50	25	45	20	21.57	14.43	970.65	286	684.65	27.93	1099	24.42
A	3	90	10	55	45	50.88	46.00	2798	2070	728	72.80	1827	33.22

Table 16.11a Mulch factors and length limits for construction slopes

Type of Mulch	Mulch Rate	Land Slope	Factor C	Length limit[1]
	Tons per acre	Percent		Feet
None	0	all	1.0	-
Straw or hay,	1.0	1.5	0.20	200
tied down by	1.0	6.10	.20	100
anchoring and				
tacking	1.5	1.5	0.12	300
equipment[2]	1.5	6.10	0.12	150
	2.0	1.5	0.06	400
	2.0	6.10	0.06	200
"	2.0	11.15	0.07	150
	2.0	16.20	0.11	100
	2.0	21-25	0.14	75
	2.0	26-33	0.17	50
	2.0	34-50	0.20	35
Crushed stone,	135	<16	0.05	200
1/4 to 1in	135	16-20	0.05	150
	135	21-33	0.05	100
	135	34-50	0.05	75
"	240	<21	0.02	300
	240	21-33	0.02	200
	240	34-50	0.02	150
Wood chips	7	<16	0.08	50
	7	16-20	0.08	50
"	12	<16	0.05	150
	12	16-20	0.05	150
	12	21-33	0.05	75
"	25	<16	0.02	150
	25	16-20	0.02	150
	25	21-33	0.02	100
	25	34-50	0.02	75

Source: Wischmeier and Smith 1978

1 Maximum slope length for which the specified mulch rate is considered effective. When this limit is exceeded, either a higher application rate or mechanical shortening of the effective slope length is required.

2 When the straw or hay mulch is not anchored to the soil, C values on moderate or steep slopes of soils, having K values greater than 0.30, should be taken at double the values given in this table.

Table 16.11b Factor C for permanent pasture, range, and idle landslide

Vegetative canopy		Cover that contacts the soil surface						
Type and height[2]	Per cent cover[3]		Per cent ground cover					
		Type	0 20	40	60	80	95+	
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.001
Tall weeds or short brush with average drop fall height of 20in	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6 ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.003
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.001
Trees, but no appreciable low brush. Average drop fall height of 13 ft.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.001
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

Source: Wischmeier and Smith 1978

1 The listed **C** values assume that the vegetation and mulch are randomly distributed over the entire area.
2 Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.
3 Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).
4 G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2in deep.
W: Cover at surface is composed mostly of broad-leaved herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residue or both.

Table 16.11c Factor C for undisturbed forest land[1]

Percentage of area covered by canopy of trees and undergrowth	Percentage of area covered by duff at least 2in deep	Factor C[2]
100-75	100.90	.0001 - .001
70-45	85-75	.002 - .004
40-20	70-40	.003 - .009

Source: Wischmeier and Smith 1978

[1] Where effective litter cover is less than 40 per cent or canopy cover is less than 20 per cent, use Table 16.11b. Also use Table 16.11b where woodlands are being grazed, harvested, or burned.

[2] The ranges in listed C values are caused by the ranges in the specified forest litter and canopy covers and by variations in effective canopy heights.

Table 16.12 has been derived from knowledge of typical Nepalese land use patterns and from Table 16.11b. It covers most cases likely to be encountered and provides an example of deriving C values for Nepalese land use conditions.

(e) <u>Practice Support Factor, P</u>

The P factor is the soil loss ratio of a specific practice such as terracing to a standard experimental culture condition. Effectiveness of a given practice in reducing erosion would be reflected by a small P value and vice versa. P values for cut slopes will be close to 1.0 as shown in Table 16.13a. The information on P values suitable to Nepalese land use conditions has to be derived from information for other areas. P values for agricultural practices relevant in Nepal are given in Table 16.13b.

Sample Problem

The case shown in Figure 16.5 has been considered in the example below in Table 16.14 that calculates soil loss for each month of the year. The rainfall erosivity used is from Table 16.8. The agro-ecological zone that the area lies within is a subtropical location in the middle mountains of the Nepalese hills. Slope units B and C are range/pastureland with very good grass cover. It is assumed that the site is protected from overgrazing and that the grass is systematically harvested in the month of October/November and dried as winter fodder. Table 16.15 summarizes the results.

Table 16.12 C values for Nepalese land use patterns

CASE MONTH	1	2	3	4	5	6
JAN	0.20	0.20	0.20	0.032	0.003	0.032
FEB	0.16	0.20	0.20	0.003	0.003	0.003
MAR	0.16	0.20	0.165	0.003	0.14	0.003
APR	0.16	0.20	0.13	0.10	0.14	0.10
MAY	0.09	0.20	0.107	0.10	0.10	0.10
JUN	0.076	0.13	0.107	0.09	0.09	0.09
JUL	0.076	0.13	0.107	0.038	0.038	0.038
AUG	0.076	0.13	0.107	0.011	0.011	0.011
SEPT	0.076	0.13	0.13	0.068	0.011	0.011
OCT	0.067	0.107	0.165	0.145	0.17	0.011
NOV	0.093	0.041	0.20	0.12	0.06	0.12
DEC	0.135	0.041	0.20	0.12	0.06	0.12

Case Descriptions

1. An area with shrubs, tall weeds, and grass; ecologically indicating partial degradation in terms of vegetation frequency.
2. Forest with broad-leaved trees, shrubs, and grasses; not much undergrowth.
3. Pure stands of pine forest in the temperate zone of the *Himalaya*.
4. Pure cropping in which the winter crop of wheat is followed by maize as the dominant summer crop.
5. Pure-mixed cropping in which mustard in the winter is followed by corn and beans simultaneously.
6. Pure-relay cropping in which wheat is followed by corn relay with finger millet.

Table 16.13a P Factors for construction sites

Surface condition	P Value
Compacted and smooth	1.3
Trackwalked along contour*	1.2
Trackwalked up and down slope+	0.9
Punched straw	0.9
Rough, irregular cut	0.9
Loose to 12in (30cm) depth	0.8

Goldman et al. 1986.

* Tread marks oriented up and down slope.

\+ Tread marks oriented parallel to contours.

Table 16.13b P Values for contour-framed terraced fields[1]

Land slope (%)	Farm planning		Computing sediment yield[3]	
	Contour factor[2]	Strip crop factor	Graded channels sod outlets	Steep backslope underground outlets
1 to 2	0.60	0.30	0.12	0.05
3 to 8	.50	.25	.10	.05
9 to 12	.60	.30	.12	.05
13 to 16	.70	.35	.14	.05
17 to 20	.80	.40	.16	.06
21 to 25	.90	.45	.18	.06

Source: Wischmeier and Smith 1978

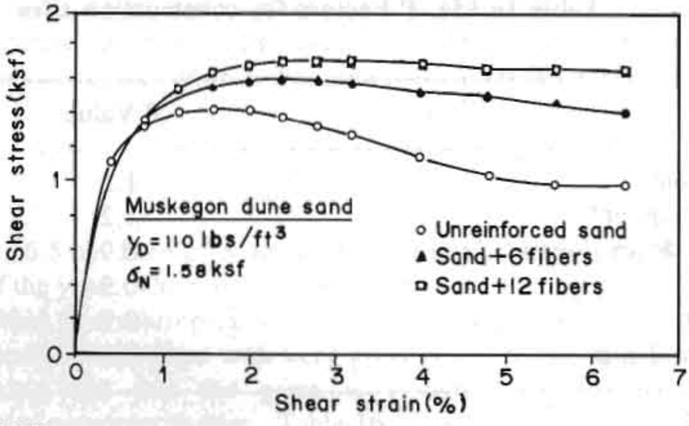
[1] Slope length is the horizontal terrace interval. The listed values are for contour farming. No additional contouring factor is used in the computation.

[2] Use these values for control of inter-terrace erosion within specified soil loss tolerance.

[3] These values include entrapment efficiency and are used to control off-site sediment within limits and for estimating the field's contribution to watershed sediment yield.

16.2.3 *Increase in Shearing Strength*

The presence of roots in a soil matrix influences the shearing strength of the soil. Specifically, the frictional anchoring of roots embedded in soil causes the roots to develop tensile resistance to shearing. Thus roots increase the shearing resistance of soil. Figure 16.6 shows the results of direct shear tests in sand with and without reinforcing fibre reeds. In Figure 16.6, notice that fibre reeds lower the loss of residual strength in addition to increasing the shearing strength.



Source: Gray and Leiser 1982

Fig. 16.6 Results of direct shear test on sand with weeds

Table 16.14 Range and pasture land - Middle Himalayan Range of Nepal

COLUMNS		C1	C2	C3	C4	C5	C6	C7	C8
TIME PERIOD	SLOPE SEGMENT	R	K	LS λ From c.10 Table 6	RKLS λ [(c.1)(c.2)(c.3)] 10^4 in metric tons per month per metre slope width	C	P	RKLS λCP [(c.4)(c.5)(c.6)] 10^4 in metric tons per month per slope width	NOTES
OCT	C	1.61	0.55	414.60	0.04	0.613	1.0	0.0005	Land use: C and B are pasture grazing land while A is a cut slope that has just been made and left bare. Grass is dominant & growth is at its peak
	B	1.61	0.50	684.65	0.06	0.013	1.0	0.0008	
	A	1.61	0.52	728	0.08	1.00	1.0	0.06	
Total					0.16			0.06	
NOV	C	0.66	0.55	414.60	0.02	0.042	1.00	0.0008	Grass withers at this time
	B	0.66	0.50	684.65	0.02	0.042	1.00	0.0008	
	A	0.66	0.52	728	0.02	1.00	1.00	0.02	
Total					0.06			0.02	
DEC	C	0.07	0.55	414.60	0.002	0.10	1.00	0.0002	Grass withers further
	B	0.07	0.50	684.65	0.002	0.10	1.00	0.0002	
	A	0.07	0.52	728	0.003	1.00	1.00	0.003	
Total					0.01			0.0003	
JAN	C	0.01	0.55	414.60	0.0002	0.33	1.00	0.00007	The grass vegetation is at its max. stage of withering; mostly litter covers the soil (10% ground contact cover)
	B	0.01	0.50	684.65	0.0003	0.33	1.00	0.00007	
	A	0.01	0.52	728	0.0004	1.00	1.00	0.00004	
Total					0.0009			0.0005	
FEB	C	1.72	0.55	414.60	0.04	0.33	1.00	0.01	Vegetation dormant. Only litter covers soil.
	B	1.72	0.50	684.65	0.06	0.33	1.00	0.02	
	A	1.72	0.52	728	0.07	1.00	1.00	0.07	
Total					0.17			0.10	
MAR	C	3.04	0.55	414.60	0.07	0.26	1.00	0.02	Minor percentage of vegetation emergence (15% ground contact cover)
	B	3.04	0.50	684.65	0.10	0.26	1.00	0.03	
	A	3.04	0.52	728	0.12	1.00	1.00	0.12	
Total					0.29			0.17	
APR	C	0.50	0.55	414.60	0.01	0.20	1.00	0.002	Little increase in green vegetation cover due to new emergence and further growth.
	B	0.50	0.50	684.65	0.02	0.20	1.00	0.004	
	A	0.50	0.52	728	0.02	1.00	1.00	0.02	
Total					0.05			0.03	
MAY	C	18.74	0.55	414.60	0.43	0.10	1.00	0.04	Large-scale emergence in new vegetation; seed germination and new growth from stolons
	B	18.74	0.50	684.65	0.64	0.10	1.00	0.06	
	A	18.74	0.52	728	0.71	1.00	1.00	0.71	
Total					1.78			0.81	
JUN	C	65.91	0.55	414.60	1.50	0.042	1.00	0.06	All green cover, vegetative stage
	B	65.91	0.50	684.65	2.26	0.042	1.00	0.09	
	A	65.91	0.52	728	2.50	1.00	1.00	2.50	
Total					6.26			2.65	
JUL	C	232.66	0.55	414.60	5.31	0.028	1.00	0.15	Futher increase in the density of green cover. Flowering period initiation (70% ground contact cover)
	B	232.66	0.50	684.65	7.96	0.028	1.00	0.22	
	A	232.66	0.52	728	8.81	1.00	1.00	3.81	
Total					22.08			3.13	
AUG	C	81.44	0.55	414.60	1.86	(90%)	1.00	0.01	Full bloom. Maximum green cover (90% ground contact cover)
	B	84.44	0.50	684.65	2.79	0.006	1.00	0.02	
	A	81.44	0.52	728	3.08	0.006	1.00	3.08	
Total					7.73	1.00'		3.11	
SEPT	C	16.35	0.55	414.60	0.37	0.006	1.00	0.00	Maximum green cover. Vegetation entering into fruiting stage.
	B	16.35	0.50	684.65	0.56	0.006	1.00	0.003	
	A	16.35	0.52	728	0.62	1.00	1.00	0.62	
					1.55			0.63	

Table 16.15: Efficiency of vegetative cover

Month	*Percentage Reduction of Erosion by Vegetation in Table 16.14*
OCT	63
NOV	67
DEC	70
JAN	44
FEB	41
MAR	41
APR	40
MAY	54
JUN	58
JUL	58
AUG	60
SEP	59

Note: per cent reductions would be much higher had the cut slope also been grassed

i) *Root Reinforcement Model*

Root reinforcement calculations make it possible to evaluate the increment in shearing strength caused by the presence of roots. The increase in shear strength, s, can be included in the numerator of the equation to calculate the factor of safety against planar sliding in an infinite slope model (see Chapter 13). Various types of vegetation can be evaluated to identify the species that adds the most to shear strength.

Figure 16.7 shows a model where a flexible elastic root passes through a shear zone of depth z. The intact root is assumed to be perpendicular to the shear zone plane. The intact root is shown to have deformed at the angle of shear distortion in Figure 16.7. The shear distortion angle can be calculated as:

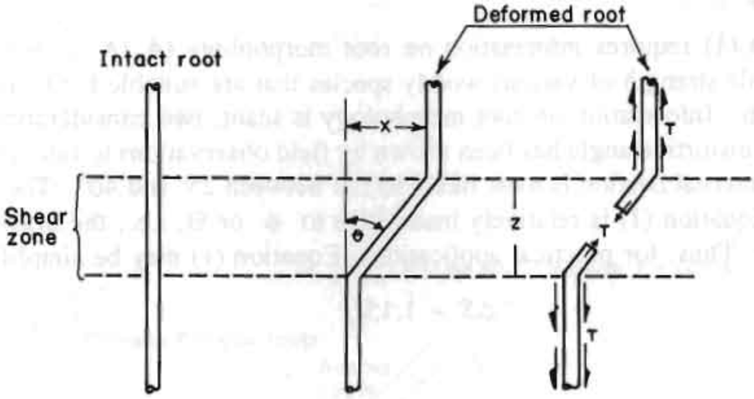
$$\theta = \tan^{-1} \left(\frac{x}{z}\right) .$$

The increase in shear strength, ΔS, can be calculated by resolving the forces due to the tension in the root as:

$$\Delta S = t_R \; (\sin\theta + \cos\theta + \tan\phi)$$

where,

t_R = tensile strength of roots per unit area,
A_R = total cross-sectional area of all the roots in a given cross-section of the soil,
A = area of the soil cross-section under study,
ϕ = angle of internal friction, and
Θ = angle of shear distortion.



Source: Gray and Leiser 1982

Fig 16.7 Root reinforcement model

The tensile strength of roots per unit area can be calculated as:

$$t_R = T_R \left(\frac{AR}{A}\right) \qquad (1)$$

where,

T_R = mean tensile strength of roots,
A_R = total cross-sectional area of all the roots in a given cross-section of the soil, and
A = area of the soil cross-section under study.

The root area ratio, A_R/A, can be calculated as:

$$\frac{A_R}{A} = \sum \frac{n_i\ a_i}{A}$$

where,

n_i = number of roots in size class i, and
a_i = mean cross-sectional area of roots in class i.

Also, if root tensile strength varies with size, the mean tensile strength of the root can be computed as:

$$T_R = \frac{\sum T_i\ n_i\ a_i}{\sum n_i\ a_i}$$

where,

T_i = tensile strength of roots in size class i.

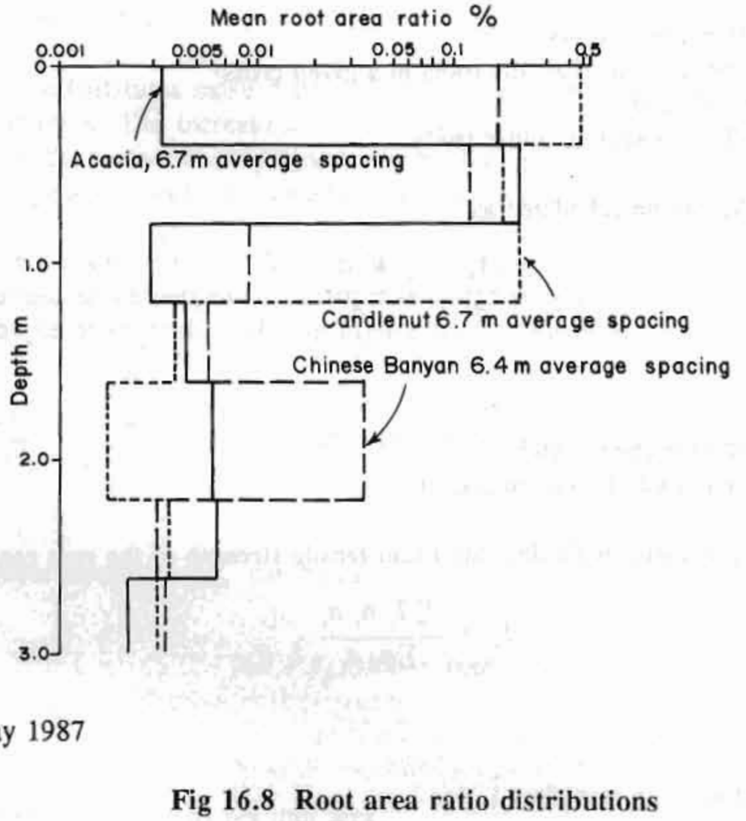
Application of Equation (1) requires information on root morphology (A_R/A) as well as data on root strength (T_R). The tensile strength of various woody species that are suitable for Himalayan conditions are given in Table 16.16. Information on root morphology is scant; two considerations are relevant in this regard: i) the shear distortion angle has been shown by field observations to fall between 40°and 70° Similarly, the angle of internal friction is most likely to fall between 25° and 40°. These facts mean that the braceleted term in Equation (1) is relatively insensitive to ϕ or Θ, i.e., the braceleted term varies between 1.0 to 1.3 only. Thus, for practical applications, Equation (1) may be simplified as:

$$\Delta S = 1.15 t_R \qquad (2)$$

where,

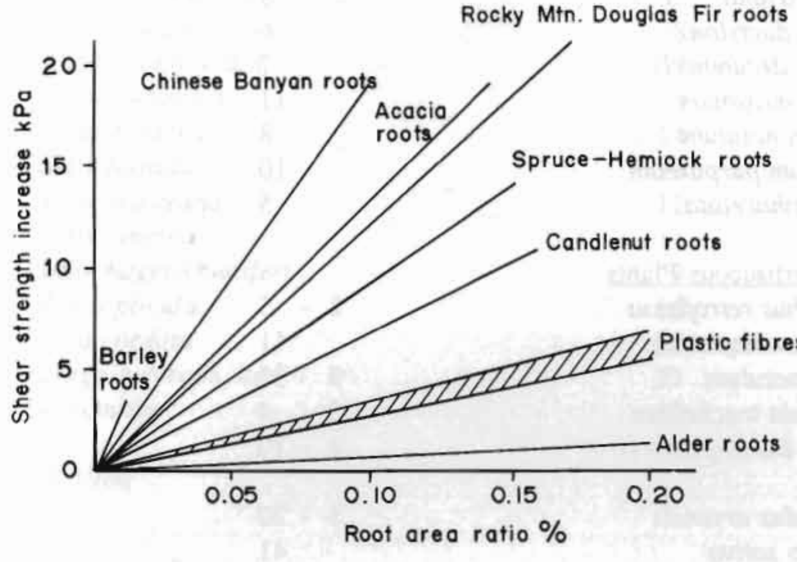
1.15 is an average value of the braceleted term in Equation (1).

The second consideration pertains to the root area ratio. The data required is the variation of root area ratio with depth for various species, as shown in Fig. 16.8. Trial pits have to be dug and measurements made to develop an inventory of species having the needed root area ratio data. Educated guesswork can be very misleading, i.e., about 2-3 orders of magnitude difference in Figure 16.9 shows the effects of root reinforcement for some species.



Source: Greenway 1987

Fig 16.8 Root area ratio distributions



Source: Gray and Leiser, 1982

Fig 16.9 Potential shear strength increase due to roots

Figure 16.9 provides a potential or upper bound estimate of shear strength increase based on a simple force-equilibrium model of fibre reinforcement. It also entails the following critical assumptions:

1. the shear distribution angle (Θ) falls between 40 and 70 degrees

2. the roots are sufficiently long or kinky to avoid pullout (slipping), and

3. there is full mobilisation of the tensile strength of the root fibres.

Research carried out by Gray and Leiser 1982 has shown that assumption No. 3 is rarely achieved.

Shear strength increase from root reinforcement in sandy soils can be estimated from the results of both laboratory and field tests (Gray and Ohashi 1983 and Ziemer 1981). Both studies showed a linear increase between ΔS_R and the root or fire biomass per unit volume of soil (see Table 16.17). The coefficient of proportionality was very similar in both studies and can be used to estimate ΔS_R based on a simple measure of root biomass per unit volume of soil or root area ratio versus depths.

Table 16.16 Tensile strength of plant roots

Plant Species	Tensile Strength (MPa)
<u>Grasses</u>	
Agropyron repens	7 - 25
Chloris gayana	8
Cynodon dactylon	6
Digitaria decumberis	7
Panicum maximum	11
Paspalum notatum	8
Pennisetum purpuream	10
Setaria sphaceiata	5
<u>Other Herbaceous Plants</u>	
Amaranthus retroflexus	2 - 5
Artemisia compestris	11
Atriplex patulum	9 - 30
Campanula trachelium	0 - 4
Caspella bursa-pastoris	4 - 10
Convolvulus arvensis	5 - 20
Medicago sativa	41
Plantago lanceolate	4 - 8
Plantago major	3 - 6
Rumx conglomeratus	2 - 6
Solanum nigrum	16 - 38
Taraxacum officinalis	0 - 4
Trifolium pratense	11 - 18
<u>Woody plants</u> (trees and Shrubs)	
confusa	11
Alnus firma var yasha	4 - 74
Alnus firma var multinervis	51
Alnus incana	32
Alnus japonica	41
Betula pendulai	37
Ficus microcarpa	16
Picea abies	27
Picea sitchensis	23
Pinus desiflora	32
Pinus radiata	18
Populus nigra	5 - 12
Populus deltoides (USSR)	38
Populus deltoides (New Zealand)	36
Populus euramericana (1-78)	46
Populus euramericana (1-488)	32

Plant Species	Tensile Strength (MPa)
Populus yunnanensis	38
Quercus robur	32
Robinia pseudoacacia	68
Salix purpurea (Booth)	36
Salix matsundana	36
Salix fragilis	18
Y Salix dasyclados	17
Salix elaeagnos	15
Salix helvetica	14
Salix hastata	13
Salix starkeana	12
Salix cinerea	11
Salix hagetschweileri	9
Thuja plicata	56
Tilia cordata	26
Tsuga heterophylla	27
Vaccinium	16

Source: Schiechtl 1980

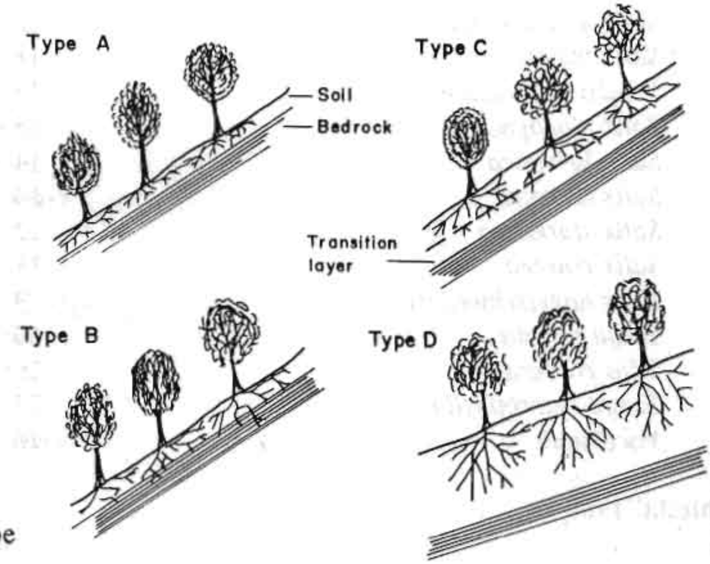
Table 16.17 Summary of root fibre contributions to soil shear strength

FIBRE OR ROOT SYSTEM	MAXIMUM FIBRE OR ROOT BIOMASS CONC.		SHEAR STRENGTH INCR. PER UNIT FIBRE CONC.		MAX SHEAR STR. INCR. MEAS. IN TESTS (PSI)
	AREA RATIO (%)	WT. CONC. lbs root of soil	PSI lb/cf	kPa kg/cu m	
VERTICAL SURFACE, LATERAL ROOTS Tree roots (*pinus contorta*) Vertical shear surface, coastal sand Live roots < 17 mm diameter *in situ* direct shear test	0.78	0.31	7.4	3.2	2.3
LAB TESTS ON FIBRE-PERMEATED SANDS Reed fibres (*phragmites communis*) Natural fibre: diameter = 2.0 mm Uniform sand Direct shear test	1.70	0.68	8.7	3.7	5.9
AVERAGES	1.24	0.50	8.1	3.5	4.1

Source: Received from Gray personally in 1990

ii) *Root Anchoring*

Figure 16.10 shows conditions where frictional anchoring can or cannot develop to make roots capable of providing tensile resistance.



Source: Tsukamoto and Kusakabe

Fig 16.10 Slope classification based on root reinforcement and anchoring

Type A shows a case where a shallow topsoil layer is resting on a bedrock with little or no fractures. The roots cannot find anchor inside the rock but will attach themselves to the rocks provided there is some anchoring. Also, the roots will develop functional resistance along their lengths in the soil layer. A minimum root length, L_{min}, is needed to make the frictional anchoring sufficient to present pullout before the tensile strength of the root, T_R, is attained:

$$L_{min} = \frac{\tau_r\ d}{L_1\ \tau_b}$$

where,

d = root diameter, and

τ_b = limiting bond stress between root and soil.

While the root will increase the shear strength of the soil if L_{min} is attained, root reinforcement may not be relevant for case A where the plane of failure can be the soil-rock interface. The root system will not help against sliding on that interface.

Type B is identical to Type A in all respects, except for the fact that the underlying rock is fractured. The root system will penetrate the rock and find sound anchoring. This case is one where the roots can make a full contribution to shear strength by tensile resistance. Roots will weaken fractured rock, however, and it is important to ensure that the fracture pattern is not going to be disturbed so that a wedge is destabilized.

Type C shows a case with thicker soil layers. Soil density and shear strength increase with depth in Type C. Roots will find firmer anchoring as they penetrate the transition layer provided L_{min} is attained. This case is suitable for root reinforcement as well.

Type D shows a case where the soil layer is thick. The failure plane is likely to be below the root system. Although the root system will increase shear strength in the rooted zone (as L_{min} will probably be attained), the root system cannot help stabilize a deep-seated slide. Root reinforcement is unsuitable for such cases where a potential for deep-seated slides exist.

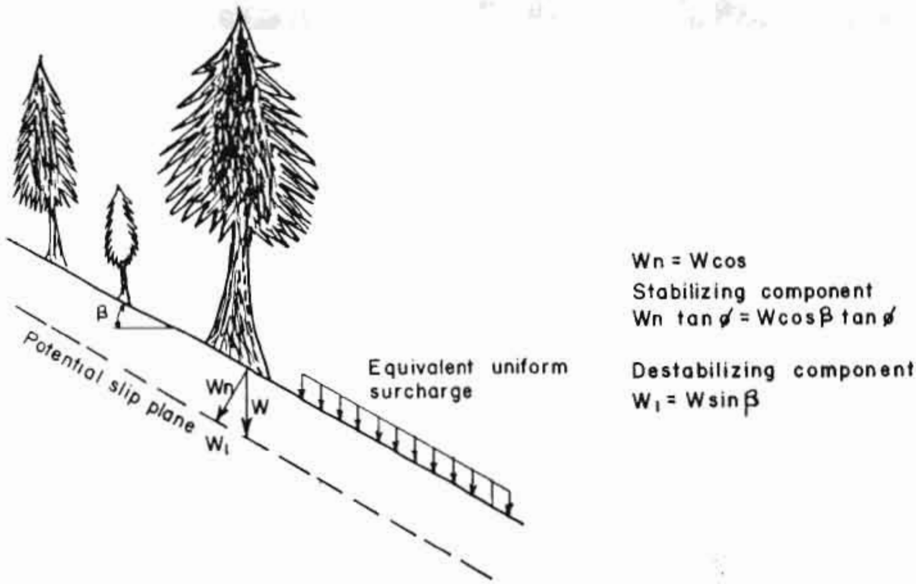
iii) *Surcharge Effect*

The surcharge that a tree creates on a slope is depicted in Figure 16.11.

In terms of an infinite slope model (Chapter 13) surcharge will have a beneficial effect on stability if:

$$C < \gamma_w H_w \tan\phi \cos^2\beta \qquad (3)$$

where,
- H_w = piezometric height above sliding surface,
- ϕ = angle of internal friction of the soil,
- c = cohesion of soil,
- β = slope angle, and
- γ_w = density of water.



Source: Greenway 1987

Fig. 16.11 Surchage effect of tree weight

Using Equation 3, if the effect of surcharge is seen to be beneficial to stability, a conservative estimate of surcharge should be used in the infinite slope model, i.e., the gross weight of trees on the slope divided by the gross slope area. If surcharge is evaluated to be adverse to slope stability, the estimate of surcharge should be biased conservatively again; in this case surcharge may be estimated as the weight of an average tree divided by its stem area.

iv) *Example Problem - Sandy Soil on Fractured Bedrock (Fig. 16.12)*

For the infinite slope model of sandy soil overlying fractured bedrock,

a) find the F.S. of the slope against planar failure along the bedrock, and
b) evaluate woody plants to ensure a F.S. of 1.2.

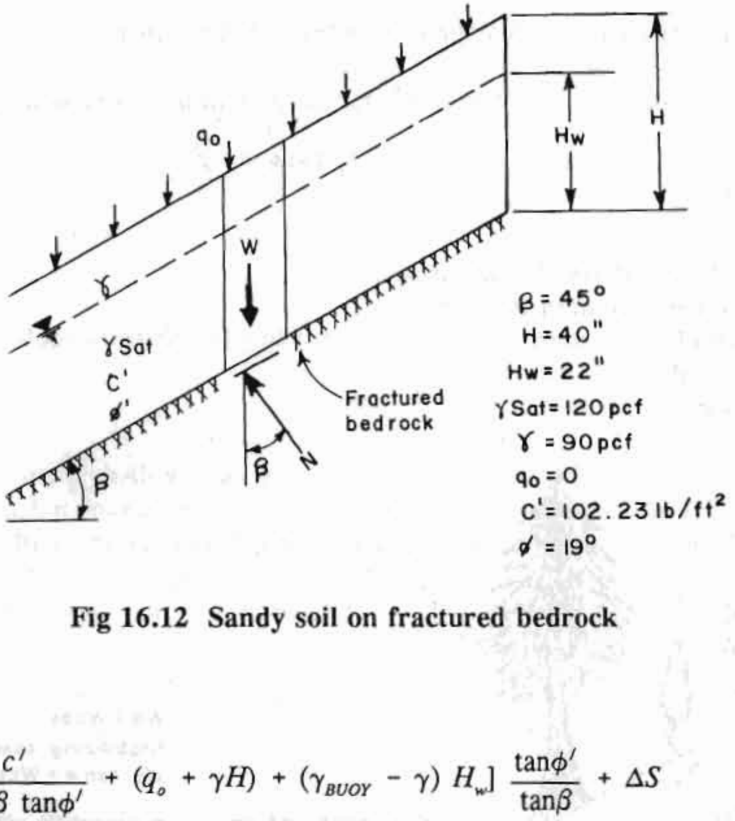


Fig 16.12 Sandy soil on fractured bedrock

Solution

a)
$$F.S. = \frac{\left[\frac{c'}{\cos^2\beta\ \tan\phi'} + (q_o + \gamma H) + (\gamma_{BUOY} - \gamma)\ H_w\right] \frac{\tan\phi'}{\tan\beta} + \Delta S}{[(q_o + \gamma H) + (\gamma_{SAT} - \gamma)\ H_w]}$$

$$= \frac{\left[\frac{102.23}{\cos^2 45^\circ\ \tan 19^\circ} + 90(3.33') - 32.43(1.83)\right] \frac{\tan 19^\circ}{\tan 45^\circ}}{[90(3.33) + (120 - 90)\ 1.83]}$$

$$= \frac{(594 + 299.70 - 59.35)\ 0.34}{299.70 + 54.90}$$

$$= \frac{283.68}{354.6} = 0.80\ .$$

b) *Surcharge Effect:*

$$\gamma_w H_w \tan\phi \cos^2\beta$$

$$= (62.43 \frac{lb}{ft^3}) (1.83ft) (\tan 19°) (\cos^2 45°)$$

$$= 1.67 lb/ft^2 \quad .$$

Surcharge is beneficial to the stability of infinite soil slope, when $c < \gamma_w H_w \tan\phi \cos^2\beta$ (Gray 1982). As c=102.23 lb/ft^2 > 19.67 lb/ft^2 the effect of surcharge on the slope will be adverse. The surcharge can be estimated as the weight of an average tree divided by its stem area.

Suppose the species Acacia were to be evaluated for its effectiveness in increasing the shear strength. Furthermore, assume Acacia has a surcharge of 104.43 lb/ft^2 directly beneath itself. Then:

$$F.S. = \frac{[\frac{102.33}{\cos^2 45° \tan 19°} + 104.43 + 90(3.33) - 32.43(1.83)] \frac{\tan 19}{\tan 45} + \Delta S}{[(104.43 + 90)(3.33) + (120-90)1.83)]}$$

$$= \frac{594 + 404.13 - 59.35) 0.34 + \Delta S}{404.13 + 54.90}$$

$$= \frac{319.19 + \Delta S}{459.03}$$

or,

$$\Delta S = 231.84 \ lb/ft^2 \quad .$$

Using Equation (2),

$$\Delta S = 231.84 \ lb/ft^2 = 1.15 t_R$$

$$\therefore t_R = 201.60 \ lb/ft^2 .$$

For Acacia, at a depth of 1m, A_R/A = 0.003 x 10^{-2}. Similarly, Table 16.17 gives T_R = 11 MPa for Acacia. Thus t_R = (2.32 x 10^5 lb/ft^2) (3 x 10^{-5}) = 6.96 lb/ft^2. Since 6.96 lb/ft^2 is much less than the required additional strength of 201.60 lb/ft2, Acacia will not be suitable.

Suppose Chinese Banyon also had q_o = 104.43 lb/ft^2. For Chinese Banyon, A^R/A = 0.009 x 10^{-2} and T_R = 6 MP_a. Thus t_R = (3.37 x 10^5 lb/ft^2) (9 x 10^{-5}) = 30.30 lb/ft^2 which is also inadequate. It can be concluded that neither Acacia nor Chinese Banyon are suitable for stabilizing the slope.

16.2.4 *Moisture Content and Groundwater Table Reduction*

The principal mechanisms responsible for the effects plants have on soil moisture content are i) rainfall interception, ii) increase in surface roughness leading to higher infiltration, and iii) transpiration. This section only cites evidence that plants affect soil moisture content and groundwater table. Neither analysis of the plant-soil mechanisms nor predictions of the extent of soil moisture content reduction are addressed here. Readers are referred to the work of Tien H. Wu, Professor of Civil Engineering, Ohio State University, Columbus, for an analytical framework to predict pore-water pressure changes caused by evapotranspiration.

i) *Interception Losses*

Interception losses, caused by vegetative foliage, vary by vegetative cover characteristics and rainfall intensity. Table 16.5 shows an observation of interception losses from an evergreen rainforest in Brazil. Other observations have shown that interception losses of rainfall can vary between 10 per cent and 100 per cent with decreasing rainfall intensity.

ii) *Infiltration*

Roots, vacant root channels, and increased surface roughness in the rooted area cause higher infiltration rates. The angle of the slope affects the degree to which infiltration is increased. Figure 16.1 shows the effect of grass on infiltration rates.

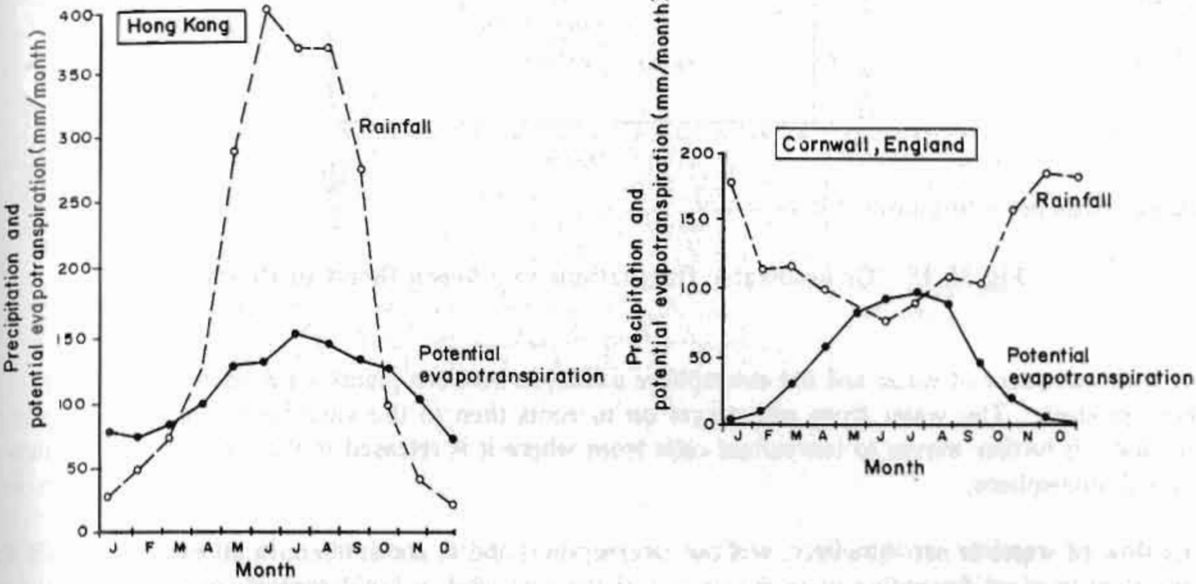
iii) *Transpiration*

Plants that transpire most are called **phreatophytes**. Aside from the characteristics of the plant, that make it a phreatophyte, the weather, climatic, and seasonal factors, as well as slope attributes (aspect, moisture, and soil type), influence the transpiration of a plant. Thus, the transpiration rate is a plant and site-specific parameter. Only data from identical areas reflect what the transpiration rate may be for a given slope. Moreover, transpiration rates change over the year so the effect of transpiration on critical groundwater levels must be studied as a function of time. An illustration of the site-specificity (seasonal and climatic) of transpiration is provided by the examples shown in Figures 16.13 and 16.14.

Just as transpiration reduces the groundwater level, a sudden removal of plants increases the groundwater level. Thus clearfelling for road construction may create instability. An illustration of this phenomenon from a clearfelling in Denmark is given below in Figure 16.15.

Exploiting Transpiration Phenomenon

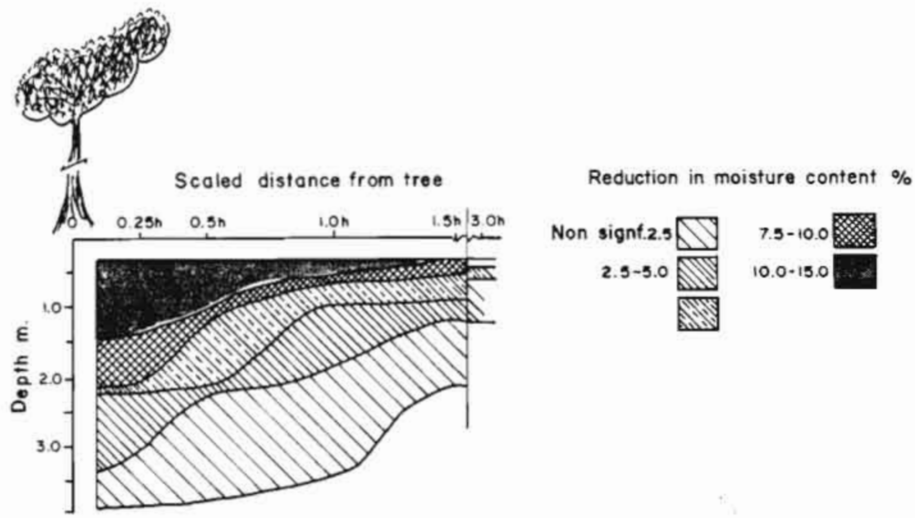
Transpiration has been, so far, considered as a necessary evil of water loss by plants. About two thirds of the water, falling as precipitation in temperate lands, is returned to the atmosphere by transpiration. This example explains the magnitude of the phenomenon and it is for this reason that plant physiological research on transpiration, especially in the field of agriculture, has been heavily involved in understanding the process in order to devise ways to control it. In the present context, using the transpiration phenomenon positively, as a method to drain out more water from the soil to help stabilize roadside slopes, is unique. The discussion, therefore, concentrates on aspects that are of interest in exploiting this phenomenon in the context of reducing the moisture content. The focus will be to know what the key organs of plants involved in transpiration are and how their function is regulated. Are transpiration rates of species measurable to affect their selection for roadside slope stabilization?



Greenway 1987

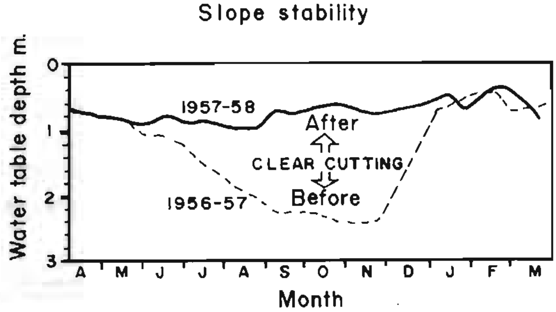
Fig 16.13 Comparative evapotranspiration rates

Moisture content, due to extraction of soil moisture by roots, affects the distribution of soil moisture (and pore-water pressures) around the root area. Again, the actual impact is site-specific, but the reduction of moisture decreases at increasing distances from the plant. Figure 16.14, illustrates the case.



Source: Biddle 1983

Fig 16.14 Soil suction response of a model slope



Source: Hostener - Jorgensen 1967

Fig 16.15 Groundwater fluctuations in a beech forest in Denmark

The soil is a source of water and the atmosphere a sink; in between plants act as factors operating on the whole process. The water from soil passes on to roots then to the vascular tissue of the stems and branches. It further moves to leaves/leaf cells from where it is released in the form of vapours into the external atmosphere.

This flow of water is not, however, without interruptions and is not uniform in all plants. It does vary from plant to plant depending upon the impact of the sum total of both internal and external resistance factors. In other words, it is also known as the mechanism regulating transpiration.

A. Internal Mechanism to Regulate Water Flow

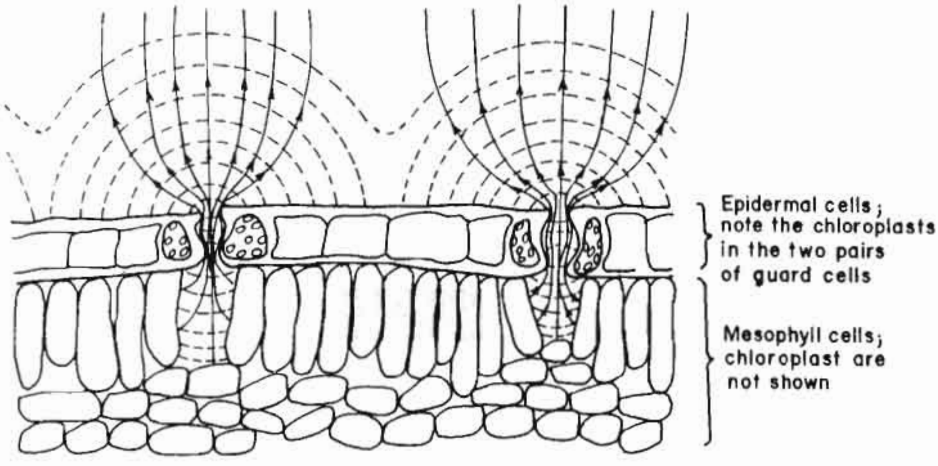
There are two plant organs that regulate transpiration.

i. Stomata in leaf epidermal tissue. Water loss occurs principally through stomatal pores on the leaf surfaces (Fig. 16.16).

ii. Cuticle layer of waxy material on the leaf surface.

Cuticle transpiration is of academic interest only and there is, in fact, a very small amount of water passing through the cuticle. In mature plants it is thick and practically no water loss takes place through it in most species. The epidermis of a leaf can be considered a multiperforate system through the pores of which outward diffusion of water vapour occurs. It is useful to think of diffusion through this pathway as being analogous to the flow of an electric current through a circuit. The greater the resistance, the smaller the flow. By visualizing the process in this manner, the pathway of diffusion can be considered to be a system of resistances in series. These can be grouped in two categories 1) the internal resistance, and 2) the resistance external to the leaf.

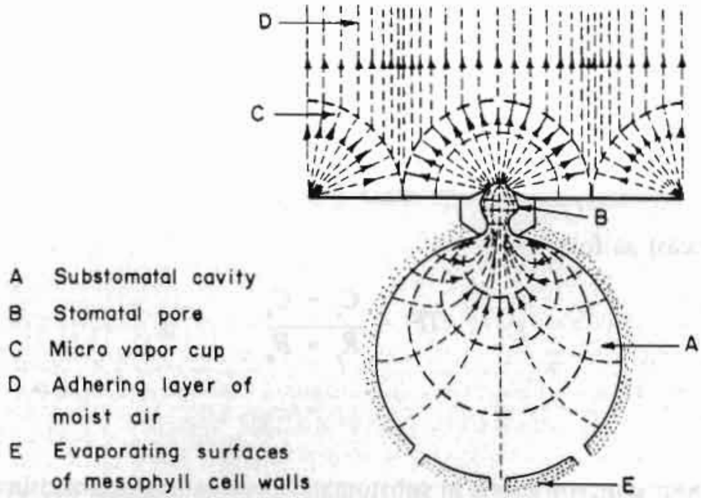
The internal resistance to outward diffusion of water is associated with stomata and depends on their shape, size, stomatal pore size, and opening (Fig. 16.17). Also the internal resistance to outward diffusion of water vapour depends upon the number of stomata per square centimetre of leaf surface, i.e., the stomatal frequency.



Source: Gates 1962

Fig 16.16 Schematic diagram of the diffusion pathway of water vapour in stomatal transpiration from a leaf

Path of diffusion of water vapour shown as solid (arrowed) lines. Surfaces of equal water vapour concentration are shown as dashed lines.



Source: Gates 1962

Fig 16.17 Idealized representation of the diffusion pathway of water vapour, from a stomata of *Sebrina pendula*, shown in median transverse section

Paths of diffusion of water vapour are shown as dotted (arrowed) lines. Surfaces of equal water vapour concentration are shown as dashed lines.

The greater the stomatal frequency, the smaller the internal resistance of the leaf. The external resistance is mainly in the form of a thin boundary layer of unstirred moisture through which water vapour molecules must diffuse. This boundary layer consists, in part, of microvapour cups that cover the ends of the stomatal pores and in part of a sheet of moist air that covers the entire surface of the leaf (Fig. 16.17).

Evidence shows that under natural conditions stomatal resistance is far more important than boundary layer existence in determining transpiration flux (Fig. 16.18). Figure 16.18 also shows that transpirational flux at any given stomatal aperture is always lower in still air than in moving air. In moving air, when wind blows over a leaf, even at low velocities, the boundary layer is swept away. Thus, the rate of transpiration depends primarily on stomatal apertures for regulating transpiration.

Estimation of Transpiration Rates

Rate of transpiration for individual plants is expressed in units such as grains of water vapour per second per plant. It is also approximate to use the term 'Transpiration Flux', meaning the quantity of water vapour transpired by a unit area of leaf surface in a unit of time. The units used most often are, $gm.^{-2}h.^{-1}$ or $g.cm.^{-2}s^{-1}$. Under field conditions, such as the present roadside slope context, the transpiration rate is approximately expressed in terms of a unit land area, e.g., gal $acre^{-1}$ day^{-1}.

$$\text{Transpiration flux} = \frac{\text{Magnitude of the driving force}}{\text{Total resistance in the diffusion pathway}}.$$

1. Driving force is the difference in concentration of water vapour between a leaf and bulk air beyond the leaf.

2. Total resistance is the sum total of the stomatal resistance and the boundary layer resistance.

Thus, the equation is recast as follows:

$$TF = \frac{C_l - C_a}{R_s + R_e}$$

where,

C_l and Ca are water vapour concentrations in substomatal cavities in a leaf and in the bulk air beyond the leaf respectively; R_s is the stomatal resistance and R_e is the resistance of the boundary layer of water vapour external to the leaf.

It can be used in field studies. In the usual field applications, relative humidity inside a leaf is assumed to be 100 per cent, making it easy to calculate *cl* (water vapour concentration) if the leaf temperature is known. *Cl* can be calculated from the measured relative humidity of air and temperature of the air above the leaf. R_s is measured with a potometer. Since truly still conditions are rarely if ever realized in nature, R_e can be assumed to be zero in field studies. Knowing the values for C_l, C_a and R_s, TF can be calculated by modifying this equation:

$$TF = \frac{C_l - C_a}{R_s} .$$

Field Conditions

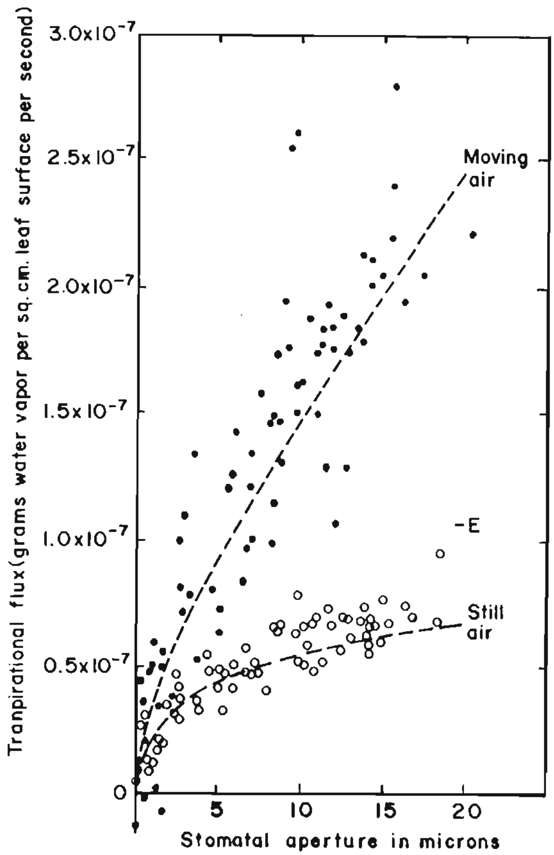


Figure 16.18 The relation between transpiration flux and stomatal aperture in still air and moving air

Experimental values in still air are indicated by open circles and those in moving air by block dots. The dashed lines represent theoretical values.

Source: Bange 1953

Measurement of Transpiration rates

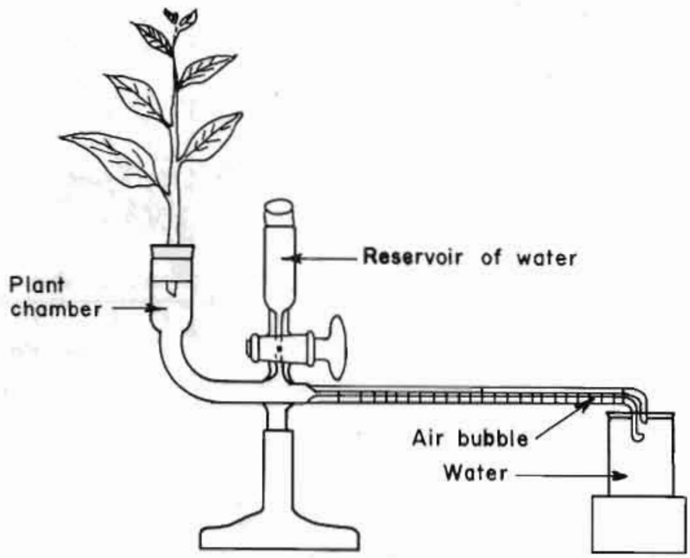
The techniques used to measure transpiration rates are both simple as well as complex with sophisticated measuring devices.

1. The Pysimeter method or gravimetric or pot method. A potted, intact plant is selected and the soil around the roots is watered thoroughly. Then the pot and the root system are sealed within a

container composed of material impervious to water (e.g., a sheet of polythene or a metal sheet) so that the loss of water is only through the plant. Now the entire assembly is weighed periodically, say at hourly intervals. The loss in weight represents the quantity of water transpired. Evaluation of the rate of transpiration in terms of a unit of evaporation area (e.g., gm cm^{-1} $hour^{-1}$) requires that the total leaf area be estimated. Also to be recorded is whether the leaves of the experimental plant have stomata on one side only or on both sides.

In another version of this technique, air is passed over the transpiring tissue and then is conducted through an absorption vessel containing a water vapour absorbent (e.g., anhydrous calcium chloride or phosphorous pentoxide). At the same time, a stream of air is passed at the same rate directly through a separate water vapour absorption vessel, without passing over plant tissue. The difference in the gain in weight of the two absorption vessels represents the quantity of water vapour transpired during the experimental period. With this technique, even the transpiration rates of plant communities rooted in outdoor habitats have been estimated. In such cases large transparent plastic tents have been used.

Transpiration measurement by **potometer** is another way suitable for laboratory level experimentation. It is explained in Figure 16.19.



Source: Kramer 1959

Fig 16.19 The potometer method of measuring transpiration

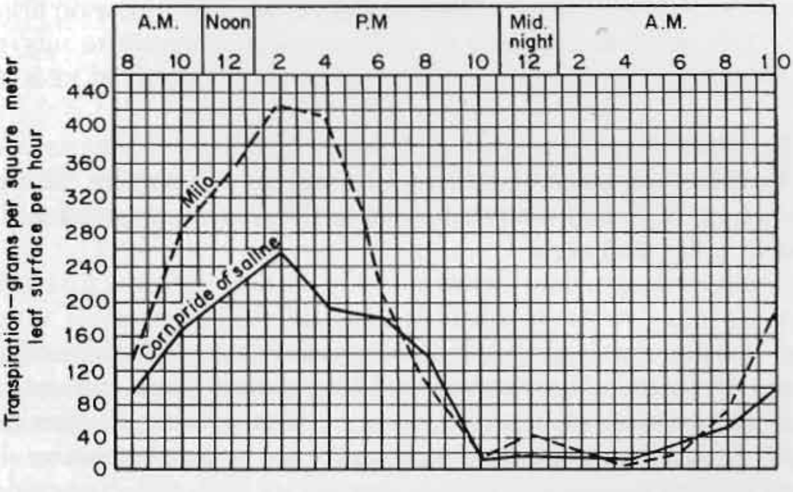
The stem of a cut shoot is placed in a closed chamber of water. To prevent the formation of air bubbles in open xylem vessels, the stem should be cut under water. The chamber is attached to a graduated capillary tube into which an air bubble is introduced (by lifting the tube momentarily out of the water in the beaker). The rate of travel of the air bubble across the length of the graduated tube can be used to demonstrate the effects of environmental changes on the rate of transpiration. The air bubble can be returned when necessary to the right hand end of the capillary tube by admitting water through the stopcock. In another type of potometer, the plant chamber is large enough to admit the entire root system of a small plant.

Loss of water through stomata depends on the opening and closure of their pores. Stomatal pores open and close in response to changes in one or another of the following environmental factors:

i. the supply of water to the leaves,
ii. the temperature of the leaf environment,
iii. light availability, and
iv. concentration of carbondioxide in the leaf environment

Under general drought conditions, creating leaf water deficits, the stomata of a plant will remain closed, even overriding all other stimuli positive to stomatal opening. The effect of temperature is noticeable especially at the extreme ranges, i.e., either below 0°C or above 30-35°C.

Since transpiration is energized by solar radiation, the diurnal cycle of transpiration (Fig. 16.20) can be expected to parallel the radiation received at the surface of the earth.

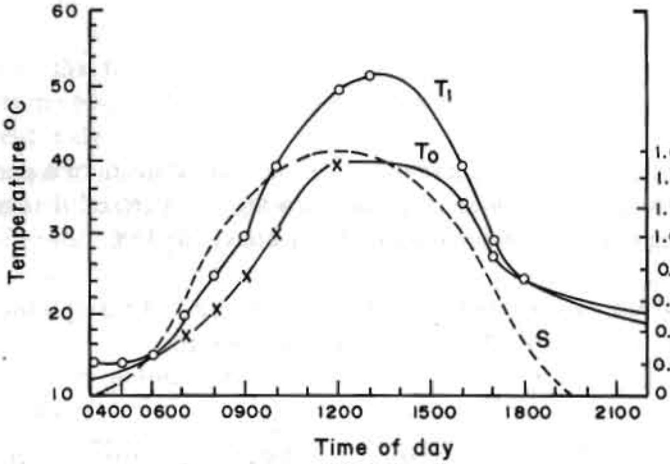


Source: Miller 1938

Fig 16.20 The transpiration rates of maize (Pride of Saline) and sorgu, (Milo) grown under the same conditions in Kansas

That this is so can be seen by comparing Figure 16.18 with the diurnal cycle of solar radiation shown in Figure 16.21.

Figure 16.21 also shows the temperatures of a fully sunlit, exposed leaf and the air around it during the day and night, under conditions assumed to be ideal. The night time leaf temperature is usually a few degrees below air temperature because leaves lose heat by thermal radiation to the sky and receive relatively little heat from the air around them. In the morning, after the sun rises, a sunlit leaf warms quickly, and its temperature rises above the temperature of the air. But, at the same time, the stomata, which were closed during the night, will be open. Thus the leaf will transpire and lose heat. As a result, the temperature of a sunlit leaf is usually only slightly higher than the air temperature (see Fig. 16.21). The temperature of a shaded leaf also will follow a diurnal cycle similar to that shown in Figure 16.21, except that daytime temperature will probably not exceed the temperature of the air around it.



Source: Gates 1966

Fig 16.21 The variation in solar radiation received at the surface of the earth (S) air temperature (T_a), and temperature of a fully sunlit, exposed leaf (T_l) during the course of a day and night

Under both conditions stomatal openings remain closed even if other environmental conditions favour opening. If the supply of water is adequate and leaf temperature is not extreme, light induces the stomatal pores to open and darkness induces their closure. Thus stomata are open during the day and closed during the night. Stomatal movements in most higher plants are **photoactive**.

Moderate sunlight brings about maximum opening in most temperate plant species. However, the response time varies from species to species. Experimental evidence shows that **potassium ions** have a critical role in stomatal opening.

Concentration of carbon dioxide in the atmosphere external to a leaf is yet another factor that has been found to influence stomatal movement. If leaves are exposed to concentrations of CO_2 above the natural atmospheric level, i.e., approximately 300 ppm, they show a tendency to close, affecting transpiration adversely. In maize, for example, stomata can be closed by raising the concentration of the surrounding atmospheric carbon dioxide (CO_2) to about 1,000 ppm, keeping all other conditions normal. For soybeans this critical Co_2 level is 2,500 ppm.

This means that each species requires different CO_2 concentration levels to cause the closing of its stomata. It has important implications for roadside vegetation plantations in which plants are exposed to higher levels of CO_2. Thus, for choice of species for roadside plantation, CO_2 concentration levels and the critical endurance values of plants could be important factors.