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Planning of Revegetation in Severe Environments Based on Provision of Vegetational Shelter

By

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荒廃地の植生復元に関する研究

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Abstract

Severe environments are related to a high level of environmental as well as man induced stress and disturbance. If such environments are not rehabilitated by revegetation, a desert-like condition might develop.

In this study for revegetation of these environments the concept of vegetational shelter has been introduced. This is defined as live shrubes, bushes and trees, which, while growing themselves, at the same time, contribute to the development of planted trees around them and their environments; by providing stability (reduction of the level of stress and disturbance) and by adding organic matter to the system.

Coastal sand dunes and devastated hillslopes have been chosen. Site factors such as edaphic, plant, temperatures of air, surface soil and erosion of hillslopes have been taken as indicators of the effects of vegetational shelter. Based mainly on the results of this study, patterns (models) for planning the revegetation of unstable sand dunes and devastated hillslopes have been developed. The most important elements of this planning are the establishment of vegetational shelter and the planting of first main tree species (needle leaved) and second main tree species (broad leaved) in several years and in different stages.

Key words: Severe environment, Stress, Disturbance, Vegetational shelter, Stage planting.

Contents

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Introduction

The increasing population and rapid industrialization in the world, particularly, in recent decades, have caused a substantial incease in the level of exploitation of natural resources. In this process land resources, especially, forest and range resources, have been over exploited in many places, leaving vast areas of land without a vegetation cover. Where the climatic conditions are very harsh, natural recovery of vegetation could not take place and the bare land surface are exposed to the action of rain and wind resulting in severe erosion and other disasters and leading to the formation of devastated and severe environments. If the damage goes on unchecked in such environments the ultimate result will be the formation of desert-like barren areas.

The situation is especially grave in developing countries, where with increase in population and economic activities, demand for wood as fuel and as timber for domestic as well as export item is increasing.

All these put pressure on forest and range resources of these countries, resulting in depletion of these resources and in some instances even leading to desertification.

This is a complex and difficult problem related to diverse fields of social and natural sciences. Naturally, solving it, especially, restoring the vegetation cover also will not be a simple task and will definitely require long term research. It will also require a correct perception of the problem by people, difficult and sometimes controversial decisions by governments and costly investments.

Without any doubt, protection against unplanned cutting of wood and overgrazing is recommended as a very necessary first step. This will prevent further deterioration of forested and range lands and will achieve at least, a partial rehabilitation of these environments. The second step could be the revegetation.

This study, however, has been undertaken to tackle part of the above mentioned problem, namely the restoration of vegetation cover and especially the forest establishment in severe and devastated environments. For this purpose the environmental conditions of bare, forested sand dunes as well as those of devastated, afforested hillslopes have been investigated. Based on the results and conclusions from this study and the findings of other workers, patterns for planning the revegetation of severe environments were recommended. One of the most important element of this planning is the concept of vegetational sheltering as a means of reducing the level of disturbance and stress. Also by this method organic matter is added to the system which improves the site factors in severe environments.

I. Study method and study areas

1. Study method

Severe environments are thought to be related to a high level of environmental disturbance and stress. Many workers such as GRIM (1977), WHITE (1979), SMITH (1985) discussed the effects of stress and disturbance on individual plant as well as upon vegetation as a whole. GRIM (1979) whose work is the most comprehensive in this regard, divided the external factors, which are limiting plant biomass in any habitat, into two categories of stress and disturbance. He defines stress as "conditions that restrict production e. g, shortages of light, water or mineral nutrients and suboptimal temperature", and the disturbance as "being associated with the partial or total destruction of the plant biomass and arises from the activities of herbivores, pathogens, men (trampling, mowing and plowing) and from phenomena such as wind damage, frost, desiccation, soil erosion and fire".[14]

It seems, however, that stress and disturbance also strongly influence plant growth, especially, the growth of tree seedlings in the initial stages of the establishment of forest and can be said to be limiting factors for afforestation in severe environments.

To minimize the level of the effects of stress and disturbance on planted seedlings in severe environments, sheltering of trees is thought to be a necessary step in the process of forest establishment. Many workers referred to various types of shelter and their effects on the growth of trees in the process of forest establishment and also on the growth of trees for other purposes. PAPER (1983) recommended plastic net tree guards as shelter for trees.[43] TUELY (1985) suggested plastic tubes as individual tree shelter, which will reduce animal damage and enhance early growth by providing a greenhouse effect.[48] JENSEN (1985) mentioned sheltering properties of screens.[28]

All such and other forms of mechanical shelter protect individual, also groups of trees, against damage by man, animal, snow and strong wind. In severe environments, however, in addition to the above mentioned effects of a shelter, the soil improvement effect of it, especially, the addition of organic matter to the system, with the help of a shelter, is certainly very important.

Other workers mentioned the combination of mechanical shelter (wooden fences) and the fast growing pioneer bushes and trees as shelter for protection of newly planted trees in severe environments. HIGASHI (1976) suggested the zensei-rin (preforest tree belts) sheltering method for forest establishment in severe environments in Hokkaido.[17] According to this method at the first stage, several rows of fences (composed of poles and bamboos) are erected and tree planting is carried out between these fences. Since the fences are usually destroyed by strong winds and seedlings are exposed, thus resulting in injury and damage to the plants. A simultaneous planting of fast growing trees such as willows (in the first line) and the planting of needle leaved trees (behind the first line) as main species have to be carried out. The willows attain sufficient height in a short period of time and, therefore, will provide shelter for the main trees — even when the fences are destroyed by strong winds.

SAITO (1984) and ITO (1985) put forward the "gisei-rin" (sacrifice and nursing tree lines) sheltering method. In this method fences are erected and the pioneer tree and bush species are planted around the main trees — usually a needle leaved tree species.[25,44]

Using woody material for sheltering could be beneficial in areas where such material is abundant and easily available. But in those regions, where the vegetation has been destroyed and there is already a shortage of wood for use as fuel and building material, the use of poles and other woody material for shelter will put an extra burden on the forest. Because the woody material used for construction of fences and other structures as shelter are supplied from man-made or natural forests and other areas containing vegetation. Especially in large scale afforestation projects, where for creation of shelter a considerable amount of woody material might be used, this will indirectly contribute to the over-exploitation of the very forest; for creation, expansion and protection of which these projects will be implemented.

In this study, however, the concept of vegetational shelter has been introduced for revegetation of severe environments. Vegetational shelter is defined here as live shrubs, bushes and trees, which, while growing themselves, at the same time, contribute to the development of planted trees around them and their environments; by providing stability (reduction of the level of disturbance and stress) and by adding organic matter to the system.

Hereinafter, for the sake of brevity the vegetational shelter will be called only shelter, and other forms of shelter when referred to will be mentioned by their respective names.

According to this concept, in the initial stages of revegetation in severe environments, the surface of land is stabilized by using locally available non-woody material such as stones, soil and clods of earth and by constructing alternate terraces. The revegetation is carried out in several stages: by planting soil improving, fast growing shrubs, bushes and trees or trees other than these in several lines as sheltering trees in the first stage. In the subsequent stages when the sheltering trees grow to a certain height, in a block of land, the outside lines are kept intact, but the alternate inside lines are cut and the main tree species are planted between them. In this process, with each time planting of the main species the sheltering species will be cut. The outside lines are not cut, until the canopy of the main species is closed. The cut parts of sheltering plants are mixed with soil.

In this way, two objects are accomplished : i) shelter is provided for the main species, ii) soil improvement and surface stabilization is achieved by the addition of organic matter (leaves, twigs and branches of sheltering species before and after cutting) to the soil. Another advantage of this concept is that the material mentioned above can be procurred free of charge or with nominal charges. These are available almost everywhere and can be transported by simple means, available in the villages to the project site. Also by handling the material and working in the project, employment opportunities can be provided for a large number of seasonal or fully unemployed people, specially in developing countries.

After the plantation reaches to maturity, among the groups of trees a mutual vegetational sheltering is established. In this stage, e. g, in areas where strong winds are the main agent of disturbance and stress, first line(s) of trees facing the wind, sand or snow drift, act as shelter for trees in the middle of the forest. Tree line(s) in the middle of the forest act as shelter for trees and their environments in the end of the forest. These sheltering trees reducing the level of disturbance and stress, add organic matter systematically and continuously to the sheltered site and help the organic matter to remain in place and accelerate its decomposition, finally advancing the process of mineralization of organic matter and the development of environmental site factors. In this way each line(s) of trees in a plantation acts as shelter for trees growing behind them, and the effects of shelter are expected to increase progressively, the further and deeper the forest extends.

At the advanced stages of plantations established in devastated hillslopes where the main disturbance is soil erosion by run-off water, the forest canopy, the understory and the undergrowth act as a multilayered shelter for the ground surface. A dense canopy and its understory are expected to absorb the intensity and energy of rain drops, prevent run-off, add organic matter to the site and provide stability for its decomposition and mineralization. This will consequently lead to the improvement and development of environmental site factors in such areas.

It, therefore, can be said that in the advanced stages of plantations established in severe environments, where wind is the main agent of disturbance, shelter is frontal and horizontal, and where the rainwater as run-off is the main agent of disturbance shelter is layered and vertical.

The vegetational shelter as mentioned before, implies in the beginning stages of the revegetation of severe environments as well as in the advance stages when the plantation is mature.

In this study, in addition to defining the concept of shelter and its possible effects on newly planted seedlings in the initial stages of revegetation in severe environments, an attempt has also been made to evaluate the effects of shelter in the mature plantations in coastal sand dunes and in devastated hillslopes. For this purpose a number of environmental site factors (edaphic, plant) have been used as indicators of the effects of shelter, in these environments.

Waterlogged, saline, bare and active sand dunes, bare and devastated hillslopes are all disturbed and stressed and, therefore, can be called severe environments — though in different forms and levels. In this study, however, coastal sand dunes and hillslopes, devastated mainly by man's action have been investigated. Based mainly on the results and conclusions of this study, patterns of planning for revegetation of bare sand dunes and devastated hillslopes in semi-arid regions has been developed.

The reason for choosing these two types of environments for this study in Japan, where in general humid climatic conditions prevail, is the fact that: though bare and devastated sand dunes and hillslopes in humid regions and in semi-arid regions could differ in many aspects, nevertheless, most of the limiting factors for revegetation of these environments given below; 1) erosion of the surface, 2) instability of the surface, 3) high temperature on the surface, 4) low moisture content of the soil, 5) deficiency of clay and nutrient material, are the same in both humid and semi-arid regions.

2. Study areas

1) Natural conditions

Sunasaka seaside forest and sand dunes are located 8 km to the north of the town of Esashi, Hiyama district in the southern part of Hokkaido (Fig. 1). It covers a total area of about 88.0 ha (1.5 km long and about 0.58 km wide), out of which 65 ha are planted with *Pinus thunbergii* and 23 ha consist of either bare sand dunes or sand dunes covered, mainly, with natural vegetation of seaside dunes. It is marked as compartment 545 in the forest map of Hiyama district.

The northern border of the area is Sunasaka sandy hills and its southern border adjoins the River Assabu. The unforested part of the dune system is composed of three ridges running more or less north-south, parallel to the coast line. Starting from the seashore, first comes the fornt dune which was formed as a result of vertical fencing at the early stages of sand dune stabilization work. After slacks and depressions there is a discontinuous middle dune, slightly higher in elevation than the front dune. In front of the pine forest, in the more inland areas, there lies a discontinuous natural dune.

From shoreline to inland there is an open area, about 50 m wide, parallel

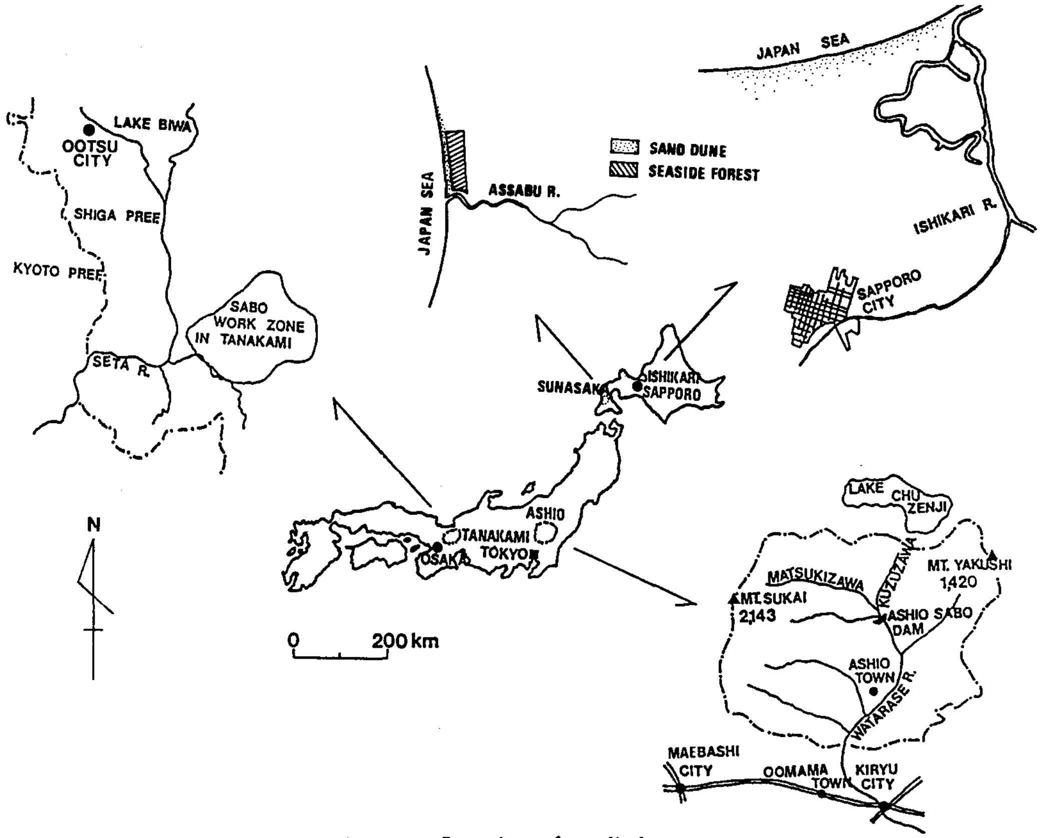


Fig. 1. Location of studied areas.

to the fornt dune, which has been exposed to strong winds from the sea and contained few plants of *Carex kobomugi*. Then until the seaward side of the front dune, *C. kobomugi* formed a fairly dense cover and is dominant. "This is a dune forming plant which has the capacity to renew growth in response to sand covering, it has xerophilous nature: coriaceous glossy and thick leaves and a deep rooting system. Also it has the capacity to produce vertical and prostrate rhizomes against sand accumulation and so when a shoot is overwhelmed by sand, one or more buds develop a vertical shoot which unfolds leaves on reaching the surface. Thus the more covered with sand, the more vigorous *kobomugi* will be" [NAOKI (1979)].[42]

The ridge of the front dune was sparsely covered with *Elymus mollis* (Hamanin-niku) and *kobomugi*. These two species grow in April and are present until the end of October or beginning of November. Their over-ground parts, which provide a vegetation cover, though sparse, for the ground surface, however, die in winter; the season when strong wind blows.

The inland side of the front dune contained a mixed vegetation of *E. mollis*, *C. kobomugi*, *Plantago japonica*, *P. lanceolata*, *Poa annua* and *Artemisia stelleriana* — *E. mollis* being the dominant species. The vegetation of the middle dune and of the depressions between the middle and natural dunes was composed of *Rosa* *rugosa*, *E. mollis*, *Amorpha fruticosa* and *A. stelleriana*. The seaside of the natural dune supports a sparse cover of shrubs and bushes, while its inlandside has a thick vegetation cover and the land surface is fairly stabilized in comparison to front and middle dunes. *R. rugosa* formed the principle plant on this dune as well as on sandy hills to the north of the study area. It seems that this plant invades the more inland and relatively stable sand dunes. Other bushes covering the natural dune are *Elaeagnus umbellata* and *A. fruticosa*, both natural and planted, and *Oenothera lamarckiana*.

A few meters from the natural dune, the plantation of *Pinus thunbergii* began. The understory of the plantation is mainly composed of *Quercus mongolica*, *Q. dentata*, *Elaeagnus umbellata* and *Populus alba*.

According to the climatological data recorded from 1967 to 1971 at the Esashi weather station, the annual mean air temperature was 9.5 degrees centigrade, and data from 1979 showed the maximum temperature to be 32.8 and the minimum minus 10.3 degrees centigrade. Total annual precipitation was between 1200~1300 mm which come down as snow during the winter and as rain during the spring and summer. Strong winds blow in the months of December and January. Monthly average wind force during these months reaches to more than 9.0 m/sec. which is one of the strongest all over Japan (Fig. 2). The most frequent direction of wind from autumn to early spring is WNW from the sea of Japan to the inland, and during the summer is in WSW direction.

Ishikari sand dune system is located about 15 km to the northwest of the city of Sapporo and is extended to the northeast and southwest sides of the bay of Ishikari on the Japan Sea, into which the Ishikari River drains. The sand dunes close to the coast contain some sparse natural vegetation such as *Carex kobomugi* and *Elymus mollis*. The dunes in more inland areas, however, are mostly planted with *Pinus thunbergii*.

The average annual precipitation and temperature in this area are 1,117 mm and 7.3 degrees centigrade, respectively, with heavy snowfall from November through March. In inland areas, the snow depth reaches to more than one meter mostly in February. As Ishikari sand dunes are situated along the Japan Sea coast, strong winds blow from late winter through May. Wind direction is mainly southeast throughout the year, and has an annual average speed of 4.1 m/sec.

Ashio district, with an area of 185 km² is situated at the extreme western

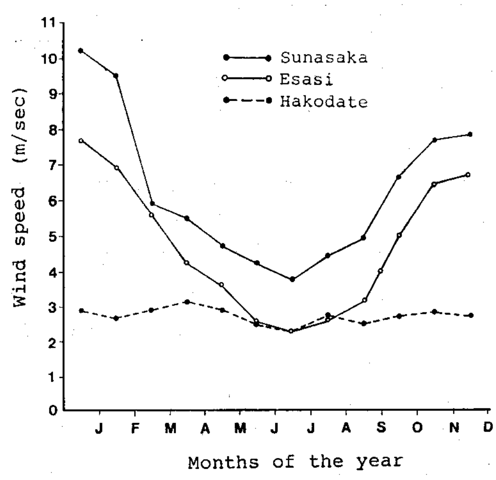


Fig. 2. Average wind speed (1979–1983) in Sunasaka and adjacent areas. (Based on data from Hokkaido Meteorological Department and Sunasaka Meteorological Station).

edge of Tochigi prefecture of Japan. The average annual precipitation, temperature and wind speed are 1,636 mm, 11.3 degrees centigrade and 1.7 m/sec, respectively. The highest temperature, however, is 34.3 degrees centigrade and the lowest minus 15.0 degrees centigrade. The temperature of May-September plant growing season averages 20.4 degrees centigrade. Most of the rain falls during the growing season and is under the influence of Typhoons during the months of August and September.

Frost heaving is a problem for revegetation of the area because it damages planted seedlings. According to the data from 1968～1972, the early frost first occurs mainly during the month of October before the snowfall.

The bulk of the bedrock in Ashio is Palaeozoic strata consisting mainly of shale. In this there are intrusions of various types of igneous rocks such as granite and quartz — porphyry, etc, due to the occurrence of volcanic activities. Covering these underlying rock types can be seen rhyolite, andesite, and/or volcano-clastic materials. While, over much of the devastated land soil has been washed away leaving the bedrock exposed, there is clay loam in mountainous and hilly areas and on gentle slopes. In general, however, the soil is thin, and is of poor fertility.

Prior to devastation, the natural forest in Ashio area was composed mainly of *Fagus crenata* (buna), *Quercus mongolica* (mizunara), and *Tsuga diversifolia* (kometsuga). In general, however, the natural vegetation of Ashio belongs to the following five types: *Pseudosasa purpurascens* (suzutake), *Sasa nipponica* (miyako-zasa), *Betula ermanii* (dakekanba), *Miscanthus sinensis* (susuki) and *Clethra barbinervis* (ryobu).

Tanakami mountains cover an area of 5,100 ha and are located in the upper reaches of the Yodo River, which flows out of the Biwa lake. It is the extreme southern part of Shiga prefecture in western Japan.

In comparison to the average annual precipitation of the country which amounts to 1,700 mm, the precipitation of this area is in general low. This can be clearly seen from the precipitation of Ueno 1,506 mm, Kobe 1,367 mm and Okayama 1,218 mm which are situated in this area. Air temperature is generally mild. The soil temperature, however, on the surface layers of the bare ground reaches up to 50 degrees centigrade in mid-summer.

The base rock of the area is granite in which deep weathering has taken place. The sandy material produced from this rock is "susceptible to dryness, has a low absorption capacity for nutrients and is highly erodible" [ISHIBASHI (1981)].[24]

In the ancient times (as the documents from 17th century show) the Tanakami mountains were covered with well stocked *Cryptomeria japonica* (Japanese cedar) and *Chamaecyparis obtusa* (Japanese cypress).

2) Investigation in study areas

In Sunasaka, a belt transect, 10 m wide and 850 m long, was taken. This extends across the front, middle and natural dunes and the stand of black pines, thus forming a cross-section of the whole area. Five sample areas were chosen along the transect belt, three inside and two outside the forest. Along this transect belt, tree height and DBH were measured in the plots of 10 m×10 m in the sub-compartments which were planted in 1939, 1940, and 1943. Also the same measurments were carried out outside the belt in plots planted in 1941, 1944, 1947 and 1949. The composition of vegetation was recorded along the transect belt as well as outside it, including the undergrowth. The inclinations of ten most deformed trees in each plot along the transect belt and in one plot outside it were measured to determine the degree of stem deviation from the straight position. One tree (the most deformed one) from each plot has been cut for stem and compression wood analysis.

Soil profiles were dug up to a depth of 50 cm in all the sample areas. Soil samples were taken from the surface, Ao layer, A horizon and from below the Ao layers ; 5, 20 and 50 centimeters deep. The samples brought to the laboratory and their soil mositure contents were measured by the gravimetric method. The pF of soil samples was determined using a Kokusan Centrifuger. A part of the samples was airdried for one week and the airdry moisture was determined. The total organic matter content was measured by ignition loss under 700 degrees centigrade in a furnace. Carbon and nitrogen were determined with a Yamagimoto CN Corder, CEC (cation exchange capacity) with an Orion Ionmeter, and the pH with a TOA Ionmeter. A mechanical analysis of the soil was carried out by sieving and with a Recording Sedimentor RS 1000 using a chemical stabilizer for prevention of the coagulation of particles.

Air and soil temperatures were measured (in Ishikari and in Sunasaka) using a digital thermometer.

A preliminary field observation of the Ashio and Tanakami mountains was carried out in July, 1982 and March, 1983, respectively. The purpose was, first to become familiar with these two areas, which were considered to be the representative devastated hillslopes in Japan. Then in August, 1983 the revegetation systems in Ashio and Tanakami were investigated. The plantations established as a result of the application of these systems and their effects, mostly in the form of soil and plant conditions, were studied.

The measurements were carried out in a series of eight plots (plot size 10 m× 10 m) which were set-up in slightly, medium and highly damaged areas of Ashio mountains. In each plot tree height, DBH, litter thickness and soil pH were measured. Kind of afforestation works applied, erosion features and the natural invasion of plants were investigated. The effects of sabo dams (erosion and sediment control dams) on rehabilitation of these areas was determined by investigating the natural invasion of plants behind them. Two such dams were selected. The amount of deposited sediments, percentage of the area invaded by plants and the ages of deposits were studied by using tree ring method.

3) Degree of sheltering in study areas

It has already been mentioned in the section on the study method that in the mature stages of plantations, established in severe environments, a mutual sheltering exist among the trees against the actions of agents of disturbance. The degree of exposition, of the mutually sheltered areas, however, to the actions of these agents is not the same. There could be areas highly exposed, as a result of which some trees could sustain damage, lose some of their sheltering properties and not provide complete shelter for other trees and their environments. The reverse could be true for the least exposed areas where trees were not damaged and did not lose their sheltering properties. Also there could be areas in between.

The possibility also exist that parts of a plantation may develope well and providing sufficient cover and shelter for the surface of the land, while in other parts the plantation develope poorly and, not been able to provide adequate sheltering against disturbance. Thus, it can be said that in this way different degrees of sheltering are found in a plantation. The significance of the degree of sheltering, however, is that it could affect the development of site factors accordingly.

Based on the presence and absence of vegetation cover in critical seasons (time when strong wind blows or strong rain falls), the damage inflicted by disturbance to this cover (when present) and the significance of these damages to the sheltering properties of trees, four degrees of sheltering has been found to exist in Sunasaka seaside forest and in the plantations in Ashio and Tanakami mountains (Table 1).

In Sunasaka, plot 5 was located outside the forest on the front dune, very close (41 m) to the seashore and was exposed to strong wind blowing from the sea and had very sparse vegetation cover in summer and was found to be bare in winter, when strong wind blows. As a result, this plot was continuously exposed to the highest degree of disturbance from sand and snow drift. The ground in Plot 4, located on the seaward side of the natural dune, was sparsely covered by shrubs and bushes in summer, similar to polt 5 and was found to be mostly bare in winter. Due to this and its closeness to seashore, sand and snow drift occurred and strong wind constantly removed organic debris and disrupted their decomposition. This could be seen from the thickness of Ao layer in this plot. These two plots, therefore, have been designated as "unsheltered".

Plot 3, located at the beginning of the plantation and was covered by pine trees which were directly exposed to strong wind, sand and snow drift and salt spray from the sea. As a result of these disturbances a number of trees in this plot were dead and the stems of living trees were highly inclined (ave. 29.0 degrees) and branches grew only in their leeward side. This plot has been named "partly sheltered".

Due to the absorption of the impacts of disturbance by trees in the plot 3, the trees growing behind them in plot 2, in the middle of the forest, contained very few dead trees and their inclination was 3.5 times less than the stem inclination of the former and some branches grew also in the windward side of the stems. This plot was named "sheltered".

Finally in plot No. 1 at the end of the forest there were no dead trees at all, inclination of the stems of trees was 6.0 times less than that in the middle of the

Table 1. Classification of degree of sheltering in mature plantations

Criteria	Sunasaka seaside forest (A)		Ashio & Tanakami hillslopes (B)		Degree of sheltering proposed for fields A & B
	Effects of disturbance	Corresponding location in plantation	Effects of disturbance	Corresponding location in plantation	
Vegetation cover present all over the year and is not affected by disturbance	Not significant	End of the plantation	Not significant	Forests	Highly sheltered
Vegetation cover present all over the year but slightly affected by disturbance	Tree stem inclination	Middle of the plantation	Slight danger of recycling of erosion	Well developed plantation	Sheltered
Vegetation cover present all over the year but strongly affected and damaged by a high level of disturbance	High degree of stem inclintion, high number of dead trees, branches growing only in the leeside	Begining of the plantation	Danger of recycling of erosion	Poorly developed and sparse plantation	Partly sheltered
Vegetation cover absent all over the year or only in the seasons when there is a high level of disturbance	Erosion of the sand surface, removal of the organic debris from the land surface	Front, middle dunes and a part of natural dune.	Erosion of the surface soil, rockfall and soil flow	Bare hillslopes	Unsheltered

forest and branches were found growing in both windward sides and leeward sides of the stems. This plot, therefore, was named "highly sheltered".

In Ashio and Tanakami mountains, the cover which was provided for the hillslope by the plantation and the thickness of Ao layer under the plantation were taken as the indicators of the degree of sheltering. In both of these areas there were places where revegetation did not succeed. The land surface was not sheltered and was partly or completely bare. In such places soil erosion was active and Ao layer was either very thin or not formed at all. In other parts, where plantation was poorly developed and the land surface was partly sheltered, there was a danger of recycling of erosion. The effect of shelter, however, is very clear in well developed plantations and in areas where already the forest has been established. In the latter case, disturbances such as surface erosion (rills and gullies), soil flows and rockfalls have not been seen. The Ao layer is thicker, due to the stability provided by the shelter, than the Ao layers of the poorly developed plantations.

Thus it can be concluded ; i) in plantations, growing in windy areas, the impact of disturbance by wind which is not absorbed by the first line of trees and are penetrated further in the forest, is minimized by the trees in the middle of the forest, and the effects of sheltering of the above mentioned two lines (beginning and middle of the forest) are so strong that the impact of disturbance is not felt at the end of the forest; ii) in the devastated hillslopes, the cover provided to the surface of the slope by shelter, results in the reduction of the impact of disturbance. These indicate that the effects of shelter can vary, according to the degree of stability it provides. Also, the development of environmental site factors, which depends mainly on the reduction of stress and disturbance, can be influenced by variation of these degrees.

II. Some aspects of severe environments

1. Inland dunes of semi-arid and arid regions

Active sand dunes occur in several large sand — seas, that cover an area of about 4,000,000 km^2 in the big deserts of the Sahara, Arabia, Asia, South Africa and Australia. Other areas of the same desert, about 2,000,000 km^2 in all, are covered by fixed dunes (Fig. 3).

The semi-arid and the total of arid and hyper arid areas in the five continents, on the other hand, are 18,000,000 km^2 and 28,900,000 km^2, respectively (BAUMER and SALEM, 1980).[5] This indicates that the sandy areas occupy about 12.6% of semi-arid and arid regions — a considerable area for exploitation.

BAGNOLD (1954) classified the main observed characteristics of the various types of sand dune formations, which are found in nature, as follow:[4]

A — Deposits caused by directly fixed obstructions in the path of sand driving wind, e.g, by bushes, rocks or cliffs. These are termed sand shadows and sand drifts, that are dependent for their continued existence on the presence of the obstacles and can not move away from it.

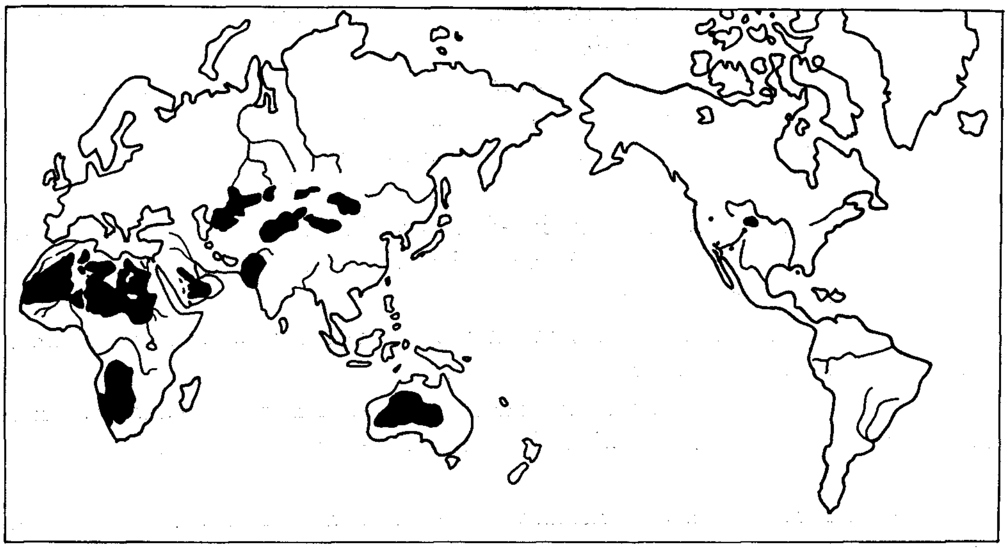


Fig. 3. World distribution of desert big active and fixed Pleistocene sand dune fields. (After TSOAR and ZOHAR, 1985).

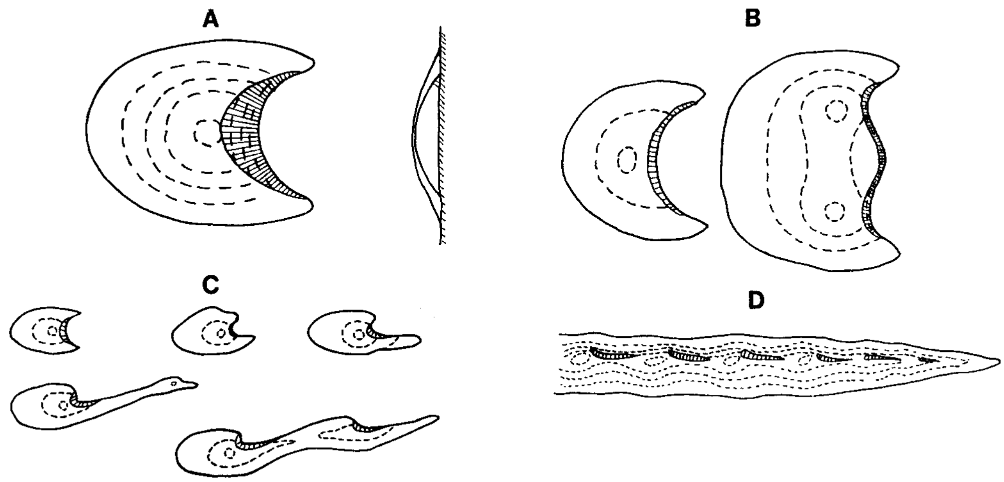


Fig. 4. The barchan dune A, double barchan B, transition from barchan to longitudinal dune C, and symmetrical longitudinal dune chain D.
(After BAGNOLD, 1954).

B — True dunes. A single dune, may be defined as a mound or hill of sand which rises to a single summit. Dunes may exist alone or attached to one another in colonies or as dune chains, and are independent of any fixed surface feature. Although capable of movement, from place to place, they are able to retain their own characteristic shape. A special feature of all dunes, according to BAGNOLD (1954), is the slip-face where the slope of the dune surface reaches the limit of steepness imposed by the angle of shear of the deposited material.[4]

True dunes assume two fundamental shapes: 1, The Barchan or Crescent dune and 2, The Longitudinal or Seif dune (Fig. 4). Seif and Barchan dunes are more mobile and are generally without vegetation. Rounded longitudinal dunes are more stable on the wind side and less stable on the downwind side. So the tail is colonized by plants but the downwind side is not (GHOSE, 1985).[13]

C — Sand sheets

MAINGUET (1985), however, introduced a new classification.[37] He groups the active dunes into three families which included a wide variety of forms and coincide with three main aeolian regime:

A′ — Crescent dune family is generated by an aeolian flow with one dominant direction perpendicular to the dune.

B′ — Linear dune family corresponds to an aeolian flow having two main wind directions or a dominant wind direction divided by a topographic obstacle. This is an oblique dune.

C′ — Star dune family is indicative of an aeolian regime without dominant wind.

MAINGUET (1985) also notes that parabolic dunes and sandridges correspond to dominant deflation and exportation in a sand sheet, and are erosional forms of sand dunes.[37]

BAGNOLD (1954) found no distinctive difference in the material, forming the different dune shapes.[4] He concluded that the dune type was determined by the character of the wind — by its relative period of variation in strength and direction. According to him the longitudinal dunes form as a result of wind blowing from several directions, while the barchans are formed when the wind is uni-directional.

He said that "sand have the power of self accumulation, utilization of the energy of the wind to collect their scattered components together into definite heaps. This is the reason that dunes can retain their identity and can move from place to place".

Sand dune texture affect the mobility of the dunes by the wind, the percolation rate of water and its movement through the soil, the soil water holding capacity and its temperature. All these characteristics of sand are very significant for plant growth and for agriculture. Generally, soil particles have been classified into four classes: gravel, sand, silt and clay. A number of different classification of grain size have been devised all based on the above mentioned classification of soil particles (Fig. 5).

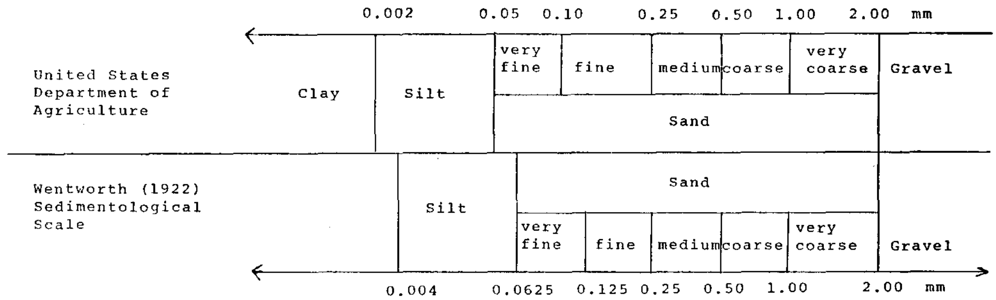


Fig. 5. Terminology and class intervals of soil particle by the two main classification systems.
(After TSOAR and ZOHAR, 1985).

GHOSE (1985) notes that desert sand is composed of quartz grains mixed with feldspar and some limes with very small percentage of hornblend and ilmenite.[18] Iron oxid is also present as coating over the sand grains. This affects the colour of sand grains. The pale colour of shifting sand is due to the removal of iron coating, during saltation.

The source of the desert dunes, seems to be, mainly, alluvium and dead drainage system, as well as weathering bedrocks leaving residual quartz grains in the form of sand sheets (GHOSE, 1985, TSOAR, 1985).

TSOAR and ZOHAR (1985) mentioned that "frequent winds are not capable of drawing along particles coarser than 1.0∼2.0 mm. The most mobile particle size for the frequent winds is the fine sand −0.125 to 0.250 mm".[47] The very fine particles are moved by air in suspension, because turbulent air flow has vertical velocity fluctuations, which exceed the sedimentation velocity (BAGNOLD, 1954). The higher the wind velocity, the greater its vertical velocity. The smaller the grain size, the lower its sedimentation velocity (TSOAR and ZOHAR, 1985).

TSOAR (1985) found that "suspended particles deposited on active sand dunes are not stable, but are carried away during sand storms since the impacting sand grains provoke the release of the silt and clay to the wind. If the dune is fixed or has become semi-stabilized through vegetation, then the aeolian silt and clay deposition is trapped by the coarser sand sizes and conveyed by the percolating rain water to deeper layers. By this process, the clay and silt contents in the dune system can be raised from less than 1.0 percent in active dunes to 10.0 percent and more in fixed dunes".[47]

The fine sand is moved by saltation — the bouncing and jumping movement of grains. On falling back to the ground, these grains have enough momentum to induce saltation in other fine sand grains on the surface. Medium and coarse sand grains are too heavy to be thrown-up into the air, so that only a small forward movement — creep occurs. TSOAR (1985) observed that "because of the difference in pace between the jumping fine sand and the slower coarser surface creep, the fine sand tends to accumulate into dunes separately from the coarser sand".[47]

2. Coastal sand dune devastation and revegetation

The source of coastal sand dunes, which form less than one percent of the total area of desert dunes (TSAOR and ZOHAR (1985)),[47] is the upstream watershed of the rivers which flow to the sea. These rivers carry sand particles to their estuaries, from where seawave carries these particles to the nearby beach, where the dunes are formed. Strong winds carry the sand to more interior areas.

Coastal sand dunes are found in arid as well as in humid areas. The coastal dunes in the humid regions of Japan are not wider than several kilometers. But in arid areas, as TSOAR and ZOHAR (1985), are observed some ancient coastal dunes which migrated inland, creating a wide belt of 70 to 80 km.

Sand dunes are formed in coastal areas of humid, semi-arid and arid regions, as well as in the deserts. These dunes are, however, different in some respects :

Coastal dune	Desert dune
Important site for recreation, urban and industrial activities, and to lesser extent agriculture activity.	Occasionally inhabited and utilized by nomadic tribes as pasture.
High water table.	Low water table.
Features masked by form, introduced by moisture and vegetation.	Lognitudinal and crescentic shape.
Sand is transported by water.	Origin of sand is either an escarpment or a series of depressions and sometimes the origin is not clear.
Uniformity of grain size (mostly fine sand).	Grain size depends on the origin of sand, but mostly are in the medium and fine range.

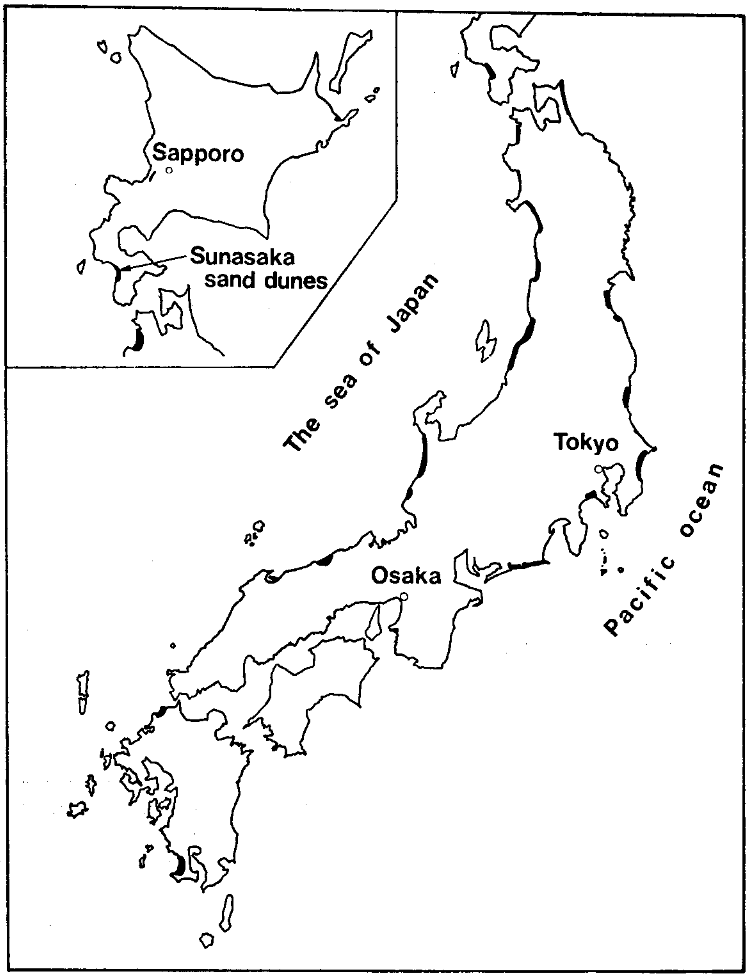


Fig. 6. Distribution of sand dunes in Japan.
(After NAKANO, 1962).

In Japan the coastal sand dunes occupy an area of about 100,000 ha [IKEDA (1963)],[22,23] and are mainly located along the coasts of the Sea of Japan and the Pacific Ocean (Fig. 6).

In the past, the vegetation cover of these dunes were destroyed, mainly, due to the over-exploitation by man for use as fuel and for the processing of fish in coastal villages. As a result, vegetated sand dunes turned bare. Where strong wind blew, moving sand dunes encroached on agricultural land and villages and, occasionally, even covered them partially. The fixation of these dunes, therefore, become a pre-requisite for the exploitation of sand dune ecosystem. Also for the development of the areas, threatened by the moving sand dunes. For this purpose extensive sand dune stabilization work, especially, in the postwar period started in Japan. As a result of which, most of the bare and active sand dunes had already been fixed and revegetated. Nowadays, sand dunes are very important sites for recreation and sometimes urban and industrial activities. In areas where plantation for the sand dune fixation has already been established, the exploitation of some forest products, such as mushrooms, are also very common.

In bare sand dunes in Japan forest was established by: fixation of moving dunes, followed up with planting of trees.

Fixation of sand dunes was carried out by the creation of an artificial dune, close to the seashore — called the front dune and by covering of inland bare dunes with straw mats. The front dune is created 90 m to 100 m inland from the seashore, in order to cut-off the fresh supply of sand blown from the sea to inland.

As a rule for the formation of front dune, first a nucleus, which is either brushwood fence, bamboo-blinded fence, fern fence or paling fence, is created. All these fences are permeable. The nucleus is created by erecting one fence or two fences a few meters apart, parallel to the seashore and at a distance from it corresponding to the position at which the crest is required (Fig. 7).

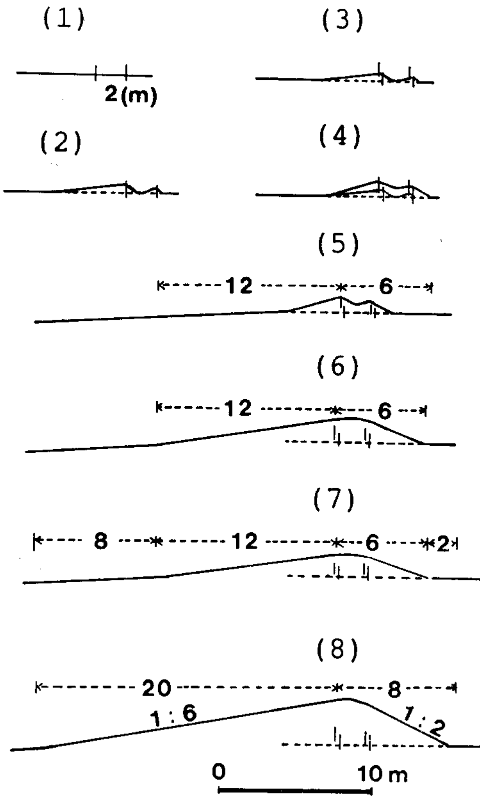


Fig. 7. Steps in the formation of front dune. (After HIGASHI, 1979).

Brushwood fence is inserted 30 cm in the ground and remain 60 cm to 1.0 m high on ground. First pales are driven with about 1.0 m intervals, iron wire or bamboostalks are tied to them horizontally. Then brushwood is put on vertically with a moderate degree, for the penetration of air. Finally, iron wires or bamboostalks are tied horizontally on them. Fern fence is erected in almost the same manner as the brushwood fence.

When the erected fence is nearly burried, a new fence is erected on the top the former or at a place 50.0 cm windward from it. If the new fence is erected on the leeward side of the old fence, it might be blown down by the force of the already accumulated sand which may form a sand heap. If necessary, wing fence, facing the prevailing wind at right angles, is erected on the windward side of the main fence. By suitable combination of the main fence and wing fence, sand dune will be formed in any desired direction.

A desirable front dune should attain the followings: a) the necessary height. b) a windward side slope of not steeper than 12.0 degrees. c) a leeward side slope as steep as the angle of repose of the sand dune. d) a broad and flat crest. Also the dune must run straight, parallel to the coast line and it must be far enough from high water line to be out of danger of wave erosion.

After the front dune is constructed, the inland bare sand dunes are covered with straw mat, as a means to prevent the erosion of sand surface. This work is carried out simultaneously with planting. The tree widely used for the establishment of sand dunes in Japan is *Pinus thunbergii* — Japanese black pine.

In 1870s the coastal dunes of Sunasaka were covered with a natural forest of *Quercus mongolica*, *Q. dentata*, and *Acer mono*. From 1890–1910s, the natural forest was cut for fuel and for the processing of Nishin (a kind of fish) by fishermen living in the nearby villages. By the late 1920s, the whole area turned into bare sand dunes. As a result, strong north-west wind, drifted the bare sand up to a distance of 7.0 km inland. Thus burrying the agriculture land. To rectify the situation the following actions were taken in Sunasaka:

— 1934, 25.6 ha of devastated land in Sunasaka was proclaimed as national forest and protection area against sand drift. In the subsequent years a total of 59.32 ha of national land was added to Sunasaka and the total area of national forest in this area reached to about 84.9 ha.

— 1937–1938, construction of fences for sand accumulation and wind protection started and *Pinus thunbergii* and *Acer mono* were planted in an area of 20.01 ha. But due to the destruction of fences by wind almost all planted trees died.

— 1939–1940, distribution of natural dune, soil and plant conditions were investigated and a vegetation map of the area was drawn. 33 species of plants were examined for planting.

— 1941–1946, planting continued until 1945. Only 20.0 ha was planted.

— 1947–1953, construction of front dune started. New planting proceeded well and re-planting of the failed areas was carried out. Fire protection facilities and forest roads were constructed. Thinning started from 1953.

— 1954–1963, most of the main planting works were completed.

The sand dune stabilization work, which started from mid-thirties, composed of the following: the creation of the front dune — close to the seashore, fencing for protection against wind, and straw covering for protection from strong heat and for soil moisture conservation in summer — in more inland areas.

In Sunasaka, starting from the seashore, first comes the front dune which was formed as a result of vertical fencing at the early stages of sand dune stabilization work. Two rows of fences, 1.8 m in height, 2.0 m apart and 1500 m long, parallel to each other were erected. When the first fence was covered by sand, a second fence was erected on the tope of it. The work continued until most of the sand particles were deposited on the seaward side, ridge and inlandward side of this artificially constructed dune, and the largest amount being on the leeside.

Despite the formation of front dune, sand drift did not stop completely and was still a problem util the year 1975. In the winter of 1974-75, for example, about 30 cm to 50 cm thick layer of sand was found eroded from the bare areas.

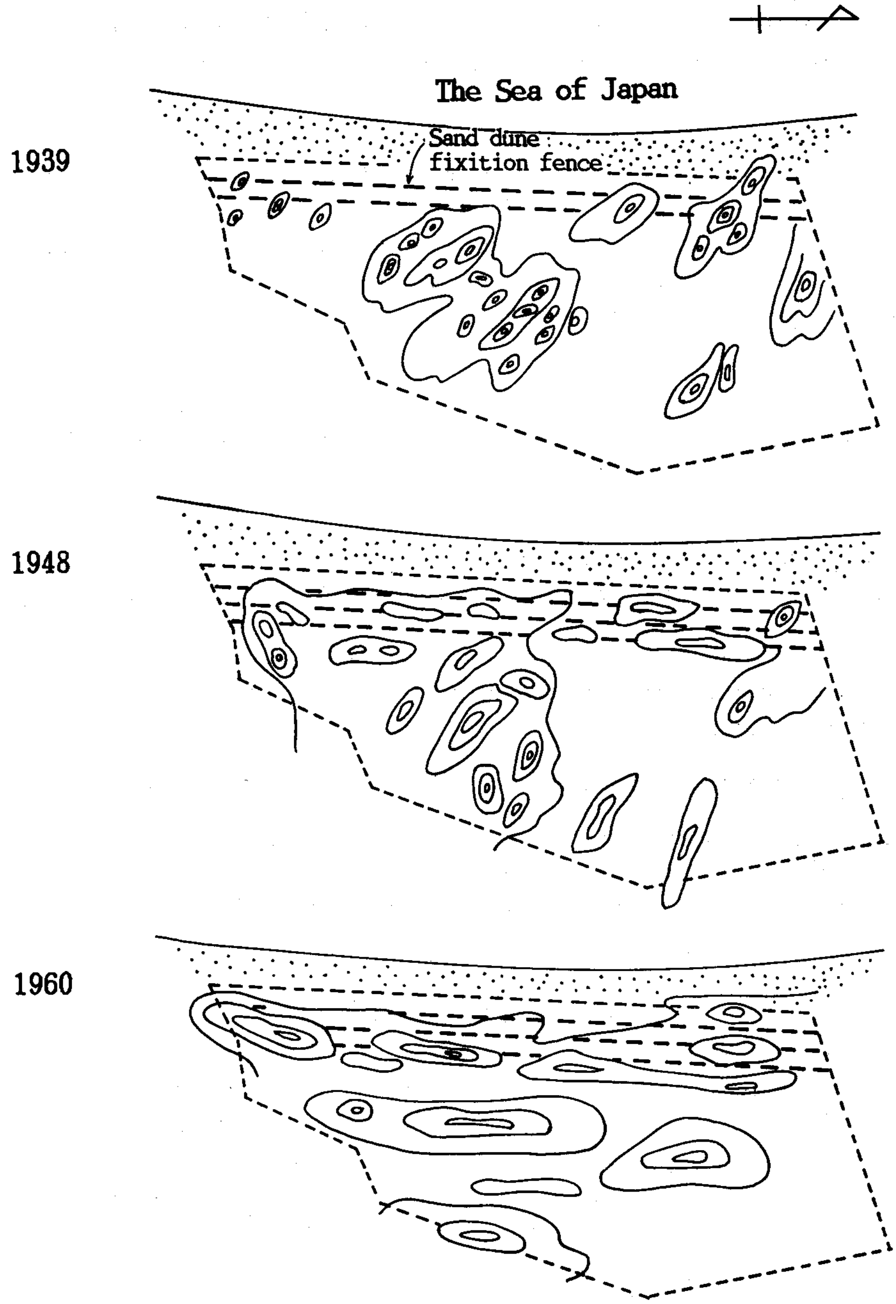


Fig. 8. Changes in topography of coastal sand dunes in Sunasaka due to the construction of sand dune fixation fence. (After HIGASHI, 1979).

After the formation of the front dune, the position and direction of sand dunes have changed considerably. As can be seen from Fig. 8: in 1939, when the front dune was still in the process of formation, a large number of small dunes, mostly directed towards the inland, existed; in 1948, when the front dune was already formed, but did not attain the necessary height, the position of dunes remains irregular; in 1960, however, when the front dune acquired the necessary height and had affected the wind direction only few large uni-direction dunes were formed.

For revegetation of the area, a total of the following 33 species of grasses, shrubs and trees were planted experimentally: *Pinus thunbergii* (Kuromatsu), *Acer mono* (Itayakaede), *Quercus dentata* (Kashiwa), *Fraxinus mandshurica* (Yachidamo), *Populus alba* (Gindoro), *Elaeagnus umbellata* (Akigumi), *Amorpha fruticosa* (Itachihagi), *Abies sachalinensis* (Todomatsu), *Populus nigra* (Popura), *Prunus* spp. (Sakura), *Betula* spp. (Shirakanba), *Pterocarya rhoifolia* (Sawagurumi), *Fagus crenata* (Buna), *Ligustrum obtusifolium* (Ibota), *Acer negundo* (Negundokaede), *Gleditschia japonica* (Saikachi), *Populus maximowiczii* (Doro), *Deutzia crenata* (Utsugi), *Larix kaempferii* (Karamatsu), *Cryptomeria japonica* (Sugi), *Thujopsis dolabrata* (Hiba), *Paulownia tomentosa* (Kiri), *Sorbus* spp. (Nanakamado), *Castanea* spp. (Kuri), *Juglans* spp. (kurumi), *Aesculus turbinata* (Tochi), *Albizzia* spp. (Nemunoki), *Quercus* spp. (Nara), *Ulmus davidiana* (Harunire), *Carpinus laxiflora* (Akashide), *Alnus pendula* (Himeyashabushi), *Alnus hirsuta* (Keyamahannoki), and *Pinus pentaphylla* (Himekomatsu).

According to a survey carried out by the Esashi District Forest Office, only the first of the above mentioned eleven species could survive the harsh environment of Sunasaka.

Planting of trees was carried out wherever a stable area was found and continued until late sixties. Two main species of trees, namely, *Pinus thunbergii* and *Quercus dentata* were chosen for planting. *Pinus thunbergii* showed a very high rate of survivability. At present this species forms more than 98.0% of the composition of the plantation in Sunasaka. Simple pits were dug for the planting of bushes and trees. In the first line soil improving bushes such as *Amorpha fruticosa* and *Elaeagnus umbellata* were planted and than the main tree of *Pinus thubergii*. The soil improving bushes grew up to a height of more than 1.0 m. In order to reduce their competition with the main tree, they were cut after four years. In order to prevent the erosion of the surface of the bare sand, the surface of land was completely covered with straw mat.

3. Hillslope devastation

Devastation of hillsolpes is closely related to destruction of its vegetation cover. This can happen by natural causes such as volcanic eruptions, long lasting droughts etc., as well as by man's action. Here, however, land devastation caused by mismanagement and neglect of conservation measures by man, in the hillslopes of Ashio and Tanakami mountains is discussed.

In Ashio mountains, the main cause of hillslope devastation was SO_2 gas emission from the copper smelting factory (1884-1956). A large forest fire in 1887, and indiscriminate forest cutting, as fuel wood for smelting and for mine timber also greatly contributed to the destruction of vegetation cover in these areas.

From 17,828 ha natural forest of Ashio (main species before devastation: *Fagus crenata*, *Quercus mongolica*, and *Tsuga diversifolia*), the vegetation cover of a total of 14,263 ha was destroyed in different degrees.

The level of damage to vegetation cover was classified as light (7,860 ha), medium (3,840 ha) and severe (3,155 ha). In the area of light damage, only leaves of the plants were damaged for sometimes, then the leaves turned back to normal. In general the vegetation survived. In the zone of medium damage, plant species sensitive to SO_2 gas were seriously damaged and died and the remaining vegetation were very scattered. Vegetation in the areas close to the smelting factory (source of the SO_2 gas) and area along the valley (where the factory was located), were destoryed completely and as a result bare mountain slopes appeared. These areas were classified as heavily damaged.

After the cessation of the emmision of the gas from the smelting factory in 1956, vegetation to the light and medium damaged areas was restored to a great extent by natural invasion of plants and by application of some revegetation work. Heavily damaged areas, however, were not recovered completely. A total of 2,500 ha were remained bare until July, 1983.

In Tanakami mountains, however, the main cause of land devastation was indiscriminate cutting of wood for fuel and for construction purposes. This area was located close to the highly developed centers (Kyoto and Nara) of that time in Japan. The precious wood of Japanese cedar and Japanese cypress from these mountains were cut unsystematically without any provision for replanting, for almost 1600 years, for construction of temples and shrines in those centers.

III. Development of some environmental site factors in coastal sand dunes as affected by degree of sheltering

1. Edaphic factors

In Sunasaka, some soil development was evident only in the top layers under the forest. Here Ao layer from 3.6 cm to 9.1 cm thick and A horizon from 0.2 cm to 0.8 cm thick were formed (Table 2). In all five plots, the layers below A horizon did not show any significant evidence of soil development (sign of color change and leaching), so the B horizon could not be designated. This indicates the immaturity of the soil and a lack of leaching from surface layers. A and C horizons were distinguished by the A horizon's dark color which is the result of accumulation of organic matter. The predominantly sandy soils below A horizon which were not darkened by organic matter and had the color of pure sand, were designated as C horizon. Both the zones of accumulation and decomposition of organic matter

Table 2. Description of plant conditions and soil profiles in Sunasaka

No. of plots	Location and distance of plots from seashore (m)	Vegetation			Soil horizon		Inves-tigated depth (cm)	Colour of fresh soil by Munsell	Tex-ture	Struc-ture	Thickness of layers (cm)			Weight of fresh litter (kg/cm^2)
		Species	Planted year	Age (y)	Layers	Thickness (cm)					L	F	H	
1	End of the forest 850 Highly sheltered	*Pinus thunbergii*	1943	46	A_0	9.1	A_0	5YR 3/1 brownisk black	—	—	1.9	1.6	5.6	0.7
					A	0.8	5	5YR 5/3 dull reddish brown	s	sg				
							20	5YR 4/3 dull reddish brown	s	sg				
					C	—	50	5YR 5/3 dull reddish brown	s	sg				
2	Middle of the forest 525 Sheltered	*P. thunbergii*	1940	49	A_0	4.0	A_0	5YR 2/1 brownish black	—	—	1.9	0.8	1.3	0.6
					A	0.6	5	5YR 4/3 dull reddish brown	s	sg				
							20	5YR 4/3 dull reddish brown	s	sg				
					C	—	50	5YR 5/2 dull reddish brown	s	sg				
3	Close to the edge of the forest 375 Partly sheltered	*P. thunbergii*	1939	50	A_0	3.6	A_0	5YR 2/2 brownish black	—	—	1.5	1.3	0.8	0.6
					A	0.2	5	5YR 5/3 dull reddish brown	s	sg				
							20	5YR 4/3 dull reddish brown	s	sg				
					C	—	50	5YR 4/4 dull reddish brown	s	sg				
4	Outside forest on the natural dune 151 Unsheltered	*Rosa davurica* *A. fruticosa* *E. multiflora*	—	—	A_0	0.3	A_0	5YR 4/2 grayish brown	—	—	0.3	—	—	0.1
					—	—	5	5YR 6/3 dull orange	s	sg				
							20	5YR 5/3 dull reddish brown	s	sg				
					C	—	50	5YR 5/3 dull reddish brown	s	sg				
5	Outside forest on the seaward side of the front dune 41 Unsheltered	*Carex kobomugi*	—	—	—	—	0	5YR 4/3 dull reddish brown	s	sg	—	—	—	—
					—	—	5	5YR 4/3 dull reddish brown	s	sg				
							20	5YR 4/3 dull reddish brown	s	sg				
					C	—	50	5YR 4/3 dull reddish brown	s	sg				

s: sand, sg: single grain

Table 3. Some edaphic factors in Sunasaka seaside forest and sand dune as affected by shelter

No. of plots	Depth (cm)	Gravel	Sand	Silt	Clay	Moisture con. of fresh soil	Porosity	Max. water holding capacity	O. M igni. loss	C	N	C/N (ratio)	Bulk density (g/cm³)	pH H_2O	Exchangeable Cations Ca	Mg	K	Na	CEC
		%													mc/100 g				
1	A_0	—	—	—	—	123.0	91.0	81.1	48.3	24.0	0.610	39.0	0.2	6.1	6.9	6.0	1.1	1.4	64.5
	5	0	96.1	1.0	2.9	1.0	51.0	26.0	1.4	0.3	0.009	33.0	1.3	5.0	0.5	0.5	2.0	0.1	23.3
	20	0	99.5	0.1	0.4	0.6	45.0	24.0	0.8	0.2	0.007	28.0	1.5	5.3	0.5	0.5	0.1	0.1	7.3
	50	0	99.4	0.4	0.2	2.7	45.0	22.0	0.8	0.1	0.007	14.0	1.5	5.9	0.5	0.5	0.1	0.1	7.3
2	A_0	—	—	—	—	54.2	85.0	80.4	31.4	17.0	0.330	51.0	0.4	6.1	2.5	1.7	0.2	0.2	55.0
	5	0	99.5	0.3	0.2	2.0	48.0	24.3	0.9	0.1	0.009	11.0	1.4	5.6	0.4	0.3	0.1	0.1	25.0
	20	0.2	99.5	0.2	0.1	1.0	46.0	20.6	0.7	0.1	0.007	14.0	1.4	5.7	0.4	0.5	0.1	0.1	6.2
	50	0.2	99.2	0.4	0.2	2.0	43.0	25.5	0.7	0.05	0.002	25.0	1.5	5.8	0.2	0.2	0.09	0.08	6.1
3	A_0	—	—	—	—	57.0	87.4	78.0	29.0	12.4	0.230	54.0	0.4	6.1	2.0	1.9	1.2	0.3	55.0
	5	0.3	98.9	0.6	0.2	0.2	49.6	25.1	1.7	0.2	0.006	33.0	1.4	5.4	0.3	0.5	0.1	0.2	10.0
	20	0.3	98.7	0.4	0.6	2.3	43.0	24.3	0.8	0.1	0.004	25.0	1.5	5.8	0.3	0.6	0.1	0.2	6.0
	50	0.2	98.6	0.8	0.4	2.6	44.0	22.3	0.7	0.1	0.004	25.0	1.5	5.7	0.4	0.6	0.4	0.2	2.2
4	A_0	—	—	—	—	0.4	62.0	39.0	6.6	3.3	0.100	33.0	1.0	6.1	4.6	2.4	0.4	0.2	11.2
	5	0	99.5	0.4	0.1	0.3	49.0	28.5	1.1	0.1	0.007	14.0	1.4	5.8	0.7	0.9	0.2	0.1	4.4
	20	0	99.7	0.2	0.1	0.4	46.0	24.6	1.1	0.07	0.006	12.0	1.4	5.4	0.6	0.6	0.2	0.1	2.3
	50	0.3	99.59	0.2	0.01	2.5	46.0	23.7	0.8	0.07	0.006	12.0	1.4	5.4	—	—	—	—	—
5	0	0	99.2	0.7	0.1	0.3	48.0	23.0	0.4	4.3	0.100	43.0	1.4	5.6	0.9	0.5	0.7	0.1	6.3
	5	0	99.1	0.8	0.1	1.0	48.0	26.3	0.6	0.1	0.100	10.0	1.4	5.6	0.8	0.5	0.2	0.1	6.0
	20	0	99.7	0.2	0.1	2.0	53.0	26.5	0.9	0.1	0.100	10.0	1.2	5.1	0.6	0.5	0.3	0.07	6.0
	50	0	99.73	0.2	0.07	2.7	45.0	25.1	0.8	0.1	—	—	1.4	5.7	—	—	—	—	—

O. M: organic matter, CEC: cation exchange capacity

Ao, and the zone of soil formation (A horizon) were relatively well developed in sheltered plots, independent of the age of the trees.

Results of mechanical analysis in Table 3 (more than 90.0% sand grains), and the working of soil between fingers and thumb in the field showed that the dominant texture of soil in all horizons, in the unsheltered as well as in sheltered plots was sand. The only difference, however, appeared in the A horizon in the sheltered plots. Though the texture of soil of these horizons were not analysed separately, they were found to be sandy loam, because they formed a cast when worked between finger and thumb in the field.

Clay particles had the highest percentage (2.9) in the 5 cm deep layers of highly sheltered plot 1, containing 46 years old trees, while, in the same layer of partly sheltered and sheltered plots, which contained 50 years and 49 years old trees, the clay content is almost 14 times less than plot 1. Also in this plot the clay content decreased regularly with depth. On the other hand in plot 2 and 3 clay content fluctuated with depth. The clay content in the 5 cm and 20 cm deep layers, in two profiles of unsheltered areas is the same (0.1%). There is, however, a sudden drop in the clay content of 50 cm deep layers.

Among many factors organic matter may play a dominant factor in determinig the other edaphic factors. When the organic matter in the soil increases than the CEC value, the total nitrogen and carbon content will increase together (NAOKI et al., 1979).[42] In the Ao layer of plot 1, where organic debris remained in place and accumulated, as a result of stability provided by the shelter, organic matter content is the highest (48.3%). This resulted in a higher moisture content, porosity, maximum water holding capacity and CEC in plot 1 in comparison with plots 2 and 3. Whereas below the Ao layer (both in unsheltered and sheltered plots) the values of organic matter are very low (Table 3). As a result the values for porosity, maximum water holding capacity, CEC, carbon and nitrogen did not increase significantly and were more or less the same. The value of bulk density increased with decrease in the value of organic matter.

Carbon and nitrogen content are also consistantly highest in all the sheltered plots, though only at the surface. This drastically declined with depth both in unsheltered and sheltered plots. Small amounts of soil moisture, in the surface layers of unsheltered plots, might have been a cause of soil instability, because dry sand particles are easily removed by strong winds. Another cause of instability is the lack of shelter. On the other hand, high moisture content in the surface layers of sheltered plots resulted in the stability of the soil.

The soils in all plots are weakly acidic. But the acidity, as was expected, is not higher in Ao layers. This might be due to the fact that: in these layers the full decomposition of organic matter is yet to take place. The acidity, however, increased in the 5 cm layers which are mixed with the A horizons, the zone of intense organic activity. This does not vary considerably with depth in sheltered plots. In the unsheltered plots, the Ao, surface and 5 cm deep layers are slightly less acidic than the 20 cm and 50 cm deep layers.

Increase in exchangeable cations with depth, which indicates leaching of inorganic cations from upper soils (DAVID and IVAN, 1985),[9] is not visible in any plot. The contents of Ca, Mg and Na are the highest in Ao layer in plot 1. While, that of K showed the highest value in plot 3. All values decreased with depth. The higher level of exchangeable Ca in the two unsheltered plots, near the sea, could be probably due to the influence of carbonate from shell fragments.

The most important color effects on the development of edaphic factors is the darkening of the surface soil layers, due to the accumulation of organic matter. Color of the surface layers in all plots inside the forest are lower in value (Mansell color system) than the underlying horizons.

2. Plant factor

It has already been stated in section 1 of Chapter I, that forest trees provide a degree of mature sheltering for the ground surface which influences the development of edaphic factors. The degree of mature sheltering also affects some characteristics of trees in plantations, growing in areas of strong wind. In this part factors such as, the tree stem deviation from straight position, the tree heights and the formation of compression wood, as affected by the degree of sheltering, is discussed.

Where environmental conditions are not severe, trees grow and attain a height in direct proportion to their age. But as can be seen in Fig. 9, in Sunasaka

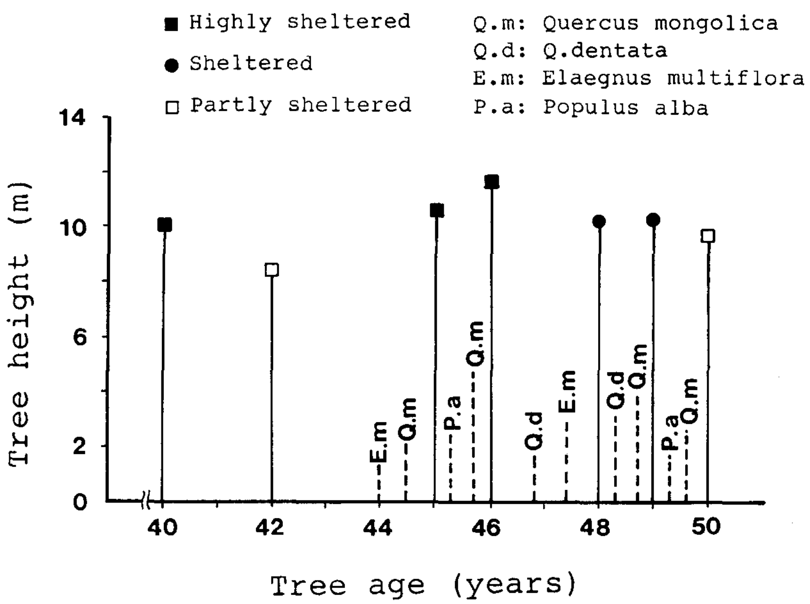


Fig. 9. Average tree height as affected by the degree of sheltering in Sunasaka

The broken lines show the height of dominant understory vegetation.

seaside forest where severe environmental conditions prevail, 46 years old trees in plot 1 (highly sheltered) and 49 years old trees in plot 2 (sheltered) are taller than 50 years old trees in plot 3 (partly sheltered). A similar trend is also visible among the trees outside the transect belt. The reason for this difference of height of trees in these plots is the degree of their exposure to the direct wind action. In other words, the degree of sheltering provided for them within the stand. Trees in plot 1 are highly sheltered and, though they are four years younger than the trees in partly exposed plot, their average height is 2.0 m more than the average height of those in the other plot.

Trees growing in those parts of the stand in Sunasaka, which are directly exposed to wind action, have the highest degree of stem deviation from the straight position. These are highly deformed. But the deformation decreases as the degree of sheltering increases. As it can be seen in Table 4, the degree of stem deviation of trees from straight position, in partly sheltered plot, is 4.5 times larger in comparison to deviation in highly sheltered plot 1, and 2.5 times in comparison to deviation in sheltered plot 2.

Table 4. Effects of shelter on minimizing wind action damage as expressed by the degree of stem deviation from straight positition

No. of plots	Number of trees in each plot	Number of most deformed trees investigated	Stem deviation from straight position (degrees)	
			Range	Average
1	22	10	2– 7	4.8
2	21	10	6–11	8.5
3	23	10	18–37	22.0
4	24	10	17–13	29.0

Compression wood which is described as an abnormal type of wood, developes typically on the underside of inclined or crooked stems and branches of coniferous trees. Together with the analogous tension wood of broad leaved trees, it is also frequently termed reaction wood, because its formation is apparently a response to unilateral gravitational stimulus. The compression wood has a reddish brown color when fresh. It occurs usually in the wide and more solid appearing annual rings. KIENHOLZ (1932) mentioned that it loses this color upon drying unless treated with vaseline or fat. It regains its color upon soaking in water.[31]

Though factors such as snow accumulation, injury, uneven lighting, spacing and release from competition are thought to be the causes for the formation of compression wood, the effects of wind are mentioned most frequently by several workers (KIENHOLZ, 1932; STEPHEN and MATTI, 1954; LOW, 1964).[33] Compression wood may develop on the leeside as a result of their stems becoming inclined. The systematic influence of prevailing wind is especially responsible for the initial development of stem inclination and the consequent compression wood formation.

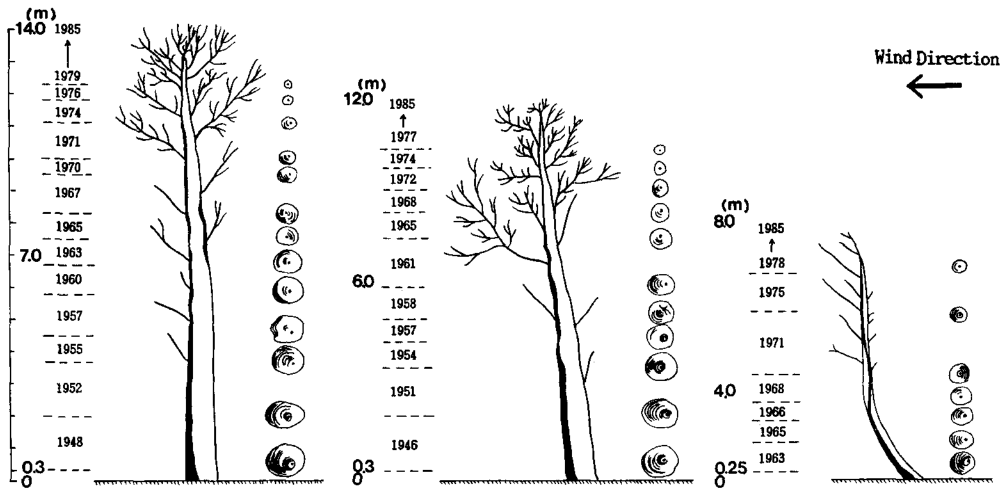


Fig. 10. Location of compression wood in stems of Japanese black pine trees (from left to right) in highly sheltered, sheltered and partly sheltered plots in Sunaska.

In Sunasaka, where topography is flat to slightly undulating and where strong wind prevail for five months in a year the formation of compression wood could be as a result of the influence of systematically prevailing wind.

Here, starting from the 30.0 cm height of the trees above the ground, samples have been taken from curved as well as straight sections of the stems for compression wood investigation (Fig. 10).

The location of compression wood in stems of investigated trees are more or less similar : it has formed in the leeside in the stems of all trees. Above certain heights (2.0 m in the tree from partly sheltered plot and 7.0 m in the trees from sheltered and highly sheltered plots). However, the compression wood has also formed in the windward sides of the trees. This indicates the fact that following the inclination the trees might have bent upwards with formation of compression wood on its lower side and eventually a stage might have been reached where upper part of the stem is in a vertical position again.

In other words it can be said that ; continued upward movement by the lower portion might then had caused the upper portion to incline past the vertical. Thus producing over-correction of the initial inclination and a change in compression wood formation to the opposite side of the stem. Subsequent correction movements resulting from this new inclination might have caused the upper part of the stem to become inclined again in the original direction. It seems likely that the irregular alternation of compression wood zones, found in the upper parts of investigated trees in Sunasaka, are due to this phenomenon. Low (1964) called it "repeated slight over-correction" and speculated that phototrophic responses of the tree crowns, due to competition for light, may also have been involved.[33] But in Sunasaka, where the forest is not very thick and a heavy thinning has not been carried out, the possibility of phototrophic responses for over-correction can be ruled-out.

In general the formation of compression wood in investigated trees, in Sunasaka, showed the following patterns : a strong formation in the lower and middle parts of stems for the first few years and then a slight formation of compression wood which continued for many years until 1985 (the year when the samples for investigation were cut). In the upper parts of the tree stems, on the other hand, only a slight formation of compression wood have taken place in one or two years and in the remaining years normal wood prevail. This pattern of the formation of compression wood has been found in all investigated trees, irrespective of their location in the plantation. This indicates that the formation of compression wood had taken place in the early stages of forest establishment, when newly planted young trees were exposed to strong wind. Because in Sunasaka, at that stage adequate sheltering against wind was not provided for the newly planted seedlings.

3. Snow distribution

Another indicator of the effects of shelter is the extremely low level of disturbance, such as erosion of the surface of sand, in sheltered dunes. Surface of the sand dune is eroded when the dune is bare, the surface of soil is dry and the wind velocity exceeds certain limits. In general "the threshold wind velocity (for erosion of) heterogeneous virgin material is about 23.0 km/h and an average figure of 16.0 km/h may be more common for graded dune sand" (JENSEN, 1976 ; GHOSE, 1985).[13,22,28] In Sunasaka though the amount of sand drift has not been measured directly, deposition of sand on different layers of snow — as an indirect evidence of sand surface erosion — has been investigated in February, 1985. As it was mentioned before, in the unforested dunes of Sunasaka, the over ground parts of the natural vegetation, such as *Elymus mollis* (Hamaninniku) and *Carex kobomugi* (kobomugi) die during the winter and the surface becomes completely bare. Moreover, in this area very strong wind blows from November to February. This strong wind removes the fallen snow and prevents its deposition, which otherwise will cover the bare sand. This occurs, especially, in strips close to the sea. The combination of the absence of vegetation and the snow cover in winter, in Sunasaka, thus causes the erosion of sand surface by strong wind. Since the erosion of surface occurs continuously through-out the winter (November-February) and at the same time snow also falls frequently, the eroded material are transported by wind and are deposited on the surface of freshly fallen snow. So when a snow profile is dug in sand dunes of Sunasaka, before the snow melts, layers of sand deposited on each layer of snow are observed clearly.

This phenomenon was investigated in a total of 9 snow profiles by digging show pits on the front dune, middle and natural dunes, as well as inside the plantation (Fig. 11). As it can be seen in the Figure, layers of sand, though very thin, were deposited in snow profiles of only unsheltered dunes.

Starting from the seashore an area of about 50 m wide and 1,100 m long has been either not covered by snow or had a thin layer of snow. Ridges of front and middle dunes were also not covered with snow and were bare. The

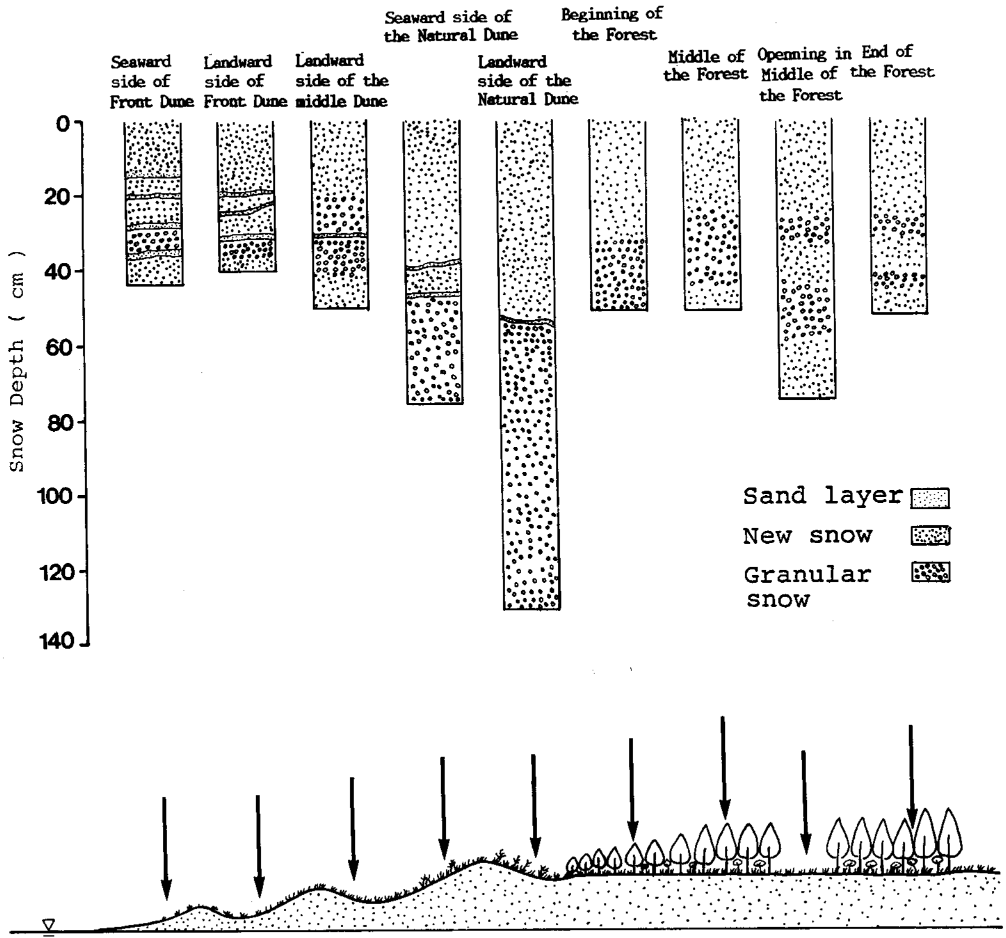


Fig. 11. Snow profiles showing deposition of sand layers on the to pof snow layers in Sunasaka.

ridge of natural dune had a thin layer of snow and some debris of natural vegetation on the surface. It was thought that the sand particles might have been eroded from the areas, not covered by snow and deposited on the nearby areas containing patches of snow cover.

The depth of snow as can be seen in the Figure, varied on the unsheltered sand dunes, from the 50 cm near the sea to around 132 cm in the area between the inland side of the natural dune and the beginning of the forest. The effects by the crowns of the trees, such as, reduction of wind velocity might be one of the causes of higher snow accumulation in this area.

The first snow pit was dug just in front of the bare areas on the seaward side of the fornt dune. Four layers of sand ranging in thickness from 0.4 cm to 0.7 cm were formed in different depth of this pit. The second pit was in the opposite side of the first pit — in the landward side of the fornt dune. The ridge of the front dune, which was exposed to strong wind, was devoid of snow cover and the three sand layers — ranging from 0.4 cm to 1.0 cm in thickness — found deposited in the second pit, had probably come from the ridge and the bare area mentioned earlier. Only one sand layer, 0.4 cm thick, was formed in the third pit. While, in the fourth pit two layers each 0.4 cm thick were formed. The last and a single sand layer of 0.2 cm thickness was observed in the pit five. In pits six, seven, eight and nine, under the plantation, no sand layer was deposited and only alternating layers of fine and coarse granular snow were formed.

Both the number of sand layers (from 4.0 cm in the first pit to only 1.0 cm in the fifth pit) and their thicknesss (from 1.0 cm in first pit to 0.2 cm in the last pit) depends, it seems, on the extent of the bare areas around the investigated pits and the distance of these pits from the sea — from where strong wind blows to inland areas.

The snow depth in sheltered areas under the plantation, along the belt transect as well as outside it, remained relatively stable — from 51 cm to 53 cm deep. Only under the forest openings the snow depth had increased and ranged between 75 cm and 82 cm. This could be due to the fact that "forest tend to accumulate snow in the openings between trees because of the mechanical effects of the crown in throwing snow away from the base of the trees and because surrounding tree crowns reduce wind velocity over the opening. Also in evergreen forest the deepest snow is found in small openings between trees" [HOOVER (1962)].[21]

Inside the forest the snow depth, however, was not affected by the degree of sheltering, as already been stated the snow depth was uniform in all investigated plots. The density and water equivalent of snow of some investigated pits were determined and are shown in Fig. 12. Both snow density and water equivalent as can be seen in the Figure, had varied with snow depth.

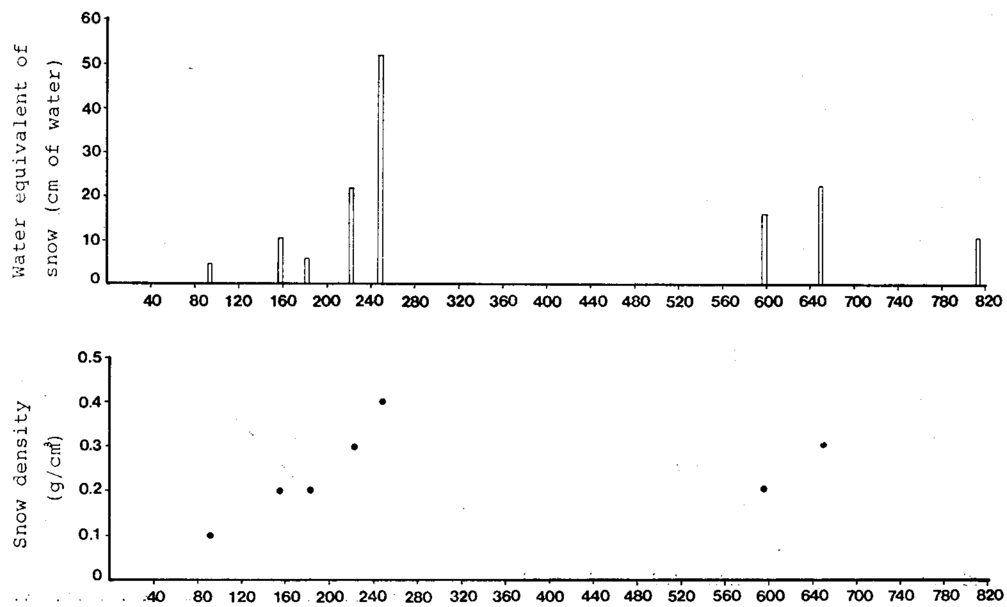


Fig. 12. Water equivalent (above) and snow density (below) in the open (0–270 m) and under the plantation in Sunasaka.

IV. Dry sand layer and its effects

1. Mechanism of formation of dry sand layer

Sheltered sand dunes always contain a layer of organic matter on the surface (Ao layer) which prevents the direct contact of solar radiation with the ground, thus a dry sand layer, on the surface of sand is not formed in such environments. Where the sand dunes are very sparsely vegetated or are completely bare and unsheltered, the above mentioned layer of organic matter is not formed. Under such conditions two thermal properties of sand particles, namely, their thermal conductivity and heat capacity causes the formation of a dry layer on the surfaces of the dunes.

Thermal conductivity is the rate at which heat will pass through the sand. Quartz, which is the main component of sand, is a relatively poor conductor of heat. About 40% of the sand volume consists of pore spaces filled with air which has a two-grade lower thermal conductivity than quartz. These together confer on dune sands a relatively poor thermal conductivity (TSOAR and ZOHAR, 1985).[47]

The sand's heat capacity measures its ability to store heat. It is defined as the amount of heat necessary to raise the temperature of unit volume by 1.0 degree centigrade. The heat capacity of dry sand is relatively moderate. It is much higher than that of air but lower than that of water (TSOAR and ZOHAR, 1985).

Due to the poor thermal conductivity of sand, transmission of heat into the lower layers of the ground is very slow. Heat is accumulated in a thin layer on the surface of the sand and causes evaporation of the soil moisture from this layer and resulting in a thin dry layer of sand on the surface. Because of large differences in soil moisture ratio between the dry and wet sand layers below it, the dry sand layer is clearly visible and distinguishable with the naked eye.

2. Effects of dry sand layer on the climate near the ground

Due to the lower thermal conductivity, dry sand layer stores a great amount of heat which affects the air temperature to a certain height above it. This happens, especially, in the hottest period of the day. During this period the temperature on the surface of dry sand layer rises to more than 60 degrees centigrade, in semi-arid and arid areas (DHIR, 1985[10]; TSOAR, 1985),[47] and to around 55 degrees centigrade

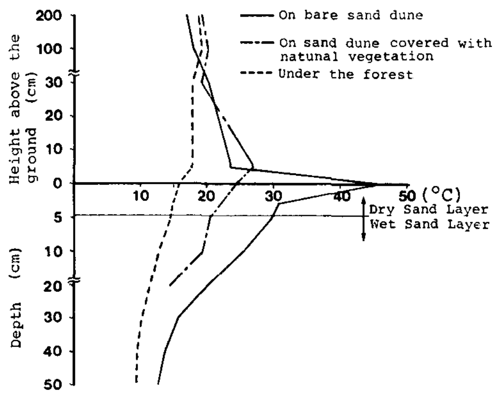


Fig. 13. Air and soil temperature profiles in Sunasaka. (May 28, 1986).

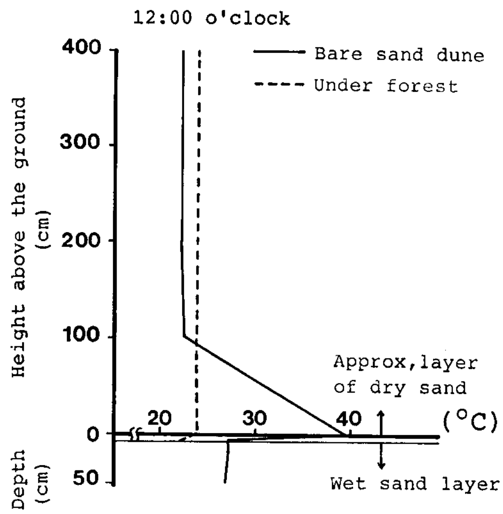


Fig. 14. Air and soil temperature profiles in Sunasaka. (July 22, 1985).

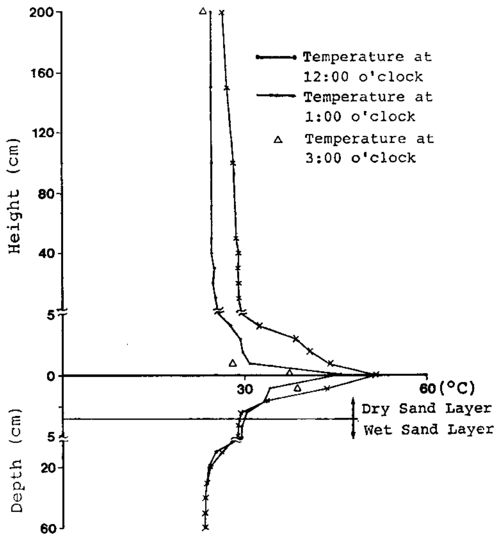


Fig. 15. Air and soil temperature profiles in Ishikari. (August 31, 1986).

in humid coastal sand dunes (measured by the author). But since the heat capacity of dune sand is not very high, in the late afternoons and in the mornings the temperature of this layer drops considerably.

Figures 13, 14 and 15 show the influence of dry sand layer on temperature which is prominant up to the height of 5.0 cm from the ground surface. This influence gradually decreases with the height and then a steady temperature prevails.

The data for Fig. 13 has been collected on a cloudless, sunny and calm day (wind speed 1.6 m/sec at the time of the measurement) at the end of May — beginning of growing season in Hokkaido. The measurements in Fig. 14, has been taken at the end of July, which is the hottest month of the year in Hokkaido, on a calm (wind speed 1.2 m/sec) but cloudy day. The maximum soil temperature at the surface of dry sand in Fig. 14 is 39.8 degrees centigrade, while, in Fig. 13, the temperature though expected to be lower, due to the lower air temperature in the month of May in Hokkaido, it rose to 46.5 degrees centigrade — a difference of 7.0 degrees. It, therefore, can be said that the rise of temperature at the surface of dry sand could be also influenced by factors other than the thermal properties of dune sand — the cloudness being one of these factors. Because the cloud absorbs most of the thermal radiation, before it reaches the ground surface.

In Fig. 13, the solid, broken and dotted lines represent the temperature on the surface of the land and the air temperature above it, i) on bare sand, ii) on sand dune partly covered by bush type natural vegetation and iii) on vegetated sand dune, in Sunasaka. The maximum temperature, measured between 2 : 10 p.m. and 3 : 50 p.m. simultaneously on the bare sand, inside the plantation and on the site with natural vegetation, were 46.0, 24.5, and 16.0 degrees centigrade, respectively.

The sites where the measurements have been carried out are close (approx. 100 m apart) and of the similar soil texture. Therefore, a difference of i) 21.5 degrees centigrade between the soil surface temperature of partly covered and afforested dunes, ii) 8.5 degrees centigrade between partly covered and bare dune and about 30.0 degrees centigrade between bare sand and forested dune, are attributed mainly to the presence and absence of shelter.

The facts in Fig. 13, is also confirmed by those in Fig. 14. The measurements in this Figure have been taken in the same place (Sunasaka) as Figure 13. As it can be seen from Figure 14, the difference of land surface temperature between the bare sand (soild lines) and the forested dunes (broken line) at 12 : 00 o'clock is 15.8 degrees centigrade. This difference is due to the effects of sheltering under the plantation, which deposited organic debris on the surface of the soil. The latter prevented the formation of dry sand and, therefore, caused the lowering of surface temperature. On the surface of bare sand dune, on the other hand, the presence of dry sand layer resulted in high surface temperature.

Fig. 15 shows the air and soil temperature of a bare sand dune, measured at 12 : 00 o'clock, 1 : 00 o'clock and 3 : 00 o'clock, in the Ishikari sand dunes, on a partly cloudy but windless day. As can be observed, the temperature at 12 : 00 o'clock on the surface of dry sand layer rose to 46.0 degrees. At the height of one centimeter it is 30.8 degrees — a difference of 16.0 degrees with the surface temperature. While, at the height of 5.0 cm, it becomes more or less equal to the air temperature above. At 1 : 00 o'clock the temperature of the surface of dry sand layer rose to 51.4 degrees and at 1.0 cm height it is 44.0 degrees centigrade. This gradually decreases to the level of air temperature at the height of 5.0 cm. At 3 : 00 o'clock, however, the temperature of the surface rose only to 36.5 degrees a difference of 10.3 degrees and 14.9 degrees with the similar measurements at 12 : 00 o'clock and 1 : 00 o'clock, respectively. On the other hand, the air temperatures at 12 : 00 o'clock, 1 : 00 o'clock and 3 : 00 o'clock, above the dry sand layer, at a height of 2.0 m, do not show a significant difference.

The measurements for Fig. 16, have been carried out in the month of July, in a calm and cloudless day, on fenced (fence height above the ground 1.8 m) but unvegetated dune in Ishikari. The temperatures of the surface of sand outside the fence, the side not shadowed by the fence, the side shadowed by the fence and the area containing a sparse cover of sand dune vegetation (outside the fence)

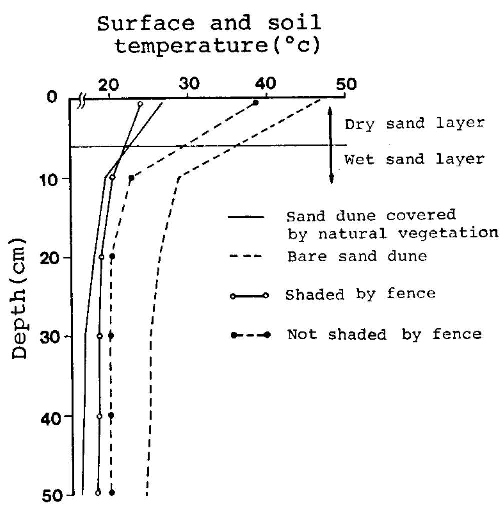


Fig. 16. Vertical gradient of soil temperature in Ishikari. (July 23, 1984).

have been 47.0, 39.0, 28.0 and 24.0 degrees, respectively. This shows that the shadow provided by the fence can reduce the temperature of the surface of dry sand layer to almost half. It, therefore, can be said that in the first stages of afforestation of bare sand dunes, for the prevention of heat injury to the stems of young seedlings, providing shade should be taken into consideration. Thus summarizing the findings as shown in Figures 13, 14, 15 and 16, it can be said that the temperature is very high on the surface of bare sand up to a height of about 5.0 cm above it. Over this height the temperature becomes lower and at the height of 2.0 m, the effect of dry sand layer on temperature vanished completely. In the forested sand dune, the dry sand layer do not form and, therefore, fluctuations of surface temperature also does not exist. Shade and cloudness are other factors, which reduce the high temperature of the surface of dry sand layer. It, therefore, is recommended that the direct sowing of tree and grass seeds on sand dunes should be avoided. Because the high temperature of surface might seriously damage the young emberyos. JENSEN (1976) reported that such damage to seeds and plants can occur even in temperate regions.[27] Also the provision of shade and shelter should be taken into consideration for newly planted seedlings, when planning the revegetation of sandy areas. The planting of trees in severe environments should be carried out, preferably, in cloudy days.

Another example of the influence of shelter on surface temperature can be observed in Fig. 17. It shows an hourly, one day observation of soil temperature, on the surface of a 17 years old man-made forest of Japanese larch, and 20.0 m away, on the surface of a bare land. The surface of ground under the forest is covered mostly by undecomposed needle leaves and some twigs. The soil texture of bare land is clay loam. As it can be seen in the Figure, the temperature on the surface of bare land at 12 : 00 o'clock rose to 45.5 degrees and at 2 : 00 o'clock

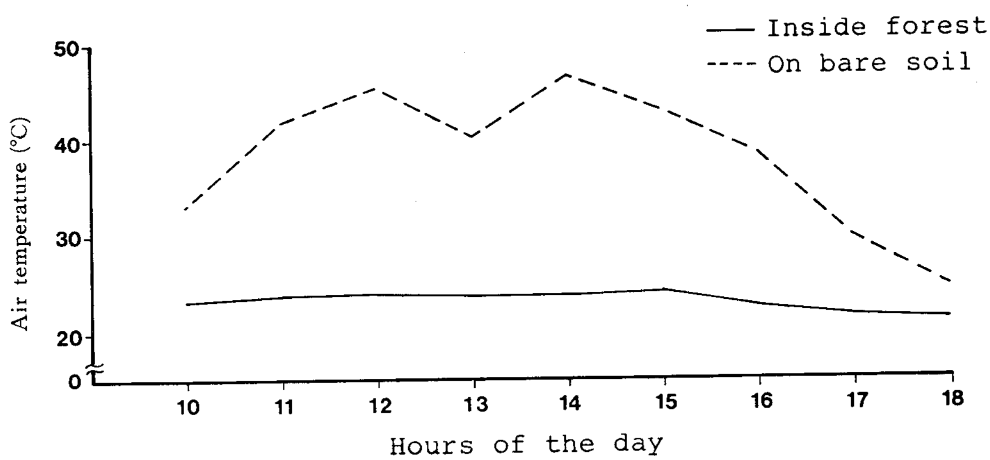


Fig. 17. Hourly temperature of the surface inside a 17 years old man-made plantation of *Larix leptolepis* and 20 meters away outside the plantation on bare clay loam soil. (August 28, 1984).

to 46.7 degrees. The fall of temperature to 40.0 degrees at 1 : 00 o'clock is due to a slight wind, which started from few minutes before 1 : 00 o'clock and stopped at around 1 : 30.

Due to the effects of shelter, however, the temperature of surface inside the forest has been steady and stable, from the beginning to the end, during the period of measurement.

Also the soil temperature, which plays an important role in plant root expansion, is affected by the formation of dry sand layer. Though the dry sand layer, as mentioned before, is not thicker than a few centimeters, the soil temperature in different parts of this layer has been found to be fluctuating greatly. In Sunasaka e. g., while a temperature of 46.0 degrees has been recorded on the surface of dry sand layer (thickness 3.5 cm), the temperature in the middle of the layer (1.5 cm deep) has been found to be 34.1 degrees centigrade, and the temperature of interface between the dry and wet sand layers has been 30.3 degrees centigrade. This shows a difference of 12.0 degrees and 16.0 degrees between the temperatures of the surface and the middle of the dry sand layer, and between the temperature of the surface and that of the interface between dry and wet sand layers, respectively.

It can be observed from the lower parts of the Figures 13, 14, 15 and 16, the soil temperature of the areas below dry sand layer, shows the same tendency as the air temperature above it. In all these cases until the depth of 20.0 cm the soil temperature is slightly higher than the air temperature of 20.0 cm above the dry sand layer. From the depth of 20.0 cm, however, the soil temperature does not fluctuate ; it becomes steady and is close to the air temperature of 20.0 cm above the ground.

Also, the difference of soil temperature of sheltered and unsheltered areas which are considerable until the depth of 20.0 cm, either disappeares or becomes insignificant in the lower depth. The difference of soil temperature, between sheltered and unsheltered sandy environments, however, is significant only in areas close to the surface of land. Here, due to the influence of dry sand layer in unsheltered areas, the soil temperature fluctuates, while in sheltered areas it is steady.

3. Effects of dry sand layer on the soil moisture regime

The high temperature caused by the formation of dry sand layer immediately above it, as discussed in sections 1 and 2, might be a disadvantage of this layer for afforestation of sand dune environments. Because it might cause injury to young and newly planted seedlings. In contrast to this, however, the effects of dry sand layer on the soil moisture in the layers below it is a great advantage for revegetation of sand dunes. Figures 18, 19 and 20, show the dry sand layer and its effects on soil moisture of the lower layers, in the months of May and July, in Sunasaka and Ishikari bare dunes, sparsely vegetated dunes and in dunes planted with Japanese black pine. The thickness of dry sand layer, formed on the surface of bare sand, ranged from 3.5 cm to 6.0 cm. The moisture content of the upper

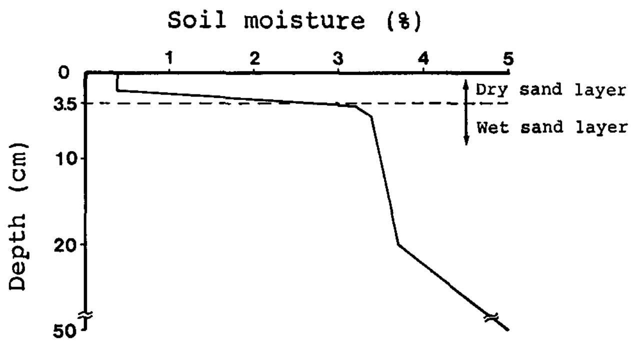


Fig. 18. Soil moisture profile of a bare site in seaward side of front dune in Sunasaka. (May 28, 1986).

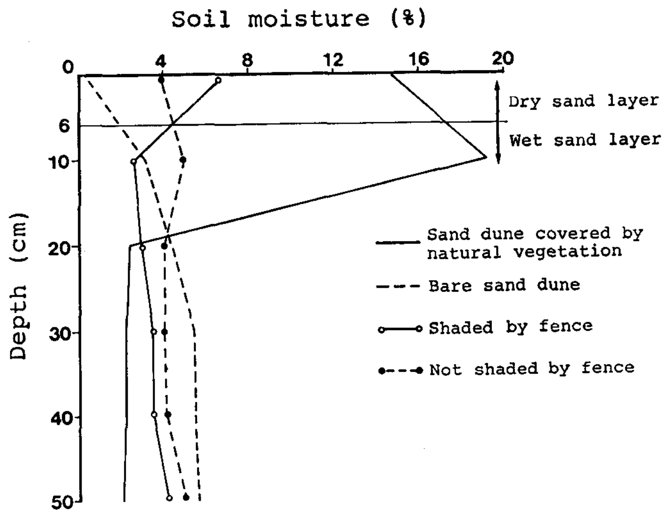


Fig. 19. Vertical gradient of soil moisture in Ishikari. (July 23, 1984).

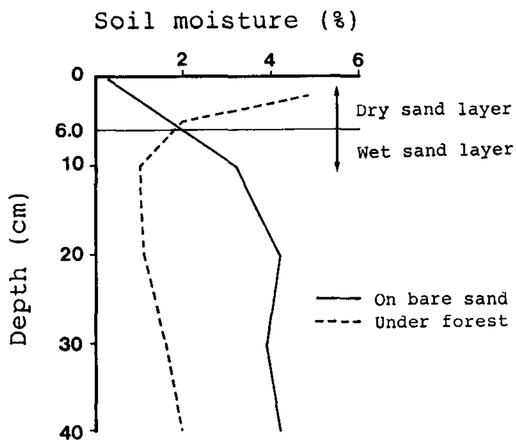


Fig. 20. Vertical gradient of soil moisture in Sunasaka. (July 23, 1985).

parts of this layer has been very low — less than 1.0%. As observed in Fig. 18, the soil moisture contents of upper and middle parts of dry sand layer are the same. The soil moisture content in the lower parts of this layer (interface between dry layer and wet layer), however, ranged from 2.0% to 2.7%.

Fig. 19 shows that the soil moisture content of a sand dune, containing natural vegetation, up to the depth of 20.0 cm is 2.0, 3.7 and 49.0 times higher in comparison to the soil moisture of the same depth, in areas not shaded by fence, shaded by fence and bare sand, respectively. The soil moisture contents of the area under natural vegetation in the depth lower than 20.0 cm, however, is 2.0 times lower than bare, shaded and partly shaded areas.

Fig. 20 shows the same tendency of low soil moisture contents in the upper layers of bare sand dune and a high moisture content in the corresponding layers under plantation, but a reverse situation in the lower depth. JENSEN (1976) also reported the same tendancy.[27] In bare sand dunes, this could be due to the evaporation-suppression effects of dry sand layer. In vegetated sand dunes, on the other hand, it could probably be due to the absorption of water by plant roots for physiological activities. Moreover, in the sand dunes planted with the needle leaved trees, in addition to the effects of tree roots, this could be due to the high water absorption and water infiltration prevention functions of decomposed humus layer under forest. In Sunasaka, e. g., most of the water has been absorbed by the decomposed part of Ao layers. The soil moisture content of these layers in highly sheltered plot is 123.0%, in sheltered plot 54.2% and in partly sheltered plot 57.0%. While the soil moisture contents of 50.0 cm deep layers, under the same plots are 2.7%, 2.0% and 2.6%, respectively. The soil mosture content of 50.0 cm deep layers in unsheltered plot, on the other hand, is 2.7% — equal to the amount of soil moisture in the same depth, in highly sheltered plot. It is even slightly higher than the soil moisturte content of 50.0 cm deep layers in sheltered and partly sheltered plots.

In order to clarify the evaporation suppression effects of dry sand layer, on soil moisture content of the layers below it, the following experiment has been carried out in a bare sand dune in Ishikari: Two pits; pit No. 1 in the ridge of the dune and pit No. 2 in the slight depression of the same dune were dug. Both pits were 60.0 cm deep. The soil moisture contents of dry sand layers and the layers below it were measured in both pits. Then a few centimeters from the pits two new sites were chosen; No. 3 close to the pit No. 1 and No. 4 close to the pit No. 2. The dry sand layers of the new sites were removed one time, in three hours from site No. 3 and two times in three hours from site No. 4.

Ten minutes after the removal of the existed dry sand layer, new dry sand layers were formed; measuring 0.4 cm in thickness in site No. 3 and 0.3 cm in thickness in site No. 4. At the end of three hours (from 11 : 30 a.m. to 2 : 30 a.m.) pits were dug in the sites No. 3 and No. 4. Soil samples for moisture measurements were taken from the same depth of these pits, as were taken from pit No. 1 and No. 2 which were still covered with dry sand layers. The results of this

Table 5. Soil moisture changes as affected by one time removal of dry sand layer in a bare sand dune

Depth below dry sand layer (cm)	Dry sand layer not removed	Dry sand layer removed one time in three hours	Difference
	Soil moisture (percent of dry weight)		
Dry sand layer	0.4	0.9	−0.5
5	4.4	3.2	1.2
10	5.0	4.1	0.9
20	5.0	5.0	0.0
30	5.5	5.5	0.0
40	6.0	6.0	0.0
50	6.0	6.0	0.0
60	6.0	6.0	0.0

Table 6. Soil moisture changes as affected by two times removal of dry sand layer in a slight depression of a bare sand dune

Depth below dry sand layer (cm)	Dry sand layer not removed	Dry sand layer removed two times in three hours	Difference
	Soil moisture (percent of dry weight)		
Dry sand layer	0.5	0.9	−0.4
5	4.2	3.1	1.1
10	5.0	4.0	1.0
15	5.0	5.0	0.0
20	6.0	6.0	0.0
30	6.0	6.0	0.0
40	6.0	6.0	0.0
50	6.0	6.0	0.0
60	6.0	6.0	0.0

experiment are shown in Tables 5 and 6.

As can be seen in the Tables, the moisture content of newly formed dry sand layer is twice of the previously existed dry sand layer. This is natural, because the evaporation of soil moisture from newly formed dry sand layer may take more time. Due to the removal of the existed dry sand layer, the soil moisture contents of the layers below it has been affected only to a depth of 10.0 cm in sites No. 3 and No. 4. Below this depth the removal of dry sand layer could not influence the soil moisture contents. Also the one and two times removal of dry sand layer, do not show a significant effect on changes of soil moisture below.

The results of the experiment indicates that the dry sand layer is playing the role of evaporation-suppressor and soil mulch and conserves the soil moisture in the layers below it. Its removal might enhance evaporation and the loss of soil moisture, especially from deeper layers. The continuous removal of this layer, as

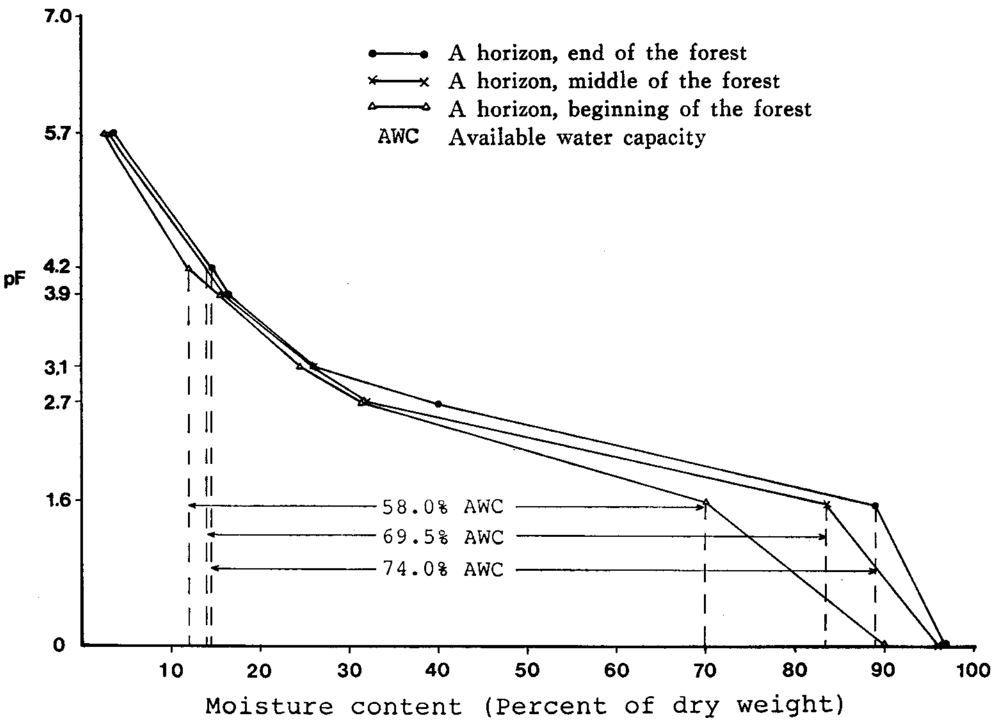


Fig. 21 a. Soil moisture retention characteristics of A horizons in Sunaska.

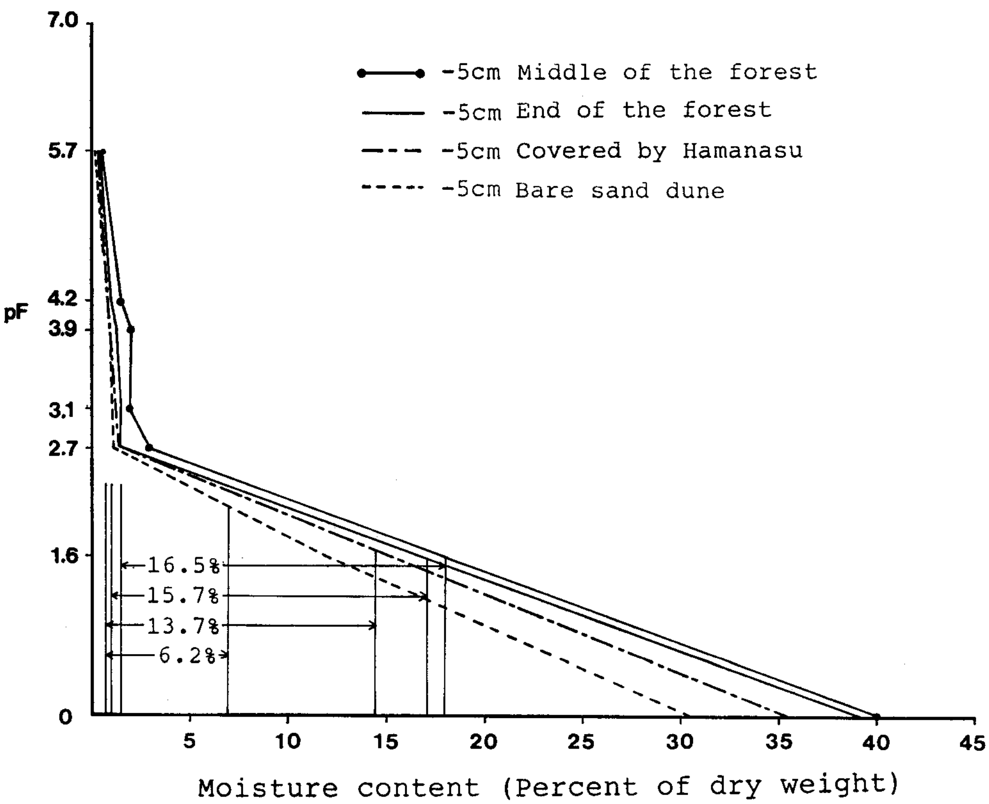


Fig. 21 b. Soil moisture retention characteristics of 5 cm deep layers in Sunasaka.

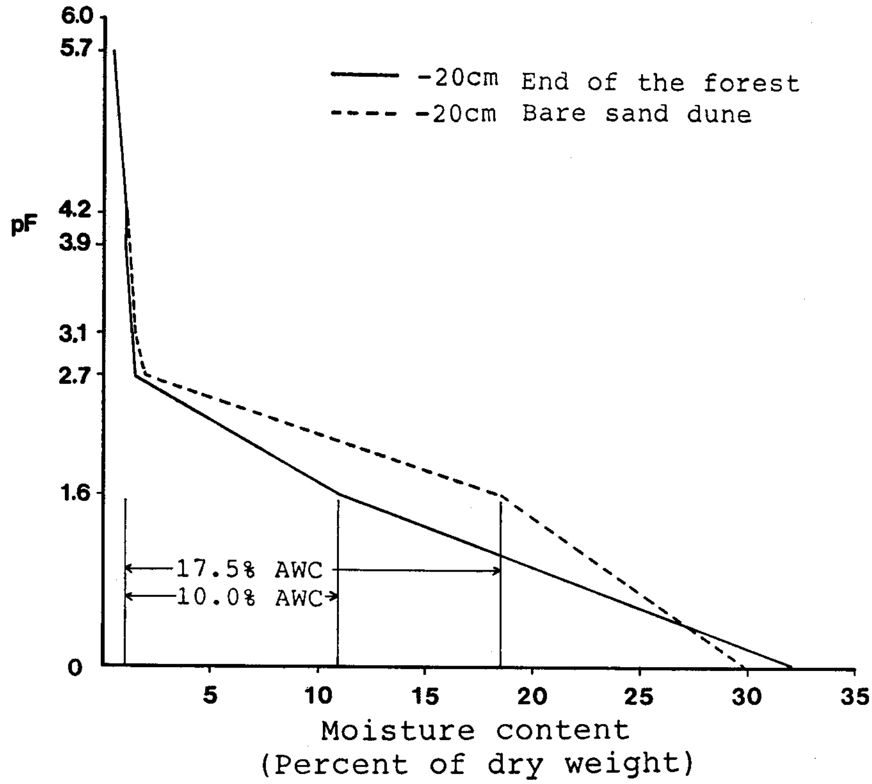


Fig. 21 c. Soil moisture retention characteristics of 20 cm deep layers in Sunasaka.

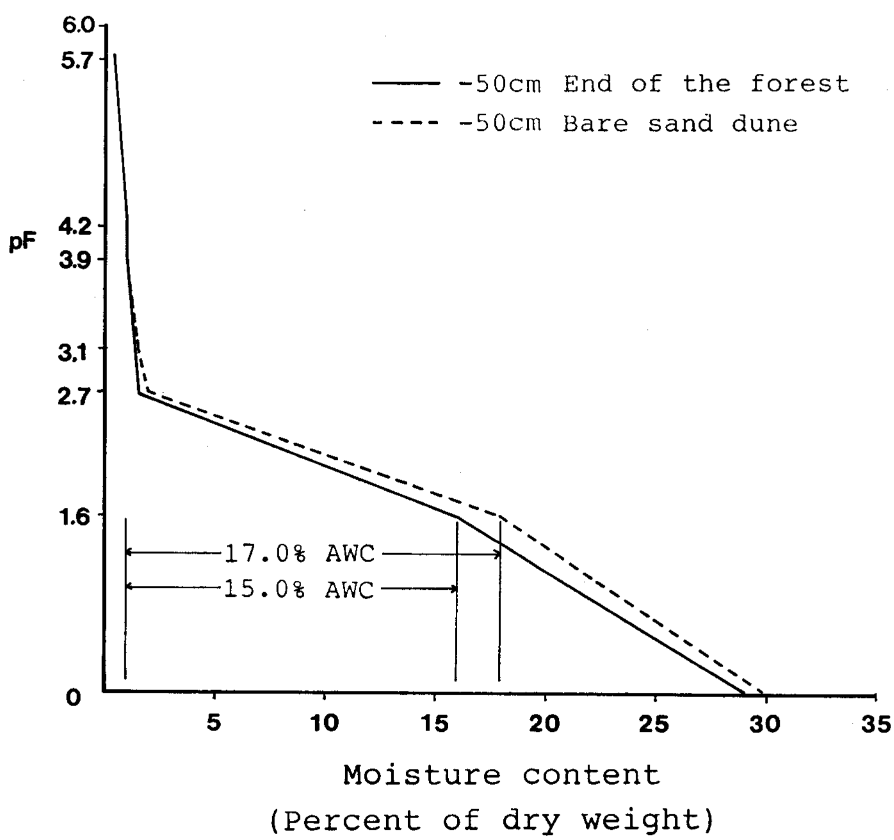


Fig. 21 d. Soil moisture retention characteristics of 50 cm deep layers in Sunasaka.

may occur when strong wind blows for a long time, may affect the soil moisture, in the layers deeper than 10.0 cm, too. It, therefore, can be argued that the erosion of the surface of sand, which removes the dry sand layers, as a result of which the soil moisture in deeper layers are lost, is the limiting factor for revegetation of sandy areas — not the lack of soil moisture as widely believed.

The water retention and available water capacity of different soil layers of Sunasaka have been measured. It is observed that these factors are higher in A horizons than the layers immediatly below it (Fig. 21 a, b, c, d). As can be seen in the Figures, the difference in soil moisture retention, between A horizons of different parts of plantation, is remarkable only in the low pF (0 to 2.7) range. The same is found to be true with soils of 5.0 cm, 20.0 cm and 50.0 cm deep layers, under the forest as well as in bare sand dunes. In the zone of high pF (3.2 to 5.7), however, these differences become very small and insignificant. A part of this figure shows that the available water capacity of A horizons is the highest in soils of highly sheltered plots, in comparison to that of sheltered and partly sheltered plots. This fact once again confirms the effects of the degree of sheltering, on the formation of A horizon and conservation of soil moisture in that horizon. The available water capacity of 5.0 cm deep layers under the forest and the natural vegetation is twice that of the same layers under the bare sand dunes. This could be due to the effects of A horizon on this layer and the high content of organic matter in 5.0 cm deep layers, under the forest. But as can be seen in parts d and c of the same Figure, the available water capacity of 20.0 cm and 50.0 cm deep layers of bare sand dune is higher than that under the forest. This confirms the finding as shown in Figures 18, 19 and 20 : the fact that the soil moisture content in deeper layers under the bare sand dunes is higher in comparison to that under forested dunes.

Soil moisture changes of sand dunes according to slope exposure and segment have also been investigated in bare sand dunes in Ishikari (Fig. 22). In this investigation soil moisture of summit and slope of north facing segment does not show much difference up to the depth of 10.0 cm. From this depth, however, the soil moisture of slope increased steadily in comparison to that of the summit. As it was expected, the soil moisture of south slope and south-facing depression, due to the exposure of this segment to radiation, is lower than the soil moisture of north-facing slope.

The soil moistures of areas other than sand dunes have been investigated inside a young, man-made forest of *Larix leptolepis* and outside it on bare ground. The same measurements had been also carried out under an old mixed natural forest of *Ulmus davidiana* and *Acer mono* and on bare soil outside it (Fig. 23). The soil texture of all these areas is clay loam. The surface of bare ground outside the young forest is plowed. While, that outside the old forest undisturbed. The root zone under the old forest continued deeper than 50.0 cm, while under the young forest there is a high concentration of roots until 35.0 cm and then only few small roots existed.

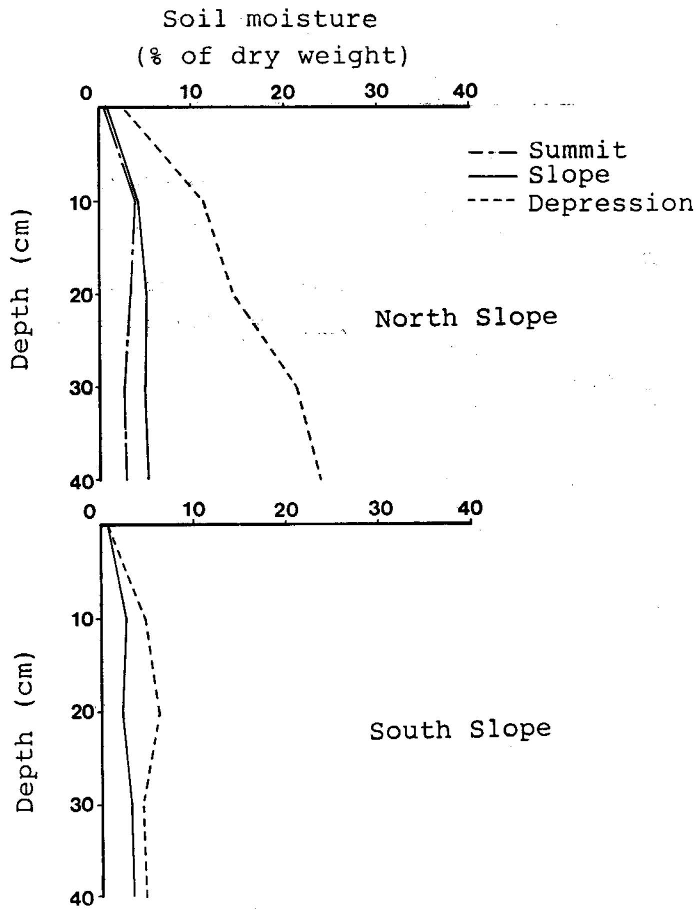


Fig. 22. Soil moisture changes according to topography in sand dunes of Ishikari. (August, 1984).

As can be seen from the Figure, until the depth of 20.0 cm there is a significant difference (more than 20.0%) between the soil moisture content under the forest and in bare land. This is mainly due to the effects of shelter, which added litter to the forest floor. In the lower depth where the influence of Ao layer diminishes, the moisture content of soil under and outside the forest does not show any significant difference. This is in contrast to moisture regime of sand dunes. Here, in deeper layers moisture content of bare dune is almost twice higher than that under the forested dunes and dunes containing natural vegetation. That is mainly due to the formation of dry sand layer on the surface of dune sands, the function of which has already been explained in detail. On clay loam soils, such mechanism does not exist. Thus, the soil moisture of lower layers under and outside forest does not show large differences.

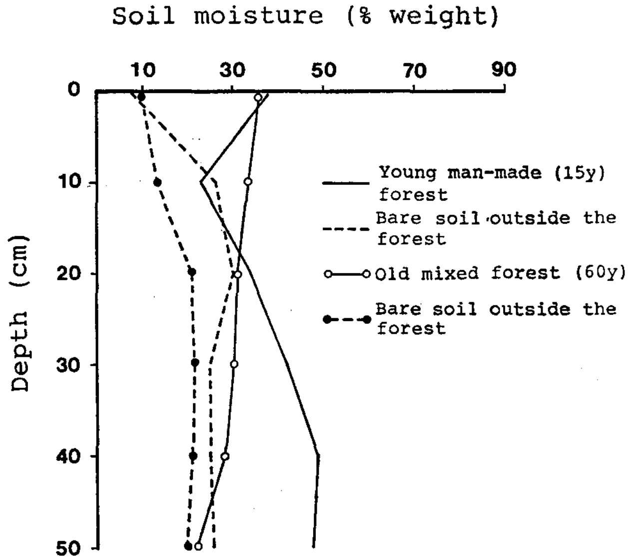


Fig. 23. Vertical gradient of soil moisture outside forests on clay loam soils and under the forests. (August, 1984).

V. Shelter establishment in devastated hillslope environments

1. Disturbance in devastated hillslopes

In Ashio, on steep valley sides, in heavily damaged areas there are bare rocks, on the foot of which numerous talus cones are formed. MACHIDA et al. (1975) have investigated one of these talus cones which were developed on a riverterrace on the left bank of the Watarase River, near copper refinery (Fig. 24).[35] It had a relative height of 54 m, a slope length of 92 m (from the apex to the base) and a general inclination of 36 degrees. They found that the dominant factors of the formation of the investigated talus cone, are the following three processes:

1) The coarse and well-sorted deposits (R type) were formed by rock-fall. The small particles of these fragments settle near the apex and coarse ones near the base of slope, with a tendency to increase in grain size towards the downslope direction. The small fragments and the fine materials, however, are later forced to move downslope by soil flow and debris flow.

2) The material composed of pebble-sized fragments (D type) which form a small-scale tongue, are deposited by dry fragment flow (soil flow).

3) And finally, the poorly sorted deposits (W type) which forms a set of small tongue and levee like elevation was supposed to be the product of debris flow under the condition of heavy rain.

Similar disturbances (rock fall, soil flow, debris flow) are occurring in most of the bare hillslopes in heavily damaged part of the Ashio mountains. When seeds

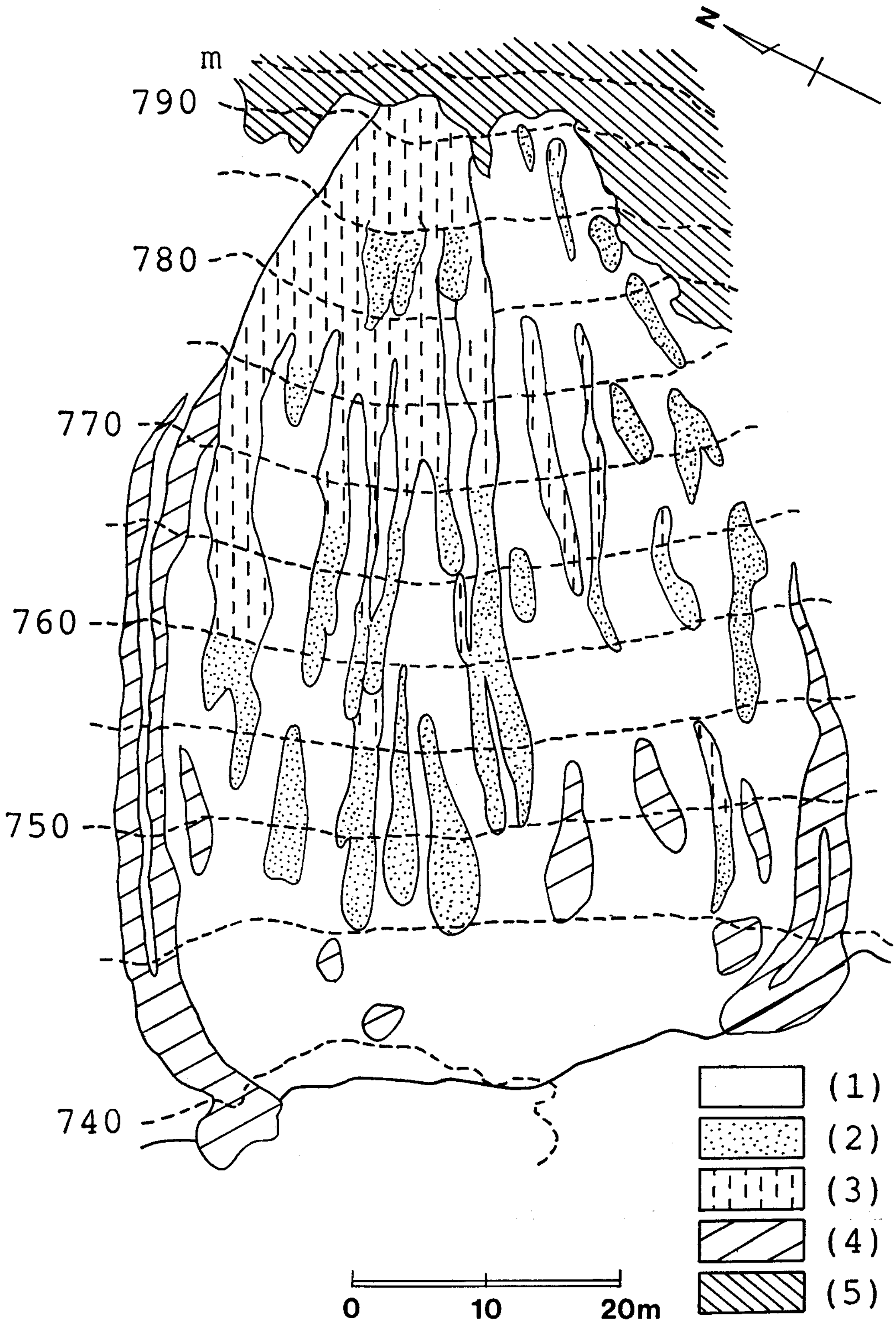


Fig. 24. Distribution of three types of deposits on the surface of a talus cone in heavily damaged hill-slopes of Ashio mountains.
(1) R type, (2) D_1 type, (3) D_2 type, (4) W type, (5) Bed rock (After MACHIDA et al., 1975).

of plants fall on such unstable surfaces, either they are displaced frequently and are damaged in the process or if remained in place and germinated, they may be destroyed by the impact of moving debris. Similarly, in such unstable hillslopes, artificially planted seedlings will be damaged by rock fall and will die consequently.

Another form of disturbance, in heavily damaged areas of Ashio mountains, is frost heaving. This occurs because in early winter ground surface is not sufficiently covered with snow and at the same time the temperature drops to below zero, resulting in the formation of ice lenses between the soil particles. When thawing, these ice lenses expand whithin the soil layer, thus forcing it upwards into a frost mound. By this process the planted seedlings are displaced and their roots are injured.

In heavily damaged area, due to the lack of vegetation cover, rills and gullies are frequently formed. As can be seen in Table 7, in an area of 1200 m^2 in a hillslope, four gullies from 7.0 m to 15.5 m wide and from 1.9 m to 5.1 m deep and a total of 22 rills were formed. This area is completely bare and the soil texture is Kanto loam (volcanic loess). This together with the concave shape of the slope, which helps concentrate runoff water, made this area susceptible to the formation of rills and gullies. In other sections of devastated areas, though rills and gullies are formed, their intensities are far lower than on Kanto loam soil. In the heavily damaged part of Ashio the above mentioned disturbances prevent the establishment of vegetation cover, by both natural invasion of plants and artificial revegetation.

Table 7. Development of rill and gully erosion on a hillside at the mouth of Matsukizawa (elev. 810 m) in the heavily damaged part of Ashio devastated mountains (plot size 1200 m^2)

Length (m)	Ave. width (m)	Ave. depth (m)	Shape of gullies	Shape of slope	Number of rills	Soil texture
70.0	15.5	5.1	V	slightly concave	22	Kanto loam
68.0	7.0	2.7				
43.0	11.0	2.8				
20.0	8.0	1.9				

Ishibashi (1981) indicated that the predominant form of distrubance in Tanakami mountains is sheet erosion.[24] He found that when the forest cover had been destroyed, the surface soil was removed mainly by sheet erosion to the extent that the parent materials were exposed.

At present, if the plantation of *Pinus thunbergii* does not develop to a mixed Pine-Alder stand, which is expected to provide a sufficient cover for the ground surface, the area could face the danger of recycling of surface erosion.

2. Shelter establishment and its effects on devastated hillslopes

In the heavily damaged hillslope in Ashio and in devastated hillslopes in Tanakami, shelter has been established by air-seeding, application of vegetation bags, direct planting of supporting and main trees and by natural invasion of plants. In this section the establishment method and the effects of restoration of vegetation cover (shelter) on these environments will be discussed.

In Ashio for restoration of vegetation cover, in very steep (more than 35 degrees) and unaccessible hillslopes, air-seeding by helicopter has been carried out since 1965. This is because the execution of engineering and planting work have been found to be very difficult and expensive in this area.

In air seeding, the following materials are sprayed: chemical fertilizer, base asphalt, seeds, cover asphalt and second time fertilizer. These were sprayed at the rate of 10.0 ton/ha with the total cost of 1,300,000 yen (1983 level). Seeds of plant species used for this purpose are trees such as: *Pinus densiflora* (Akamatsu), *Alnus sieboldiana* (Obayashabushi), *A. hirsuta* (Keyamahannoki), *Amorpha fruticosa* (Itachihagi), *Elaeagnus umbelata* (Akigumi) and herbs and grasses such as: *Polygonum cuspidatum* (Itadori), *Artemisia montana* (Yomogi), *Miscanthus sinensis* (Susuki) etc.

In this way a total of 216.2 ha of very steep hillslopes in heavily damaged parts of Ashio mountains have been revegetated by August, 1983. As a result of this the slope had been stabilized and the occurrence of soil flow and surface erosion has been minimized.

In moderately steep hillslopes of heavily damaged area, several methods of revegetation such as: point seeding, direct tree planting in pits, step work with vegetation blocks, terracing and vegetation matting have been applied, as trial and error. Recently, however, a revegetation system have been developed for application in heavily damaged hillslopes. This system is based on three years work: first year, construction of fundation work, second year, putting of vegetation bags along the contours and third year, tree planting (Fig. 25).

In this system foundation work comprises concrete plates, concrete blocks and retention walls. These are constructed as small check dams, both on hillslopes and along the stream channels.

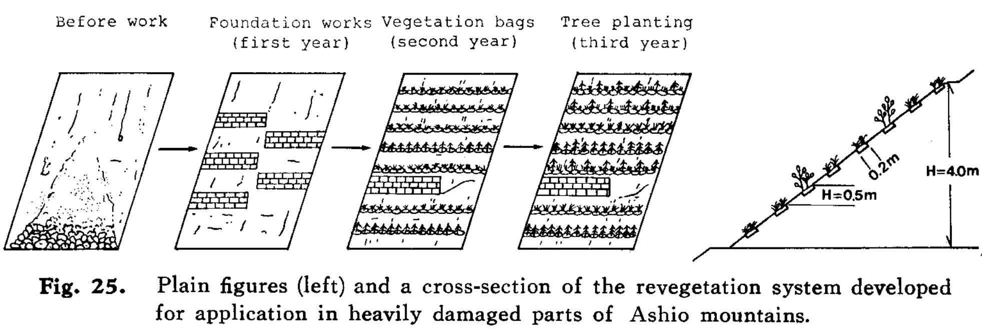


Fig. 25. Plain figures (left) and a cross-section of the revegetation system developed for application in heavily damaged parts of Ashio mountains.

Vegetation bags (25 cm × 38 cm in size) are made of cotton meshes, which does not interfere with growth of germinating seeds. Each of one hundred bags contains the following material: soil 0.3 m^3, chemical fertilizer 3.0 kg, compost and other organic material for soil improvement 25.0 kg, and plant seeds such as: *Robinia psuedoacacia* 0.4 kg, *Amorpha fruticosa* 0.3 kg, *Cytisus scoparius* (Enishida) 0.3 kg, *Pinus thunbergii* 0.3 kg and *Alnus* spp. 0.05 kg. In separate bags instead of seeds of trees, seeds of different herbs and grasses are put. In the past, both the seeds of grasses and trees were put together in the same bag. Since this had caused competition between early growing and late growing plants, it has been abandoned. Currently, bags containing seeds of grasses and trees are separated.

On the contour lines on hillslopes, simple steps of 20.0 cm to 30.0 cm wide are made and vegetation bags are put. The arrangement of putting bags up to the down slope is either i) first two rows of bags containing seeds of grasses are followed by one row of bags with tree seeds or ii) only one line of bags containing seeds of grasses followed by one line of bags containing tree seeds and two lines of bags with grass seeds.

In the third year seedlings are being planted behined the vegetation bags. Seedlings are of mixed broad leaved and coniferous species such as: *Robinia pseudoacacia, Elaeagnus umbelata, Larix kaempferii, Pinus thunbergii* and *Alnus* spp.. Table 8 shows improvement of some site factors in an area revegetated by the above mentioned system.

The effects of foundation work have been, mainly hillslope stabilization and

Table 8. Improvement of some site factors in the Ashio mountain's two formerly heavily damaged sites where three years work revegetation system has been applied (plot size 10 m × 10 m)

No. of sites	Tree species	Ave. tree height (m)	Ave. DBH (cm)	Number of trees	Degree of cover	Devel-opment	Soil tex.	Soil pH	Thick-ness of litter (cm)	Erosion features
	Robinia P. acacia	11.8	12.0	15						
1*	*Alnus pendula*	10.7	9.0	5	5	well	Kanto loam	4.7	3.8	non
	Pinus thunbergii	4.7	6.9	5						
	Robinia P. acacia	4.9	5.5	4						
	Alnus hirsuta	6.3	8.0	6						
2*	*Alnus pendula*	3.4	2.8	21	5	well	clay loam	4.4	3.6	non
	Pinus thunbergii	1.8	1.7	4						

*	Soil retaining work	Vegetation bags	Tree planting
1.	1959	1960	1961
2.	1971	1972	1973

stoppage of soil flow and rock fall. These not only provide an opportunity for tree planting in these hillslopes, but also help the natural invasion of plants. Because it creates a stable environment, where plant seeds are not removed and have a chance for germination.

In denuded steep hillslopes, where soil is shallow and lacks the necessary nutrient, vegetation bags create an artificial medium for plant growth. The main effects of plants growing from vegetation bags have been a slow improvement of the soil. This has happened through nitrogen fixation by alder and the addition of organic matter in the form of litter.

On the relatively stable deposits, such as old river terraces and on the sediments, deposited behind the erosion control (Sabō) dams, a degree of vegetation cover has been established by natural invasion of plants. The invaded plants are mainly pioneer species such as *Polygonum cuspidatum* (Itadori), *Alnus sieboldiana* and *Salix* spp.. Table 9 shows the nature of natural invasion of plants behind two Sabo dams. The effect of vegetation on these deposits have been the creation of a temporary stable condition. In the long run, however, these deposits are in danger of being scoured by strong floods and the possibility, exist that the established vegetation will be destroyed by it.

Table 9. The nature of natural invasion of plants on sediments stabilized by sabo dams

Location of dams	Length of dam (m)	Height of dam (m)	Area behind dam (m^2)	Estimated deposited sediments (m^3)	Area covered by vegetation behind dam (m^2)	Species & ages (years) of plants and area (% behind dam) occupied by plants
Matsukizawa	68.5	10.0	10,275	51,375	2,000	*Alnus sieboldiana* 5y 20%
Kuzozawa	30.0	9.0	3,070	13,818	1,512	*Alnus sieboldiana* *Salix* spp. 9y 41%

For the forest establishment in devastated hillslopes of Tanakami, a revegetation system, mainly based on slope stabilization and mixed planting of *Pinus thunbergii* and the nitrogen fixation tree of alder have been developed. In this system, first terraces are constructed on denuded mountain slopes. To stabilize the hillside, the face of the slope and the embankment of terraces in the upper parts of the slopes, are covered with sod and straw. In the lower parts of the slopes, which due to the incohesiveness of soil and the pressure from above, are considered to be less stable than the upper parts. In addition to straw and sod, concrete plates are also used for stabilization (Fig. 26).

Afforestation on the terraces has been carried out by a mixed planting of *Pinus thunbergii* and *Alnus pendula* in 1 to 2 ratio. The planting density has been from 6000 to 10,000 seedlings per hectare. The combination of black pine and alder has been adopted after repeated trial and error. The black pine has

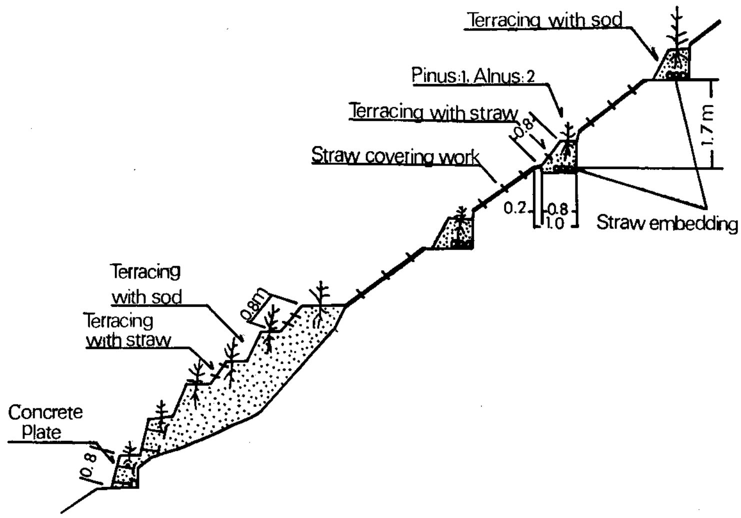


Fig. 26. A cross-section of hillside afforestation work in Tanakami mountains. (After ISHIBASHI, 1981).

the advantage of greater increment in the early stages of growth, while the alder produces litter by plant residues and also fixes nitrogen in the soil.

Ten years after planting, however, the growth of alder decline due to the competition with pine and the natural characteristics of this tree.

The aim to revegetate Tanakami mountains has been to establish a mixed pine-alder stand. In reality, however, all planted areas did not develop to such a plantation. Instead the following three types of stands have developed: (a) mixed pine-alder stand (b) alder stand and (c) thin pine stand.

The development of forest to type (a) is the most desirable, because it protects the land surface and, therefore, helps in checking accelerated erosion. In Tanakami, meanwhile, almost all of the stands planted before 1953, belong to the stand of type (c). This was due to the infertile soil developed from granit and the heavy damage to alder by insects. The stands of type (b) and (c), however, can not develop a sufficient cover for erosion control purposes and if tending work for the improvement of these stands are not carried out, the land will be subjected to recycling of erosion. For this purpose, two kinds of tending works have been developed: tending work (A) and (B).

Tending work (A) is carried out in plantation type (b), which is composed of well grown alders and dominant black pine. It includes the toping of alders at the height of 30.0 cm to 50.0 cm, in four years after planting and application of chemical fertilizer, one ton/ha, with the nutrient content of N 13.0% and K 12%. The aim of this treatment is to control the growth of alder and to stimulate the growth of pine. It is repeated for seven and ten years after planting.

Tending work (B) is applied for the improvement of type (c) stands. The main reason behind the poor growth of pine in this type of stand has been found to be the lack of nutrient material in the soil. The aim of tending work (B), therefore, has been improvement of soil properties, for a full development of plant roots, through application of fertilizer. This has been carried out by addition of material (such as straw and compost) containing a high amount of organic matter into the pit near plant root.

ISHIBASHI (1981) reported that the effect of tending work (A) and (B) was hardly noticeable after one year.[24] In the third year after the treatment, however, the pine trees in the stand attained a greater height increment than untreated trees. Increment in the tree height growth, stimulated by tending work (B) has been as follows:

Excavation depth (cm)	Kind of organic matter applied	Height increase (cm)
60.0	compost	10.0~28.0
60.0	rice straw	7.0~24.0
30.0	compost	6.0~19.0

In Tanakami, the effects of poorly developed plantation has not been very significant. Because there is a danger of recycling of erosion in areas under this type of plantation. The effects of the well developed plantation, on the other hand, had been the checking of surface erosion and improvement of the soil. In this kind of plantation, the terrace is completely covered with litter from alder trees in 5 to 6 years. While under poorly developed plantation the degree reaches to about fifty percent. ISHIBASHI (1981) found that the amount of carbon, as litter, has increased 120.0–510.0 kg/ha/y in the well established stands and only 20.0~40.0 kg/ha/y in poorly developed ones. He also found the increase of nitrogen to be 2.0~21.0 kg/ha/y and 0.4 kg/ha/y, in well developed and poorly developed stands, respectively.

VI. Discussion of the results

1. Effects of absence of shelter on plants

Shelter, when established in the initial stages of afforestation in severe environments, provide protection for newly planted seedlings from the effects of disturbance. If this protection is not provided for these seedlings from the effects of disturbance such as strong winds, the seedlings might be injured or when become mature trees, develop some defects. This might persist until the end of the tree's life and will cause the lowering of the quality of wood produced by these trees. In this part, as an e. g, compression wood formation in the stems of trees as a form of defect, occuring as a result of the absence of shelter, will be discussed.

In Sunasaka, as can be seen in Fig. 27 a, b, c, the compression wood is strongly formed in the first years of the growth of trees. This has been observed: i) in the first 9 years (1963–1972) out of 23 years, at the height of 0.2 m, 1.2 m and 1.8 m in the stems of trees grew in partly sheltered plots, ii) in the first

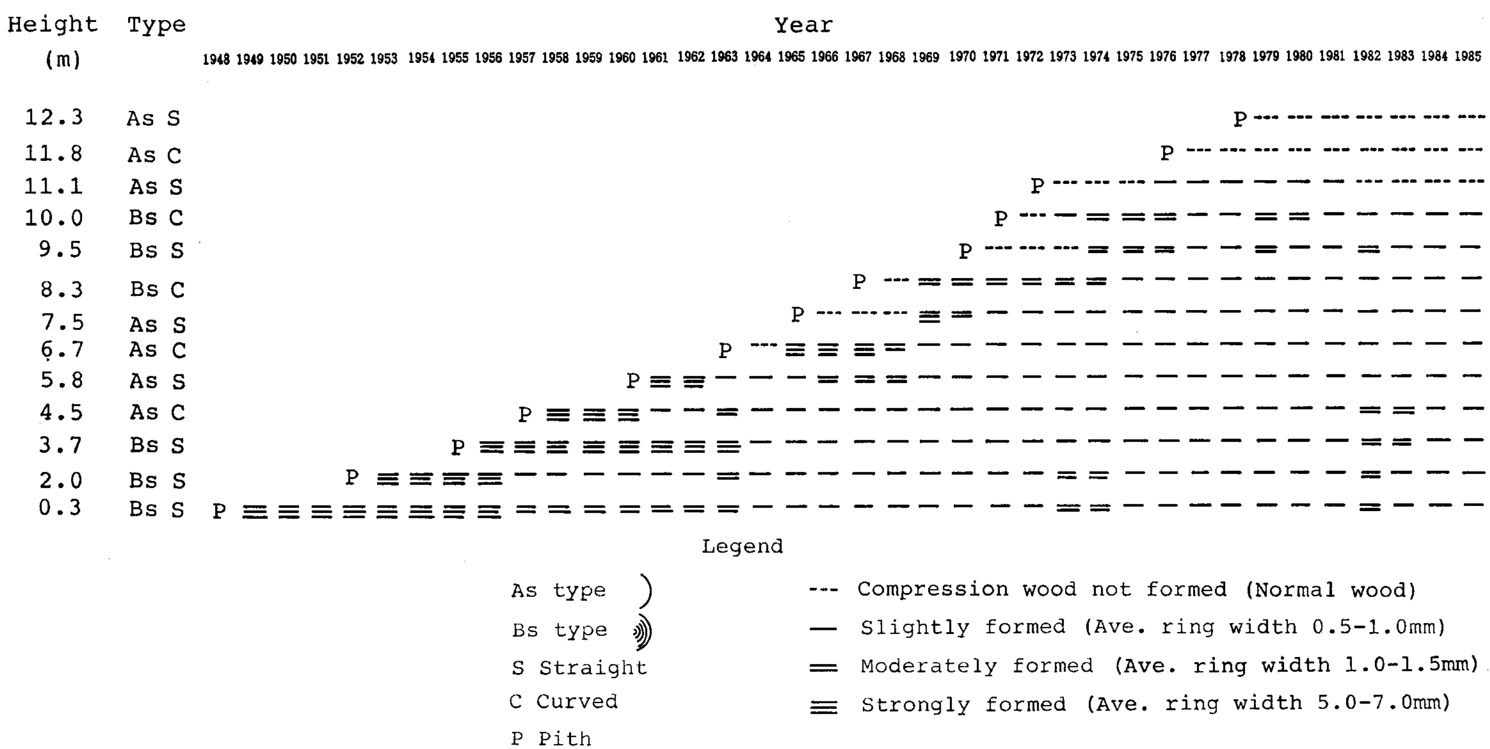


Fig. 27 a. Characteristics of compression wood in a Japanese black pine tree in highly sheltered plot in Sunasaka.

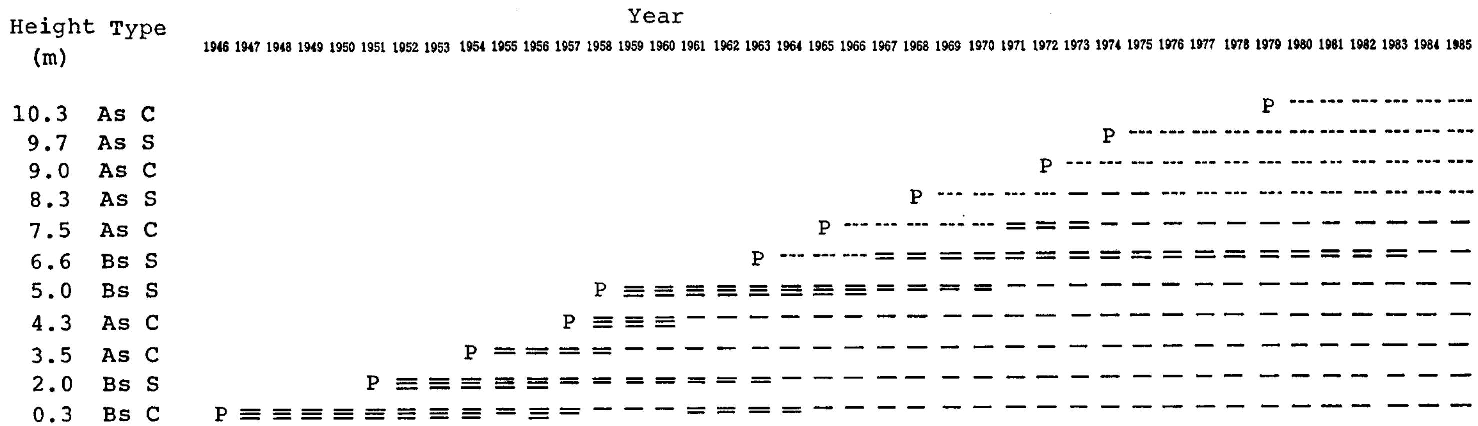


Fig. 27 b. Characteristics of compression wood in a Japanese black pine tree in sheltered plot in Sunasaka.

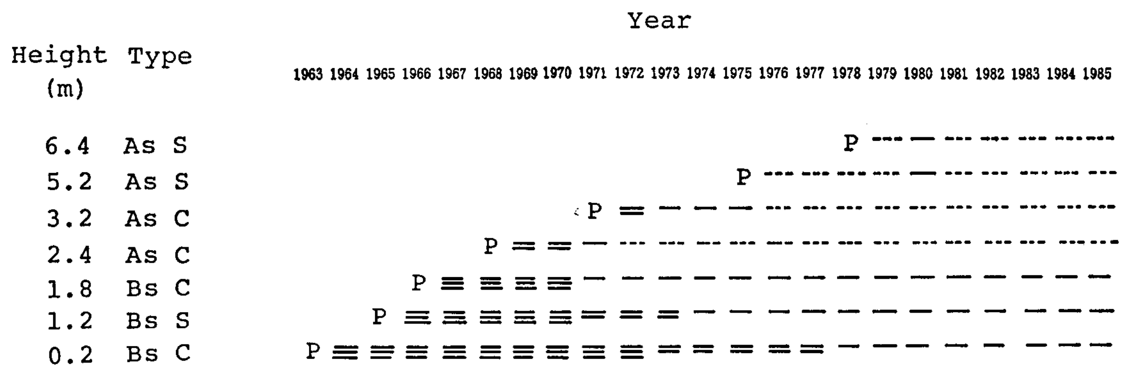


Fig. 27 c. Characteristics of compression wood in a Japanese black pine tree in partly sheltered plot in Sunasaka.

19 years (1946–1966, except in 1975) out of 39 years at the heights of 0.3 m, 2.0 m, 4.3 m and 5.0 m in the stems of trees of sheltered plots. And, finally, iii) In the first 19 years (1948–1969, except 1964 and 1968) out of 37 years at the heights of 0.3 m, 2.9 m, 3.7 m, 4.5 m, 5.8 m, 6.7 m and 7.5 m in the stems of trees in highly sheltered plot.

In the investigated tree, in partly sheltered plot, after 1972, only a slight formation of compression wood had taken place. In the tree grew, in sheltered plot, after 1966, there was a slight formation of compression wood in lower parts, moderate formation in the middle and normal wood in higher parts. In the tree, in highly sheltered zone, there was a slight to moderate formation continuously from the lower to a large section of middle parts and only in a limited section of higher parts, normal wood existed.

The strong formation of compression wood from lower parts to a certain height of the stem, e. g.: from 0.2 m to 1.8 m in partly sheltere tree, from 0.3 m to 5.0 m in sheltered tree and from 0.3 m to 6.7 m in highly sheltered tree, had taken place in the younger stages of the trees life. This is an indicator of the lack of shelter, against the prevailing wind, at the beginning stages of the forest establishment, in Sunasaka.

The slight to moderate formation in the middle and upper heights of the stems is indicator of the fact: that after the passage of certain years and the growth of trees to a sufficient height, a degree of mutual sheltering had come into being within the plantation. This helped to reduce the rate of the compression wood formation, in the middle and higher parts of the stems. Also, the fact, that in the higher parts of the stems of all the investigated trees, only normal wood was found, shows that after the passage of forty years from the establishment of the plantation, and the closure of the canopy, more shelter has been provided for the trees whithin the forest. As a result, the effects of wind is reduced to the minimum and compression wood has not been formed in the higher parts of the stems.

Compression wood, has exceptional high longitudinal shrinkage. This may lead to serious distortion or spliting during seasoning when compression wood and normal wood are present in the same piece of timber and this is considered the most important defect of timber. The formation of it should be prevented in trees. In areas where strong wind blows, the preventive measure against the formation of compression wood should be taken, preferably, at the start of the establishment of plantation, when seedlings could be curved, bent and crooked easily by wind.

2. Edaphic factors

Edaphic, climatic and hydrological factors are the most important ecological factors governing tree establishment, growth and the natural regeneration of vegetation on sand dune (KAUL, 1985[29,30] and GHOSE, 1985[19]). Among the edaphic factors, however, organic matter and clay in the soil seems to be very important for the improvement and development of the site, in sandy areas.

DAVID and IVAN (1985) noted that "organic matter in the soil is one of the main environmental factors which contribute to the improvement of other factors".[9] Basically, bare sand dunes and devastated hillslopes are severely deficient in organic matter. This is mainly due to the removal of organic debris, produced by vegetation from the soil, by wind action and water erosion. Therefore, addition of organic matter to the soils, in severe environments, is an important aim of the vegetational shelter proposed in this study and also its fundamental difference with other forms of shelter. Another aim of vegetational shelter is to provide stability to the environment.

In Sunasaka, with increase in the organic matter content of the soil, bulk density showed a tendency to decrease, while nitrogen and CEC have an opposite tendency (refer to Table 3). This is in accordance with the observations of NAOKI et al. (1979).[42] They showed the values of organic matter in sand dunes, covered with natural vegetation, to be between 0.61% to 2.4% and 0.59% to 0.63% at 0∼5 cm deep and 10∼15 cm deep layers, respectively. They also found a positive correlation between the organic matter, nitrogen and CEC factors and a negative correlation with the bulk density.

In Sunasaka, the values of carbon is considerably high in the surface layers under the plantation (12.4% to 24.0%), in comparison to the value of carbon in the same layers outside the plantation on unstable dunes (3.3% to 4.3%). Nitrogen also showed the same tendency; 0.2% to 0.61% in the upper layer of soil under plantation and 0.1% in unstable sand dunes.

In a location in the semi-aird regions of India, the same tendency was observed. Here, the values of carbon were found to be 0.21% in stable sand dune and 0.05% in unstable sand dune, while the value of nitrogen in the corresponding areas were 0.009% and 0.006%, respectively (DHIR, 1985).[10] The higher values of carbon and nitrogen in stablized dunes in Sunasaka, in comparison to the values of the same factors in stabilized dunes, in the semi-arid location in India could be due to the high amount of organic matter produced under the humid climate in Sunasaka.

In the lower layers of forested sand dune in Sunasaka, the values of carbon and nitrogen, however, did not show a significant increase over the values of carbon and nitrogen in the same layers of bare sand dunes. MIURA et al. (1983) also found the same trend.[39] The result of their studies in Kaetsu sand dunes showed that both inside and outside the forest, below the surface, the values of carbon and nitrogen are lower than 0.2%. Since no form of fertilizer is applied in Sunasaka, in recent years, it is infered that the carbon and nitrogen enrichment near the surface under the plantation could be attributed entirely to soil development, which might have occurred as a result of the effects of shelter.

Below 1.0% clay, nutrient supply seems to be limiting factor for tree growth, whereas aeolian sands with more than 2.0% clay may provide a very rich growth medium (JENSEN, 1976).[27] The significance of these negatively charged particles is in their ability to absorb, attract and exchange cations (JENSEN, 1976[27] and DAVID and IVAN, 1985).[4] In Sunasaka increase in clay content has taken place only in the surface layers (5.0 cm) of sheltered plots, especially, in highly sheltered plot. In deeper layers the clay content is quite lower than the upper layers, which fluctuates and does not show a regular pattern of decrease and increase.

The higher clay content in the surface of stabilized sand dune in Sunasaka could be due to the protective function of forest where the fine particles (silt and clay) blown-off from the surface of bare sand, might have been trapped and were not removed by wind. The increase in clay, together with intense organic activity in the surface, might have helped the formation of A horizon, which is considered as an indicator of soil formation.

Table 10 shows that below dry layer, sand dunes contain a limited but permanent supply of soil moisture, even under driest environments. As can be seen in the Table, there is no significant difference between the soil moisture content of dry sand layer in coastal sand dunes of humid areas and dune sands of deserts. The amount of soil moisture in the layers below 50.0 cm, on the other hand, is two times higher in humid areas in comparison to dry climates. This is not surprising in the face of the frequent and high amounts of rainfall, especially during the summer, in the former areas and sporadic and low amount of rain fall in the latter regions.

Table 10. Soil moisture of coastal and desert dunes

Areas	Depth of dry sand layer (cm)	Soil moisture (percent of dry weight)	
		Dry sand layer	50 cm below dry sand layer
Ishikari	4.9	0.2	5.8
Sunasaka	4.2	0.3	4.2
Tottori	6.0	0.4	5.0
Rajistan*	10.0	0.3	2.6
Najiev*	9.0	0.2	2.4

* Rajistan and Najiev deserts are located in central India and Israel, respectively.

Also, both in semi-arid and in humid regions, the soil moisture in deeper layers of unstable and bare sand dunes are higher than the soil moisture in the deeper layers of vegetated dunes. Under the semi-aird conditions, e. g., LAHIRI (1985) found that "at the depth of 45.0 cm to 60.0 cm in bare sand dunes, in the months of January, March, June and September, the soil moisture was 2.1%, 2.6%, 2.1% and 3.12%, respectively. On the other hand, the soil moisture at the same depth and in the same months, in vegetated dunes was 0.38%, 0.8%, 0.8% and 0.8%, respectively".[32] The fact that in the lower layers of sand dunes, even under very dry climatic condition, a limited but permanent supply of moisture exist is very important for revegetation of bare sand dunes. It, however, should be kept in mind that this limited amount of soil mositure might not always be sufficient to support additional plants, that are necessary to fix the dunes. Development of the fertility of the soil, therefore, might be an important factor for an optimum utilization of this limited moisture.

Another factor which affect the degree of utilization of soil moisture by plants, in sand dunes, is the fact that the movement of soil moisture in sandy soils is largely in the vapour phase (TSOAR, 1985[47] and DHIR, 1985).[10] The intersite movement of soil moisture, e .g., from sites at lower tension to the sites of higher tension, is very small in sandy soils. The degree of utilization of moisture in sandy soils, therefore, will to a large extent depend upon the "degree of direct access of the roots to the points of entrapped moisture" (DHIR, 1985). Plants, having a fibrous and multilayered root system, are expected to better suit sandy habitats. The existence of *Elymus mollis* and *Carex kobomugi* — which are having these root characteristics — in bare sand dunes, in Sunasaka, is definitely related to the ability of their roots in utilizing soil moisture. This fact, therefore, should be taken into consideration, while choosing species of plants for revegetation of sandy areas.

In heavily damaged hillslopes of Ashio, as a result of revegetation, most of the devastated mountains had been recovered. Only 1300 ha still remain bare. In the recovered areas, the soil is mostly thin and fragile. Due to the addition of organic matter in the form of litter, some improvements in the fertility of soil had taken place. For further development of the soil, the stability of slope, which affect the establishment of shelter and the remaining in place of litter, is thought to be very important. Furthermore, if the slopes are stabilized, in the still bare parts, a cover of vegetation can be established by natural invasion of plants. Because in this area, climatic conditions, especially, the amount and timing of rainfall, is favorable for the occurrence of natural invasion of plants. Under more severe environmental conditions artificial revegetation might be necessary for the establishment of shelter.

In Tanakami, the nutrient material in the soil is exhausted. This seems to be due to the fact that the nutrient, as well as added organic matter, absorbed by plants in the early stages of revegetation are restored in plantation surface, in the form of littler. Meanwhile, the change of organic matter (litter) to absorbable form, by plants (mineralization of organic matter), is slower than litter accumulation on the ground surface, in the granit-derived soils. This means that the establishment of an equilibrium between the rate of organic matter formation and its mineralization takes a long time. The application of fertilizer, therefore, is necessary util nutrient circulation reaches its equilibrium.

As was mentioned before, organic matter is the dominant factor in the development of other edaphic factors and the shelter adds a certain amount of organic matter to the soil and help its decomposition. But in the studied areas, it has been observed that despite the establishment of shelter and addition of organic matter by it to the site, the development of edaphic factors is a very slow and time consuming process. In Sunasaka, e. g., 40 years after the establishment of plantation development of edaphic factors have not taken place yet, in all the layers of the soil. A slight development of these factors has been visible only in the surface layers of the plantation. Here, the development of the factors has been mainly affected by the degree of sheltering.

3. Significance of site factors

Site factors are defined as combination of biotic, climatic and edaphic factors of the studied areas in relation to the capacity of these areas to produce forest.

The comparison of the degree of development of site factors, in two areas, can be taken as indicators of the low level of disturbance and stress in environments, where these factors are highly developed, and as an indicator of the high level of disturbance and stress in evironments where these factors are poorly developed. As has been shown in this study, in areas where the plantation is established the site factors are usually highly developed in comparison to still bare environments. This contrast clearly shows the influence of vegetation on the improvement of environment and can justify its necessity for severe environments.

Also using the development of site factors as indicator of the level of disturbance and stress in a particular area, the planner can have a knowledge of the severity of the environment in that area. This will enable him to forsee measures in his planning for the reduction of the level of disturbance, before the revegetation is actually carried out. Because even if vegetation cover is established in a productive but disturbed environment, it will not always develop as desired. SMITH (1985) also mentioned this point. He observed that "in productive, disturbed environments some characteristics of vegetation such as biomass and size of plants are small, and litter is sparse, often transient while, in productive undisturbed environments these characteristics are large and copious often persistant".[45]

Finally, on the basis of the evidence presented so far, about the development of site factors in sheltered areas, it can be argued that to improve the environmental conditions in bare sand dunes and devastated hillslopes the most reasonable way is the revegetation of these environments. This should be carried out on the basis of provision of vegetational shelter. Because as can be seen from the examples of the studied areas, this kind of shelter supplies organic matter to the system, prevents disturbance and creates favorable conditions for decomposition and mineralization of organic matter. It is, therefore, very important that from the beginning, stages of revegetation until the plantation is matured, the concept of shelter should be taken into consideration by the planners of revegetation of severe environments.

VII. Planning of revegetation in severe environments

Revegetation of severe environments should be thought as part of the process of general rehabilitation of these areas, for environmental improvement and for the human welll-being. This aim can be better achieved if rehabilitation is considered in the context of land use planning (land development, land management) of the country or even on regional basis. Because severe environments, e. g., sand dunes, causing similar problems, can cross the boundries of two or more countries. A collective action, for revegetation, by all countries involved, might give better results

Table 11. Elements of planning for revegetation of severe environments

Elements	Types of severe environments: Bare sand dunes	Devastated hillslopes
Land surface stabilization	—Construction of series of low crossdunes (sand ridges) covered with stones. —Spreading of organicdebris (branches and twigs of cut shelteringplants) on the surface. —Spreading of clods of earth and small stones on the surface of land. —Protection against cutting and uprooting of natural vegetation.	—Alternate terracing if sheet, rill and small gully erosion are the sources of disturbance. —Construction of retaining walls if rockfall and soil flow are the major source of disturbance. —Protection against cutting and uprooting of natural vegetation.
Shelter establishment	—Before planting the main species, planting of bushes and trees of *Leguminosae* and other trees either in lines or in circles as shelter. In the coming years planting of main species between them. —Surrounding with straw that part of stems of newly planted seedlings which come into contact with the dry sand layer.	—Before planting the main species, planting of bushes and trees of *Leguminosae* and other trees eitherin lines or in circles as shelter. In the coming years planting of main trees between them.
Moisture conservation	—Adjusting planting time to before rainfall or snowfall seasons. —Covering the basin of each pit with straw or stones for prevention of evaporation. —Prevention of removal of dry sand layer by creating a sparse layer of clods of earth, stones and branches and twigs on the surface.	—Adjusting planting time to before rainfall or snowfall seasons. —Covering the basin of each pit with straw or stones for prevention of evaporation. —Removal of snow from the watershed of each alternate terrace and accumulating it inside each terrace.
Soil improvement	—Mixing compost and manure with the pit's soil. —Putting organic debris such as straw in the bottom of the pits. —Planting nitrogen fixation trees. —Cutting some of the sheltering plants and mixing their debris with the soil.	—Mixing compost and manure with the pit's soil. —Putting organic debris such as straw in the bottom of pits. —Planting nitrogen fixation trees. —Cutting some of the sheltering plants and mixing their debris with the soil. —In steep slopes where soil is totally eroded and terrace can't be constructed; digging of individual pits and filling them with soil transported from other places. —In steep slopes where only coarse debris remained; 1, Construction of retaining walls 2, Putting vegetation bags, containing, soil, seeds and fertilizer, on the contour lines.
Planting in stages	—First stage; construction of low cross dunes and planting of some sheltering plants. —Second stage; cutting of some sheltering plants and planting of first main trees (needle leaved). —Third and fourth stages; planting of second main species (broad leaved). —Result: a mixed plantation.	—First stage; execution of engineering work. —Second stage; cultivation of legumes, vegetation bags. —Third stage; planting of shelter and first main trees (needle leaved). —Fourth stage; planting of second main trees (broad leaved). —Result; a mixed plantation.
Selection of planting material	—Rapid early growth, adequate height, dense crown fibrous and layered root system, thick litter producer, drought resistant, wind firmness, valuable wood product.	—Rapid early growth, adequate height, dense crown, thick litter producer, drought resistant, valuable wood product.

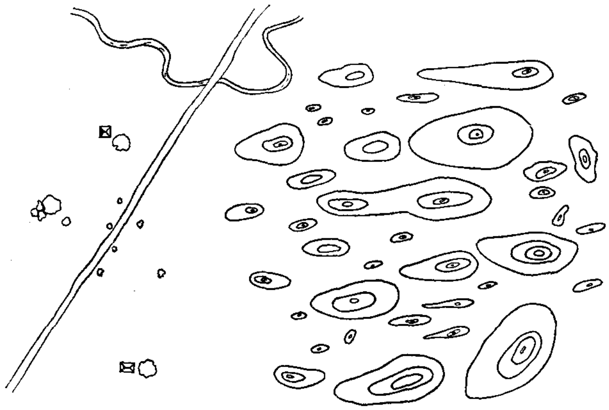


Fig. 28 a. A plain figure of an imaginary area threatened by encroaching sand dunes.

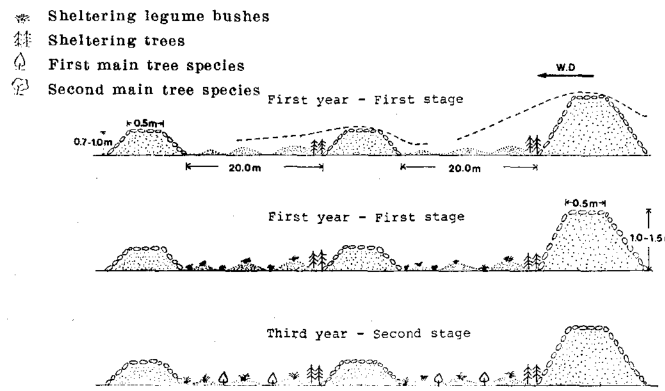


Fig. 28 b. Cross-sections of series of low cross-dunes; a pattern of revegetation for bare sand dunes.

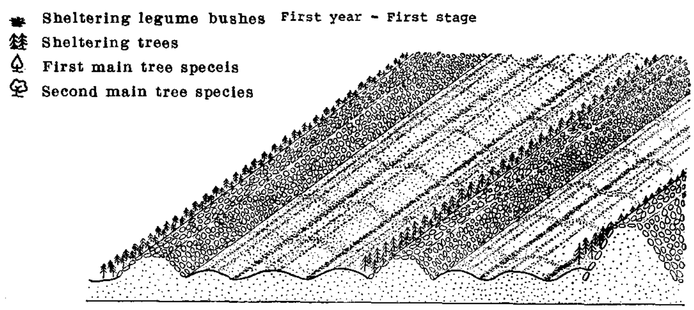


Fig. 28 c. Side view of series of low cross-dunes after completion of construction work.

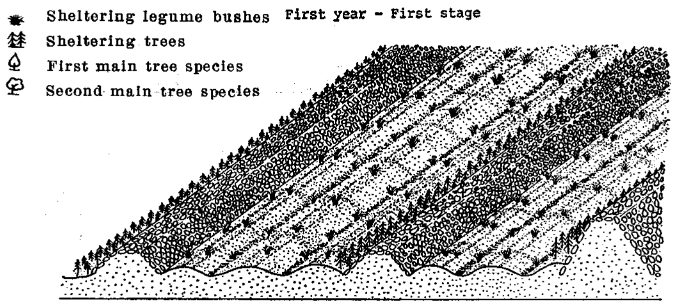


Fig. 28 d. Side view of low cross-dunes after the planting of sheltering bushes and trees.

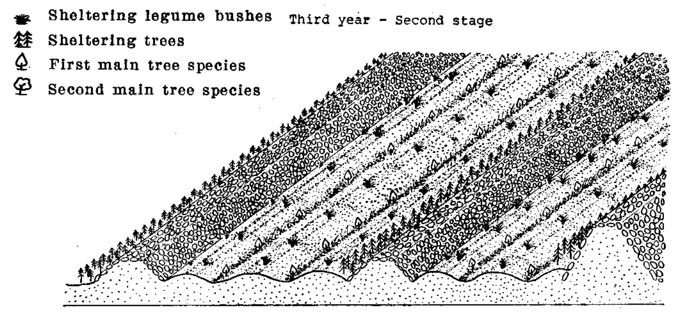


Fig. 28 e. Side view of series of low cross-dunes after planting of first main tree.

than individual action. Also that part of the problem in severe environments which is related to man's action, may have been originated as a result of bad land use planning or even a lack of such planning.

In either of these cases several human groups (farmers, landowners, land developers, merchants, politicians, city dwellers etc.) and diverse factors (social, cultural, historical, economical, climatic) might be involved. In planning the rehabilitation of severe environments, the perception of the above mentioned groups, regarding different aspects of the problem, their socio-economic interests, as well as the role of the factors mentioned above should be taken into consideration. The interested groups, through some form of representation, even should be directly involved in different stages of the planning.

In some cases, large areas might be recognized as severe environments, which may need restoration of vegetation cover. This, however, may not be feasible both economically and technically, especially, in developing countries. In planning the rehabilitation of severe environments, therefore, priorities should be given to the sites, where human settlements and vital economic installations and activities are threatened.

One may argue that the hazards from severe environments, such as the encroachment of sand dunes, could be contained by artificial means (spray of chemicals, asphalt, cement etc.), and not necessarily by revegetation. In very urgent and

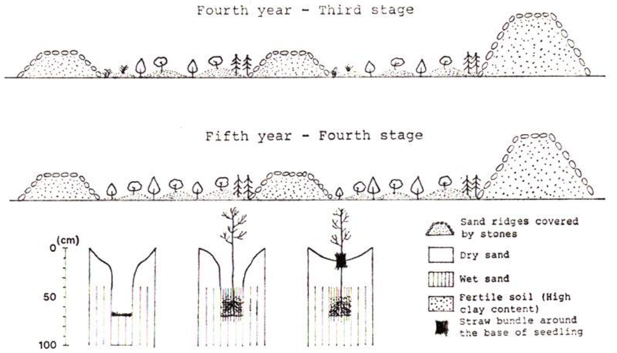


Fig. 29 a. Cross-sections of a series of low cross-dunes after the planting of first and second main trees.

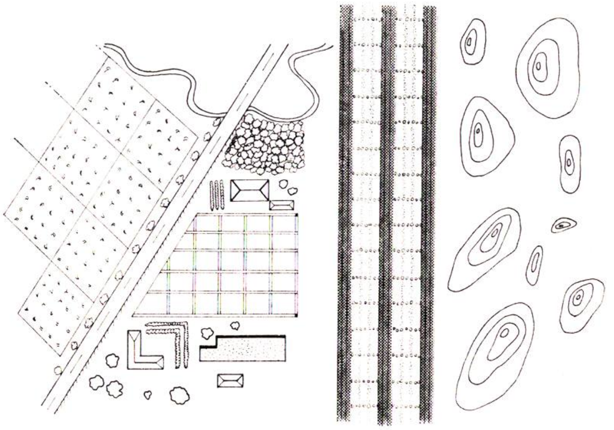


Fig. 29 b. A plain figure of an imaginary area protected from the threat of encroaching sand dunes by application of a series of low cross-dunes.

severe cases, this might be a proper temporary measure. But revegetation of severe environments will always remain as the most reasonable, durable and economic alternative of rehabilitation of these environments. Because, though this might prove to be time consuming and very slow process, it has the ability to reduce the level of disturbance and stress, restore the ecological balance between physical and biotic environments and contribute to the economics well-being of the population, by utilization of the forest products.

These advantages of revegetation, however, are not achievable in a single step. In planning the revegetation of severe environments, immediate objectives and long term objectives, should be taken into consideration. These could be:

"Immediate objectives"

1. Minimization of the level of disturbance and stress.
2. Improvement and development of the site factors.

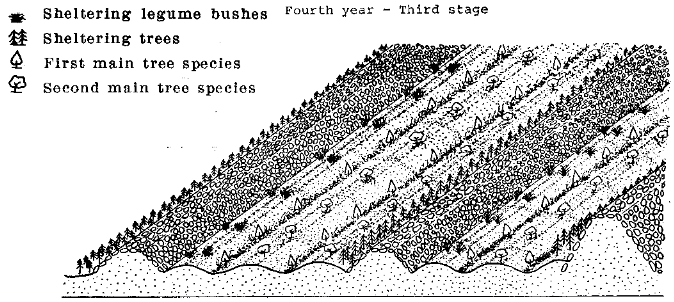


Fig. 29 c. Side view of series of low cross-dunes after the planting of first and second main trees.

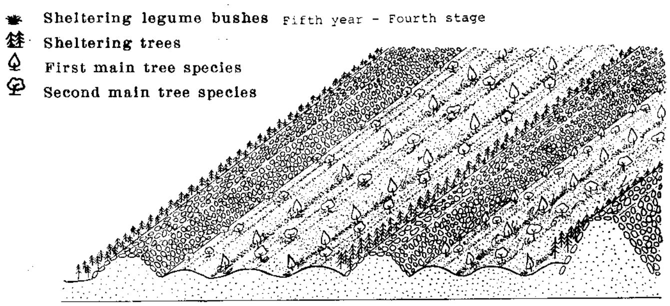


Fig. 29 d. Side view of series of low cross-dunes after the completion of work.

"Long term objectives"

1. Economic utilization (wood products for fuel, farm equipment and timber andfodder)
2. Recreational utilization
3. Fauna habitat and conservation

Both of these objectives as mentioned before, should be incorporated in land use planning drawn on the country or regional basis. The immediate objectives, however ,will remain a concern of land conservationists, while the long term objectives will be of interest to forest and land managers.

This study deals primarily with the immediate objectives of revegetation of severe environments. To achieve these objectives elements of planning for revegetation of bare sand dunes and devastated hillslopes have been outlined (Table 11). Based on the principles of these elements, the patterns (models) of revegetation have been developed which could be taken into consideration, while planning revegetation of the above mentioned environments (Figs. 28 a, b, c, d, e ; 29 a, b, c, d ; 30 a, b, c, d ; 31 a, b, c and 32).

The elements of planning on the basis of their importance and their application in time series are : 1. Land surface stabilization. 2. Shelter establishment. 3. Moisture conservation. 4. Soil improvement. 5. Planting in stages. 6. Selection of planting material.

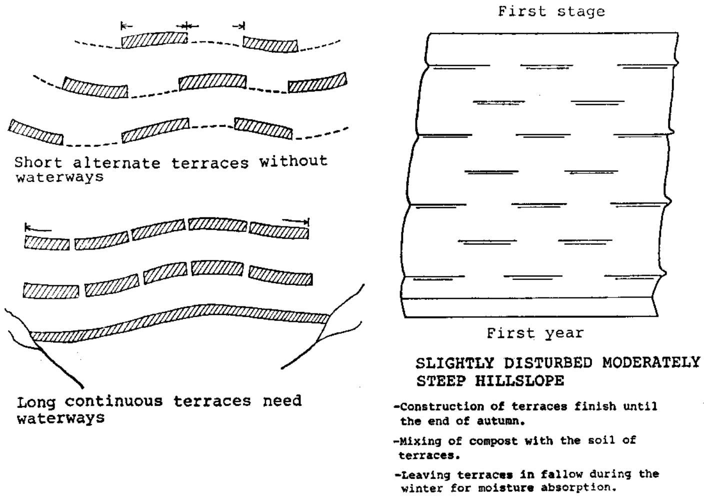


Fig. 30 a. Alternate terracing after construction in slightly disturbed hillslope.

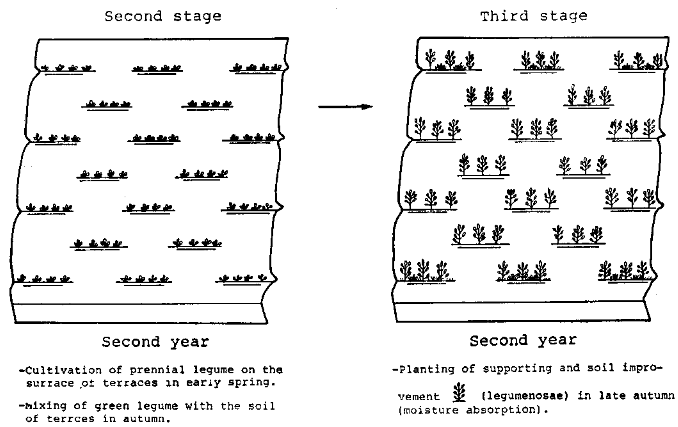


Fig. 30 b. Planting of sheltering species in alternate terraces.

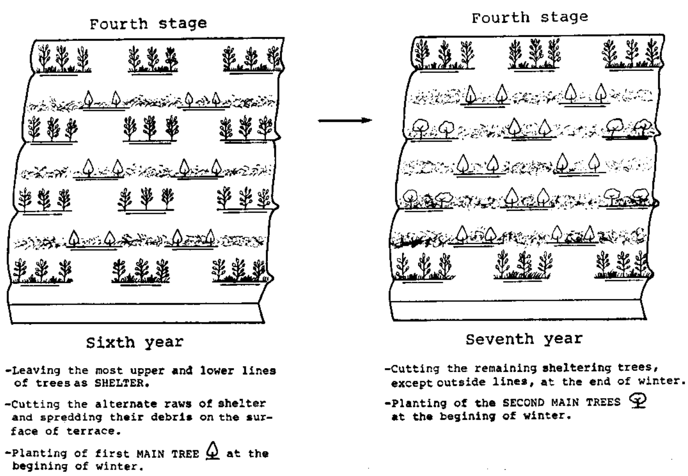


Fig. 30 c. Completion of planting of first and second main trees in alternate terraces.

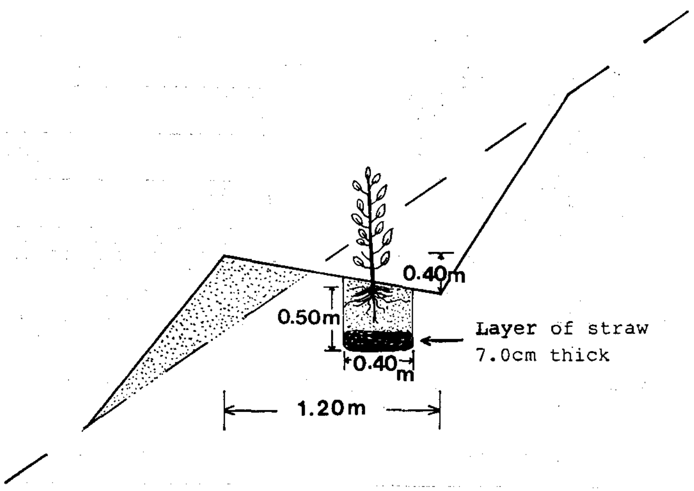


Fig. 30 d. A cross-section of an alternate terrace.

(1) **Land surface stabilization:** In severe environments unless first the ground surface is stabilized, the planted material will either be damaged, carried away or burried. This step should, therefore, be considered for the reduction of the level of disturbance, before any revegetation is carried out. For land surface stabilization the debris produced from the cutting of sheltering plants are spread on the surface of land. If there is a danger of removal of these material by strong wind or run-off water, then mixing of the material with the soil is carried out. This method could be applied both in hillslopes and in sand dunes.

In the case of sand dunes threatening a village or an economic installation, a series of low-cross dunes could be formed to stop the moving dunes. This could be carried out by forming a main low-cross dune at a point about one kilometer from the first and closest moving dune to the village, towards the attacking dunes. The low-cross dunes can be formed by moving sand from two sides by shovel or other simple earth moving equipments. Then starting 50 meters from the first main low dune, in each 20 meters or 50 meters series of low-cross dunes (height 1.0 m to 1.5 m), are created. The slope and crest of these dunes as shown in the Figures will be covered by stones. For stabilization of the areas between the two low dunes clods of earth, small stones and organic debris are spread on the surface of land.

(2) **Shelter establishment:** Establishment of vegetational shelter is necessary for protection of planted seedlings from the effects of stress and disturbance, for surface stabilization and for the improvement of the environment. Two species of plants are used for revegetation: these are sheltering species and main species. Plants which are chosen as sheltering species should have fast growing and soil improvement characteristics. Some of the sheltering species are cut in different stages

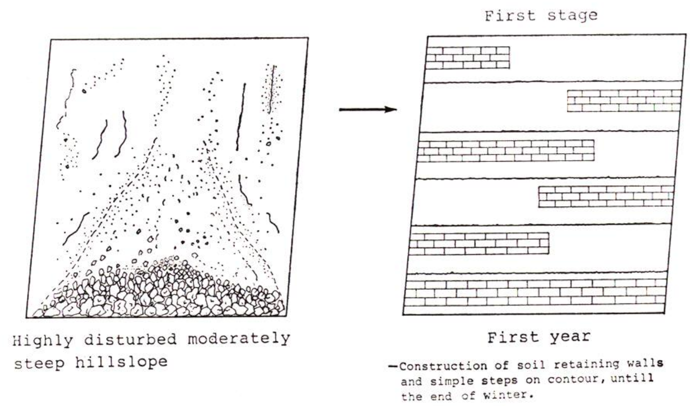


Fig. 31 a. Slope stabilization by construction of soil retaining walls in highly disturbed hillslopes.

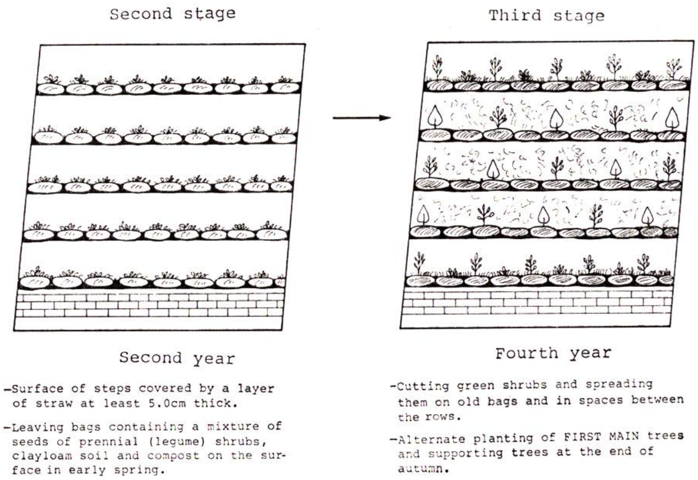


Fig. 31 b. Applicatin of vegetation bags and the planting of sheltering and first main trees in highly disturbed hillslope.

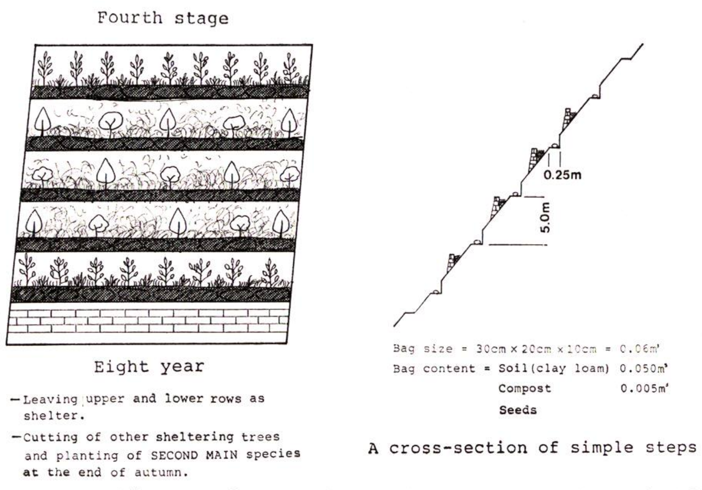


Fig. 31 c. Planting of first and second main tree species in highly disturbed hillslope.

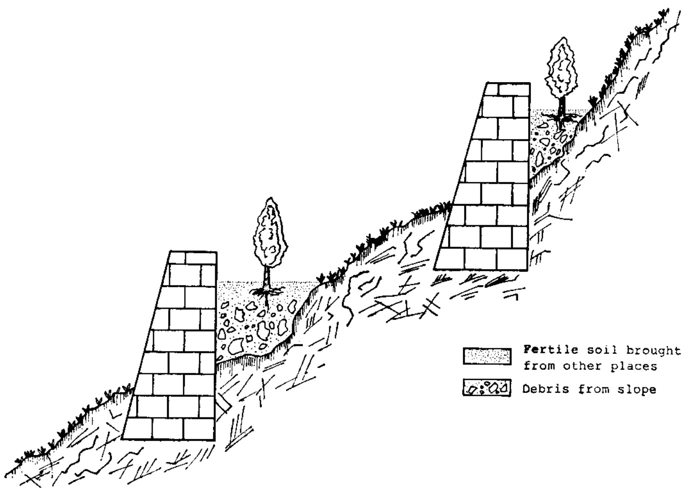


Fig. 32. A pattern of slope stabilization and tree planting in highly disturbed hillslope with very shallow soil.

before the planting of main species as well as after its establishment. The debris produced by the cutting of sheltering species are spread on the surface of the soil or mixed with it. This will serve two purposes : provide cover for the land surface, reduce the level of disturbance and, by providing organic matter to the soil, improve the site. Because some sites may be too severely degraded to support a tree cover without first being prepared by a pioneer herbaceous plant stage. But in every stage, only one line of sheltering species are cut. The main species are planted in between the remaining lines of sheltering species.

(3) **Moisture conservation :** Here the efficient utilization of precipitation, prevention of excessive evaporation and timing of planting are given top priorities. By planting in late autumn, e. g., precipitation from winter could be diverted around the already planted trees. By infiltrating into deeper layers the precipitation could help increase the moisture content of the soil around the roots of the planted trees. Since evaporation is low in winter, the infiltrated precipitation will be conserved in deeper layers for use by plants in summer.

In devastated hillslopes, alternate terracing is proposed for retention of rain water and water flowing from melted snow. In this system, each terrace has a catchment, from where the water flows to the terrace, where it infiltrate into the soil. In areas of heavy snowfall, the snow could be removed by shovels or other means from the catchment and stored in terraces. If the volume of snow overtops the terrace, it could be pressed by trampling upon or some device. If snow is accumulated and pressed inside the terrace, many times during the winter, several compact layers of snow will be formed. The compacted snow melts slowly in early spring and infiltrate to the soil where it will be conserved.

For moisture conservation in sandy areas, dry sand layer should remain intact and be preserved while planting is carried out. For this purpose in this study, for stabilization of the surface of sand, spreading of earth clods (containing a high amount of clay) and small stones have been proposed. Clods and small stones should be spread in a way to form a sparse cover on the surface of sand. A total coverage of sand surface which destroys the dry sand layer should be avoided.

Also in sand dunes the pits should be dug deeper than other places — preferably from 70.0 cm to 80.0 cm deep. In sand dune environments the low lying interdunal areas always contain wet soils. From these areas, before planting of the seedlings in the pits, a 20.0 cm thick layer of wet sand should be put into the bottom of the pit, over which the plant root is put. If wet sand can't be obtained, one or two buckets of water should be poured at the bottom of the pit.

(4) **Soil improvement:** The soils in severe environments are generally infertile, and are having a low water holding capacity. The plant growth in such soils is presumably low. Under such circumstances the vegetation cover which is necessary for protection of the land will not attain sufficient height and density. Before and during planting, addition of fertilizer and compost to the soil, therefore, should be taken into consideration. Soil improving, sheltering trees and the organic debris produced by it, will also contribute to the improvement of soil.

(5) **Planting in stages:** Since severe environments are poor in soil fertility and deficient in soil moisture, the sudden and mass introduction of main tree species which require nutrient and moisture for their growth, might increase the level of stress. It is, therefore, recommended that the planting is carried out in several stages: in the first stage, execution of engineering work, in the second stage, introduction of soil improvement and sheltring plants, and in the third and fourth stages, planting of first main tree — needle leaved, and the planting of the second main tree — broad leaved species. Depending on the conditions of the site, the time interval between each stage can be one year or several years.

The plantation which will be established as a result, will be a mixed and multistory forest of pioneering soil improving trees, evergreen and broad leaved species. In devastated hillslopes, where rain drops and run-off are the main agent of soil erosion and the latter being the main factor of disturbance; the storied crowns of this kind of plantation successively reduce the energy of rain drops, where the litter layer, physically prevent the soil particles from becoming disloged. On the sand dunes, this kind of plantation prevents the erosion of the surface of sand by accumulation of litter, and the ability of different layers of trees to reduce the wind force and its speed. Also in sandy areas a mixed plantation with both deep and shallow rooted plants might be able to utilize the soil moisture efficiently.

(6) **Selection of planting material:** The main characteristics of plant species intended for use in revegetation of bare sand dunes and devastated hillslopes should be to withstand the severity of the environment. These characteristics could have (a) resistance to drought, (b) ability to grow in infertile soils, (c) ability to withstand strong wind, (d) ability to regenerate when damaged or partially cut. One

way to find these is to choose plants already growing well and adapted in the habitats where revegetation will be carried out. These plants can be propagated in the nurseries, also established in the same localities.

Plants also should have properties such as soil improvement, fast growth to provide cover for the ground surfaces, in a short period of time, and the ability to produce good quality woods.

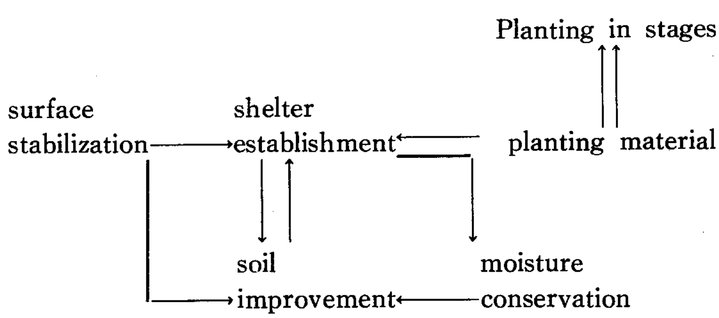
The fast growing, soil improving bushes and trees are recommended for use as sheltering plants, and the needle leaved trees as the first main tree species. The choice of needle leaved trees as the first main species is due to some characteristics of this species which make it more suitable for planting in severe environments, than the borad leaved trees. These are : lower soil fertility requirements, less site preparation requirements, interwoven litter for soil protection, and evergreeness.

Cuttings of some plants are also used for revegetation of severe environments. These should be taken from healthy branches and trees.

Direct seeding for revegetation of severe environments, especially, on bare sand dunes will not, probably, give good results, because of high surface temperatures. Even if seeds are planted at a depth of, e.g., 20.0 cm and germinate, when appearing on the surface, their fragile stems, upon coming into contact with the strong heat of the dry sand layers, might be damaged.

In devastated hillslopes if the surface of the terraces are prepared (slightly scratched) and the shade is provided, direct seeding can be carried out. Seeds used for this purpose should have the same, previously mentioned, characteristics as cuttings and trees.

The elements of planning discussed so far, especially, the four elements of : surface stabilization, shelter establishment, moisture conservation, and soil improvement are highly interconnected and their functions are overlapped. Sheltering provides surface stability, contributes to the improvement of soil, and might also help moisture conservation. Measures intended for soil improvement also will affect moisture conservation and vice versa. Surface stabilization will affect soil improvement, moisture conservation, and sheltering. The following diagram shows these interactions.



At the meantime, each of the elements discussed, have their main functions which make them independent of other elements and justify their orderly application in time. Shelter's main function is protection of the first and second main tree species, against the effects of disturbance, and the main function of the surface stabilization is prevention of erosion of the land surface. Moisture conservation has the main function of preventing soil moisture losses and keeping it around the roots of plants, while soil improvement's main function is the restoration of fertility of the soil. The most important element among these, upon which other elements will have a degree of dependency is shelter establishment. Because the main function of protection of planted trees and improvement of environmental site factors are carried out by this element.

Finally, with the application of the revegetation plan mentioned so far, the level of environmental as well as man induced disturbance and stress is expected to decrease substantially. This could lead to the improvement and development of site factors and ultimately to the rehabilitation of severe environments.

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要　約

厳しい環境下での無計画な生産活動により，世界各地で植生が破壊され，広大な土地が裸地状に取り残されている。このような荒廃裸地の放置は，“砂漠化”というより一層の環境悪化につながる。本研究は，砂漠化を防ぎ荒廃地を回復するための，森林の立地環境改善プロセスの解明と，これに基づく植生復元手法の確立を目的とした。本研究では海岸砂丘地（砂坂）と荒廃山地（足尾）を，厳しい環境下での廃荒地形成事例として取り上げ，現地調査を行なった。

1) 荒廃地の出現は，disturbance（環境攪乱）と stress（環境圧）とに密接に関係しており，これらはまた荒廃地植生復元の限定要因となる。そこで，これを抑え裸出砂丘や荒廃山地

の植生復元を図るため，植生シェルターの概念を導入した。

2) 植生シェルターとは，自力で生育している草本・低木・樹木等で，有機物を供給し，造林木を含めた周辺環境に安定性を与えるもの，と定義した。造林木が充分に生長し，樹冠の鬱閉段階では，樹木・林分間相互に植生シェルターが強く作用することになる。このシェルターは強風地では風向に対し面的に，表土流出が主な攪乱要因となる山腹では雨滴に対して層状に，地表流下水に対しては垂直的に作用していると考えられる。とくに海岸砂丘地（砂坂）では，無シェルター（裸出及び植生が疎な砂丘）・低シェルター（汀線側の造林地林縁部）・中シェルター（造林地中央部）・高シェルター（汀線から最も遠い，造林地林縁部）の4つのレベルに区分して検討することとした。

3) 研究対象地とした北海道の代表的海岸荒廃砂丘地である砂坂では，漁業用燃料材として天然林が伐採されたために，60年前には一大荒廃地と化したが，50年前から前砂丘造成とクロマツ植栽による砂丘の固定がおこなわれている。また，足尾の山腹斜面では無計画な伐採と銅製練の SO_2 ガス噴出によって荒廃が進んだが，現在では土木工法と植生工法により，部分的には植生復元が実現している。

4) 植生・土壌・気温・地温（地表及び地中）等の立地環境要因を，シェルター成立の前後において比較することにより，シェルター効果の判定を行なった。その結果，立地環境要因の改善状況はシェルターのレベル（無・低・中・高）によって異なることが明らかになった。例えば砂坂において，植生シェルターによる立地環境要素の変化を樹木指標から見てみると，風圧による樹幹傾倒度は，低シェルターが中シェルターの2.5倍，高シェルターの4.5倍となっており，また造林木の生育によるシェルター度の増大にともなってあて材形成も減少していた。

5) 土壌要因へのシェルター効果は A_0 層で認められ，有機物含有量は無シェルター・低シェルター・中シェルター・高シェルターでそれぞれ0.4%・29.0%・31.4%・48.3%であり，炭素・窒素・粘土含有量も同様の傾向にあった。一方，A_0 層より下層では土壌要因は無シェルター・有シェルターとも差はなかった。

6) 砂丘の含水量は地表の乾燥砂層の有無により左右されていた。この層は蒸発散を抑制し地下からの水分の損失を防ぎ，このため湿潤期・乾燥期を問わず，砂丘の深層では少量ながら永続的に水分が保持されていると考えた。砂坂・石狩・鳥取の海岸砂丘地とインド・イスラエルの砂漠砂丘地ともに，表層の含水量は1.0%以下であったが，地下50～60 cmでは2.4%～5.8%と高くなっていた。この点は，砂丘地における植生復元にとって大きな手がかりとなる。

7) また温度についてみると，砂坂の乾燥砂層の地温は約50°Cまで上昇するが，下層の地温は低く，気温と同一であった。すなわち，地表から5.0 cmの高さまでは温度は徐々に下がり，20.0 cmでは地表温度の影響は及んでおらず，また地下50.0 cmでは大気とほぼ等しい安

定した温度となっていた。

8) 足尾山地において，急傾斜地の激甚荒廃地では航空実播による植生復元が行なわれ，それ以外の場所では1年目には土木工法，2年目に植生袋の設置，3年目に樹木植栽という3年がかりの工法がとられた。その結果，現在は健全な森林が成立するようになり，落葉層が3.8 cmの厚さに発達するところもみられ，裸地斜面時の荒廃要因であった表面侵食は見られなくなった。

9) 以上の結果に基づき，荒廃地における植生復元計画の構想を以下のように提起した。

(1) 表土の固定……砂丘地では表面を石礫で被覆した低砂丘土塁列を造成し，列間には石・土塊を点在させる。山腹斜面には，交互状テラスを造成する。

(2) シェルターの造成……灌木・豆科木本の列状あるいは円状植栽の数年後に、主要造林木をその列間または円内に植栽し，シェルター効果を期待する。

(3) 水分の保持……○植栽は降雨・降雪前とし，植栽樹の根元をわらや小石で覆い，蒸発散抑制をはかる。○砂丘地では，石・土塊の点在により乾燥砂層の侵食を防ぐ。○山腹斜面では，交互状テラスに積雪を集め，融雪水を貯える。

(4) 土壌の改良……○植栽穴底部に敷きわら（有機物）を行ない，土壌には肥料・堆肥・一部のシェルター植物の細片を混入する。○豆科木本の植栽により窒素固定をはかる。○侵食により表土流出の激しい急傾斜地では，擁壁工と土壌・種子・肥料を詰めた植生袋を設置する。

(5) 段階的植栽……○第1段階…低砂丘土塁列・交互状テラスの造成。○第2段階…初期シェルター用植物（草本・灌木・豆科木本等）の植栽。数年後にこれらの細片の土壌混入と，針葉樹（第1主要造林木）の植栽。○第3・4段階…広葉樹（第2主要造林木）の植栽。○最終的には針広混交林とする。

(6) 植栽樹種の選定……○適用樹種は，生長が早く・樹冠が広く・落葉生産量が多く・繊維質で層状の根系をもち・耐乾性が強く・風圧に耐え・樹幹が有用材となる等の条件を満たすものが望ましい。

10) 植生シェルター効果と森林立地環境変化（とくに植生・土壌要因）についての検討結果から，disturbance·stressの抑制と，立地環境の改善を期待し得る裸出砂丘地と荒廃山地の植生復元モデルを導いた。このモデルは，中央アジア半乾燥地帯（アフガニスタン）においてその適用が効果的と考えられる。