New Restoration Engineering in Northeast Asia

Ken YOSHIKAWA

Graduate School of Environmental Science, Okayama University,
1-1-1, Tsushima-naka, Okayama 700-8530, Japan
e-mail kenchan@cc.okayama-u.ac.jp

Abstract

The environmental conditions of desertifed areas differ from those where natural regeneration of shrubs and trees occurs, and the revegetation process can be acceletated by planting shrubs and trees. A variety of countermeasures including constructing sand barriers, planting trees and establishing appropriate stocking rates must be implemented under careful consideration of both local socio-economic demands and the degraded environmental condition. This article presents the results of some revegetation trials the author undertook in China and Mongolia. It describes how countermeasures to prevent sand drift and soil erosion are needed in accordance with varying site conditions. For example, in sandy soil, sand barriers are effective at stabilizing land surfaces, whereas, in clayey soil conditions, water harvesting to prevent run-off is a useful way to protect the site's condition. In ecological restoration, proper selection of plant materials is important in terms of vegetation enrichment and social benefits. Once vegetation has been established, its consumption of water will have a strong effect on soil moisture content. Long-term density control with frequent monitoring of environmental changes is necessary to maintain the restored ecosystem in sound condition. Thirty percent is the threshold value of coverage to stabilize sand surfaces irrespective of vegetation type. Indigenous plants are the most advisable species for greening. When seedlings are introduced into an arid land system, site preparation is the main factor helping them overcome the first dry season after planting. Site preparation centers on improving the moisture supply to the seedlings and reducing overall moisture loss by eliminating weeds to mitigate environmental stress.

Key words: afforestation, checkerboard sand barrier, ecological restoration, indigenous plant, site preparation, water harvest

1. Introduction

To curb desertification and alleviate its impacts on the environment and human life, restoration and revegatation of deteriorated arid lands are valid methods (Li *et al.*, 2003). Deforested areas can be left to undergo secondary succession (Gumaa *et al.*, 1998) or passive restoration (Debussche *et al.*, 1996). The environmental conditions of these areas usually differ from those where natural regeneration of shrubs and trees occurs, and different abiotic and biotic factors hinder the establishment of introduced woody seedlings (Gordon *et al.*, 1989; Brown *et al.*, 1998; Holl, 1998; Hooper *et al.*, 2002). Thus, revegetation relying on natural processes takes a long time to restore a desirable ecosystem even under appropriate management (Zutter *et al.*, 1986; Lemieux & Delisle, 1998; Rey Benayas & Camacho-Gurz, 2004). The goal cannot be reached at all in shorter periods. Therefore, most deforested areas should be actively restored by planting and managing shrubs and trees to accelerate the restoration process.

Plantation forests can provide a range of economical, social and environmental benefits (van Dijk & Keenan, 2007), such as protection from soil erosion, increase in biological diversity and creation of carbon sinks (Vieira *et al*., 1994; Whisenant *et al*., 1995; Maestre *et al*., 2001). On the other hand, starting from around 40 years ago (Bosch & Hewlett, 1982) scientific evidence has accumulated on how afforestation of agricultural land reduces stream flows, and this has permeated into the public consciousness. At least theoretically, afforestation may lead to a decrease in the amount of water available for plant growth. For instance, deep-rooted trees growing in seasonally dry climates can access soil water and sometimes groundwater at greater depths (van Dijk & Keenan, 2007), so they can sustain greater transpiration rates through dry periods (*e.g*., Nepstad *et al*., 1994; Dye & Versfeld, 2007). Therefore, in most cases, afforestation and reforestation can decrease surface water generation by high water infiltration into the surface soil layer but prevent groundwater recharge because of their vigorous water consumption, trigger a rapid decrease in aquifers and an increase in their secondary salinization and thus compromise the sustainability of forestry and agrucuture in the long term (Nosetto *et al*. 2007).

To restore vegetation on desertified land, a variety of countermeasures must be implemented, including the establishment of appropriate stocking rates and grazing regimes, complete enclosure of desertified grassland, use of various artificial sand barriers and planting of trees and shrubs in severely desertified areas. If the original vegetation was already lost a long time ago, it can be hard to determine what the final restored vegetation type should be. It must have some connection with both the livelihood of the local community and be amenable to the stakeholders' wishes for vegetation types. Therefore, these diverse countermeasures must be implemented with careful consideration of both the socio-economic demands of the local community and the environmental condition of the degraded area, including changes in the water balance arising from restoration of vegetation. If local demand is regarded as more important than the natural condition, however, the objective of revegetation will become too different from the original plant community and it will be unsustainable because of its extreme impact on the habitat condition. Under continual environmental monitoring, the management of afforestation and reforestation in drylands must be accomplished with careful consideration of changes in condition of the natural habitat.

This article presents the results of some revegetation trials the author undertook in deteriorated lands under arid climate conditions in China and Mongolia for the purposes of examining biotic and abiotic factors affecting restoration processes and indicating points of planting techniques needing improvement.

2. Ecological Restoration

Ecological restoration is a process through which degraded land is returned to a prior natural condition, or to a condition that assures effective ecosystem functioning. The general aims of restoration are (1) to increase biodiversity and improve plant density and species composition for higher resilience of the ecosystem, (2) to increase the vegetation cover and soil water infiltration rate and decrease runoff so as to prevent erosion, and (3) to create a stable water balance for sustainable plant growth and increase the land's productivity for a higher grazing capacity. Multifaceted considerations are needed in ecological restoration of various ecosystem services to attain effective greening.

Trees directly yield construction materials, food, fuel wood, charcoal, utensils and medicine and indirectly yield materials such as leaf litter and manure for agriculture (Gerhardt & Nemarundwe, 2006). Water retention, hydrological services, prevention of soil erosion, windbreaks and shade are some of the non-market, indirect benefits associated with matured trees and woodlands. The establishment of trees in grassland ecosystems by means of both human-induced afforestation and natural invasion is taking place around the world at increasing rates (Jackson *et al*., 2002) and may intensify in the near future, motivated by a carbon emissions trading market (Wright *et al*., 2000). The colonization of some pioneer plant species on bare mobile sandy land can help to stabilize moving sand surfaces and accumulate wind-dispersed seeds beneath their canopies as an 'island of fertility' (Schlesinger & Pilmanis, 1998; Su *et al*. 2002; Li *et al*., 2003) which can promote the future colonization of other plant species. In addition, increases in vegetation coverage and above-ground biomass may also be efficient as a means of soil amelioration through interception and retention of more precipitation and aeolian dust (Moreno & Gallardo, 2002). For instance, *Sabina vulgaris*, a unique native evergreen and shrubby conifer species in the Mu-Us sandy land of the Inner Mongolia Autonomous Region (Fig. 1), showed a remarkable difference in soil structure beneath their canopies from the surrounding grassland (Fig. 2). A high proportion of fine particles in the upper soil layer occurred as a result of their creeping branches with dense needles trapping aeolian sandy dust.

Fig. 1 Bird's eye view of the Mu-Us sandy land in the Inner Mongolia Autonomous Region.

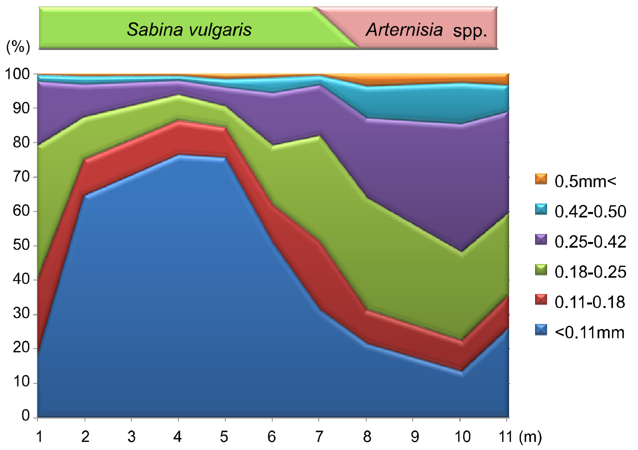

Fig. 2 Soil particle size distribution in the fixed sand dune area dominated by *Sabina vurgaris.*

3. Differences in Restorative Countermeasures for Different Soil Properties

The effects of revegetation treatments differ remarkably between sandy and clayey soil. A combination of tilling, seeding and brush packing successfully treats bare patches of clayey soil in South Africa (Visser *et al.*, 2004), but fails to produce good results in sandy soil. In clayey soil conditions, seeding treatments attain relatively good results in the first year, but almost all effects are lost in the second year. On the other hand, seeding treatment in sandy soil habitats takes a long time to have an apparent effect. The suitable measures adopted for each soil condition must be differentiated depending on the different processes of land degradation. As the loss of vegetation initiates sand drift on a sandy soil surface, sand barriers are the most effective way to stabilize the land surface. Field experiments have revealed that the establishment of sand-fixing forests on severely desertified sandy land is a viable way to restore degraded vegetation and prevent desertification (Li, 1992; Li *et al.*, 2003). On the other hand, in clayey soil conditions, water erosion is the most serious problem and the prevention of run-off by using water harvest techniques such as micro-catchment is a useful way to conserve the site's condition.

3.1 Sand barriers in sandy soil conditions

The most effective method of preventing sand movement is to introduce sand barriers. Among different barriers, checkerboard sand barriers, consisting of straw or shrub branches, are the most successful and widely applied countermeasure. As wind transportation is a near-surface phenomenon, more than 80% of sand transportation occurs within 12cm height from the ground surface even under strong winds (Li *et al.*, 2003). Increasing the surface roughness to reduce the wind velocity just on the sand surface is effective at preventing sand drift. The checkerboards, several tens of cm in height, increase roughness by more than 200 times at a height within 20 cm above the ground, and reduce the wind velocity by 20%-40% at a height of 2 m. Moreover, checkerboards consisting of organic materials can increase soil fertility. As the checkerboards remain intact for only 4-5 years after construction, the prompt introduction of perennial plants is necessary for the sustainable stabilization of sand dunes (Fan *et al.*, 1999).

An experimental site of 19 ha was established in 2005 in a large sand dune area in the western Mu-Us sandy land in Yinchuan City in the Ningxia Hui-Zu Autonomous Region. Half of the area was treated with straw checkerboard sand barriers, and four shrub tree species, *Caragana psammophyla*, *Hedysarum scoparium*, *Atriphaxis bracteata* and *Calligonum mongolicum*, were planted. People in this region believe that irrigation is indispensable for planting on sand dunes even with the sand barrier treatment. However, we tried planting shrub seedlings without any irrigation so as to simplify the pre-treatment for planting. It was thus necessary to devise a new method of planting and select an optimal planting season. As shown in Fig. 3, it was more advantageous to plant *Caragana psammophyla* and *Hedysarum scoparium* seedlings in the winter with the sand barrier treatment than in the spring. On the other hand, *Atriphaxis bracteata* and *Calligonum mongolicum* showed little difference in the effect between winter and spring when the sand barrier treatment was applied, so the results differed from species to species. However, the

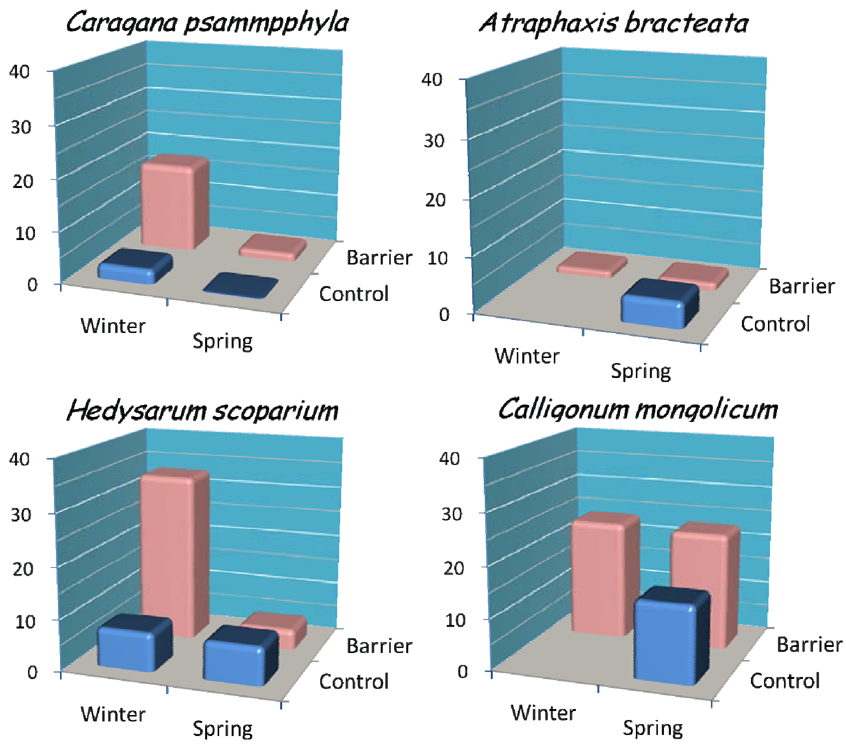

Fig. 3 Survival rates of seedlings planted in two different seasons with and without sand barrier treatment.

(a)
(b)
(c)

Fig. 4 (a) Checkerboard sand barrier, (b),(c) Aerial photo of surviving seedlings with(b) and without(c) sand barrier treatment.

similarity of survival rates between the control and the treated group in the spring planting for all species indicates the possibility of low-cost planting in spring. The spring planting in our experiment was the first trial in this region because of its difference from the traditional custom there of winter planting. This result indicates the possibility of non-irrigated plantation even in an arid sandy land at a suitable season with a suitable sand barrier treatment. The traditional planting procedures have yet room for improvement. Spatial distribution of the surviving seedlings (Fig. 4) shows that the sand barrier treatment can help distribute the survivors uniformly irrespective of the site conditions. However, an aggregate distribution of survivors in the control plot indicates that seedlings growing without sand barriers can survive only under particular local conditions related to micro-topography. The next step should be to improve planting procedures to overcome site differences in micro-topography without sand barrier treatment.

Fig. 5 Experimental plot established across a sand dune–grassland boundary.

3.2 Soil crusts in clayey soil

In clayey soil, trampling by livestock causes soil compaction and crust formation, which decrease the rate of water infiltration into the soil and increase water flow on the ground surface. Such run-off accelerates soil erosion and leads to loss of organic materials and nutrients. Moreover, soil crusts negatively affect vegetation development through inhibition of root growth (Yates *et al*., 2000). When that happens, improvement of soil physical conditions by mechanical treatment is necessary in clayey soil to increase water permeability so as to prevent soil erosion as well as to help root growth (Snyman, 2003). In the case in which a crust has formed on the ground surface, the crust must be shattered by means of mechanical cultivation (*e.g*., ripping and hollowing). Plant growth improves with deep plowing and subsoiling to decrease soil consistency. Providing above-ground obstructions such as by laying piles of branches (brush packing) can improve water permeability and soil fertility (Tongway & Ludwig, 1996). Application of organic materials can improve soil chemical and physical conditions. Combinations of these methods with seeding (van den Berg & Kellner, 2005) help restoration to succeed in clayey soil conditions.

In some cases, however, water impermeability into subsoil can help the survival of young seedlings just after planting, because of the high amount of available water in the topsoil on the crust layer. In the northern part of Hustai National Park, Tov Province, Mongolia, a number of sand dunes have aggregated at the center of a flat, open grassland. On these sand dunes, shrubs can grow well. However, in the grassland, no perennial trees can grow at all. Two plots were established across the border between the sand dune area and the grassland (Fig. 5). Trees (*Pinus sylvestris* and *Ulmus pumila*) and shrubs (*Caragana arborescense* and *Arminiaca sibirica*) were planted in 2005 to determine the effect of site conditions on their survival and growth. In Plot 1, three species showed a higher survival rate in the sand dune area (Fig. 6). However, in the other plot, all the species showed a higher survival rate in the grassland area. Only in Plot 2 had a hard crust layer formed under the clayey topsoil. This repellant soil layer helped maintain enough soil water in the topsoil to ensure a high initial survival rate in the grassland area.

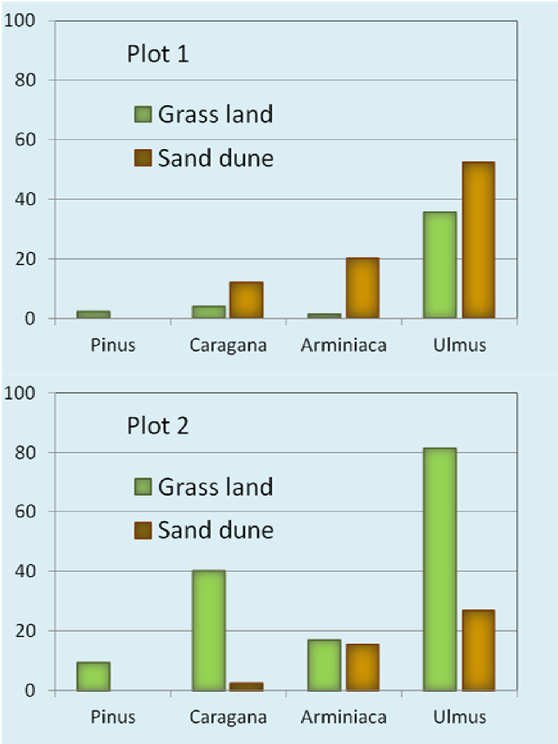

Fig. 6 Survival rate of planted trees and shrubs in the first year.

4. Plants Available for Arid Land Revegetation

Proper selection of tree species for revegetation in dry degraded lands would be considered the most important matter for ecological revival in terms of vegetation enrichment and soil amelioration as well as social benefits (Pal & Sharma, 2001). There are still not a sufficient number of plant species, however, which have desirable characteristics for revegetation in arid and semi-arid regions.

4.1 Stress tolerance

Large areas of degraded and/or abandoned cropland and rangeland in arid regions can be reforested with shrubs and trees to gain a number of environmental benefits. However, establishment and growth of woody plants in these areas are limited by high radiation and low water availability during summer, and weeds are strong competitors for resources, particularly water (Rey Benayas *et al*., 2005). A high germination rate and rapid growth with high tolerance to environmental stresses are necessary for survival in such harsh habitat conditions. The Sanbei Forest Shelterbelt project is the most famous greening project combating desertification and controlling dust emissions in China, carried out from the late 1970s (Fig. 7). Proponents insist it has achieved dramatic rehabilitation of the huge northern arid area which had been left degraded for many years (Li *et al*., 2003). However, Wang *et al*. (2010) claimed that it has failed to meet its goals to combat desertification and control dust emissions, because of the low survival rate of the planted trees and shrubs, caused by mis-selection of tree species and a large-scale monotonous form of plantation which ignores habitat heterogeneity. Consequently, afforestation and reforestation in large arid and semiarid areas must be promoted with careful consideration of both the stress tolerance of trees and variations of site conditions.

Fig. 7 A part of the Sanbei Forest Shelterbelt in the Inner Mongolia Autonomous Region.

A large proportion of environmental conditions can be changed by themselves with the development of induced plant communities, because it takes a long period to establish a matured forest. Soil moisture contents of sites in Shapotou, Ningxia Huizo Autonomous Region, which have been afforested for 25 to 45 years, have become dryer than the younger afforested sites of less than 15 years in age (Li *et al*., 2004). Furthermore, the magnitude of annual variation in soil moisture is smaller in the older afforested areas than in the younger ones. Once vegetation has been established, the water consumption by vegetation has a strong effect on soil moisture content and its temporal variation. In this process, the shrubs appearing in the initial stage with a deep-root system are replaced by the shrubs and annual plants with a shallow-root system and the total coverage of shrubs decreases because of the diminution of soil moisture as the trees grow big. Long-term density control with frequent monitoring is necessary to maintain a restored ecosystem in sound condition.

In 1989, JICA supported a project covering 110 ha of afforestation on bare shifting sand dunes using eleven tree species in Yinchuan City, Ningxia-Huize Autonomous Region. In 1991, most of the tree species showed good results in terms of survival because specific planting procedures had been used for each species (Yoshikawa *et al*., 2006). However, in 2005, more than half of the planted trees had died, except for those of three species of *Populus*. As *Populus opera* can construct a dense forest with a high survival rate, a large proportion of suppressed trees wind up growing under a small number of tall dominant trees. On the other hand, self-thinning in *Populus bolleana* can promote growth of survivors in later decades. In some cases, a high survival rate of planted trees is not necessarily a good result for forest management, because it causes severe competition among survivors with reduced functioning of the ecosystem.

(a)

(b)

(c)

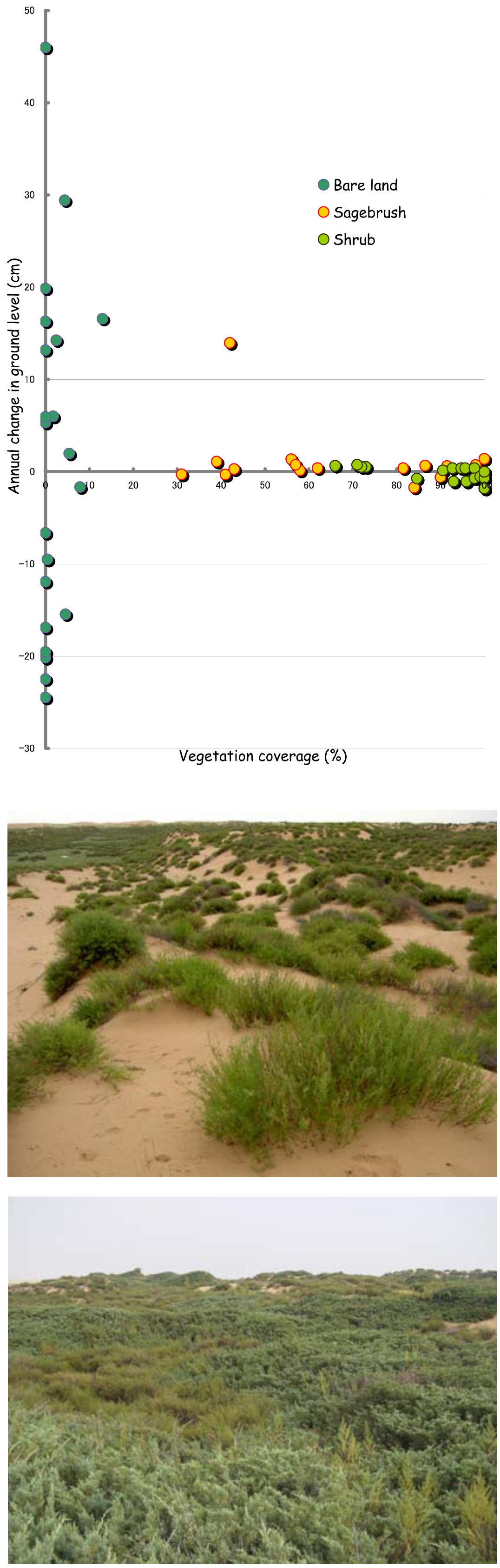

Fig. 8 (a) Relationship between vegetation coverage and annual change in ground level on a fixed sand dune area in the Mu-Us sandy land convered by scattered community of (b) sagebrush, *Artemisia ordosica* (c) dense community of *Sabina vulgaris.*

4.2 Water balance

The establishment of a local and regional water balance is indispensable for rational greening of arid and semi-arid regions with severe water deficiencies. Wide, deep root systems, and creeping stems with dense adventitious roots ensure a sufficient water supply and development in dry land. However, high abilities to absorb water are not always desirable from the standpoint of the water balance among interactive plants.

Windbreaks consisting of arbor trees can improve the microclimate for crop growth (McNaughton, 1983, 1988; Brenner *et al*., 1995) making crop yields generally higher behind windbreaks than in unsheltered fields (Ujah & Adeoye, 1984). Where windbreaks have access to groundwater or deep reserves of soil water, the effects of the windbreaks on crop productivity are not severe (Smith *et al*., 1998). Where groundwater or deep reserves of soil water are not accessible to windbreak trees, however, the suppression of water use by the trees is a vital strategy for windbreak management. Pruning of lateral roots by trenching (Onyewotu *et al*., 1994; Schroth, 1995) could be recommended to reduce below-ground competition between trees and crops (Sudmeyer *et al*., 2002; Sudmeyer & Flugge, 2005). Species with root systems that do not spread laterally for large distances near the soil surface would be desirable for such situations.

The fixed sand dune area in the Mu-Us sandy land, where there are three types of landscapes, shifting sand dunes (50%), grasslands (30%) and fixed sand dunes (20%), appearing as a mosaic (Fig. 1), was covered by sagebrush (Fig.8 (b)) and *Sabina vulgaris* (Fig.8 (c)), which can prevent sand drift with their creeping branches and improve habitat conditions. The relationship between the vegetation coverage and annual change in ground level (Fig. 8 (a)) shows that about 30% is the threshold value of coverage needed to stabilize sand surfaces irrespective of vegetation type, such as evergreen trees or deciduous shrubs. Shrubs are as effective as trees if the vegetation coverage exceeds 30%. Moreover, planting grasses and shrubs is more valid under certain site conditions, because they are more resistant to being buried by sand. For example, thorn scrubland and grassland with native plant species in Spain (Chirino *et al*., 2006) could control runoff and soil erosion more effectively than an introduced Aleppo pine plantation.

4.3 Indigenousness

Many exotic tree species used in revegetation cause major problems as invaders of natural and semi-natural ecosystems. The magnitude of this problem has increased significantly over the past few decades, with the rapid increase in revegetation and changes in land use (Richardson, 1997). Although *Prosopis juliflora* has been one of the most important exotic trees in restoring desertifed drylands in Africa, it can eliminate all competing annuals and most perennial plants from the afforestation area and its surroundings with its dense canopy and vigorous reproductive ability (El-Keblawy &

Ksiksi, 2005).

Popular and indigenous plants for which mass-production technology for seeds and seedlings has been developed are the most advisable species for greening. In Australia, for instance, the recent shift in plantation forestry away from exotic to indigenous species has resulted in great enrichment of native species within the forests (Strauss, 2001).

5. Planting and Management

5.1 Micro-topography

Site conditions differ greatly even among parts of a small sand dune (Fig. 9). For example, on the windward slope, the sand is compact and hard because of wind erosion. On the other hand, the sand on leeward slope is soft and dry because of the inflow of sand. To stabilize shifting sand dune surfaces in China, tall trees are planted on the leeward side of the dune to prevent sand from scattering away, and shrubs are planted on the windward slope to protect it from wind erosion. According to the differences in conditions at each site, different sets of species are available for each part of a sand dune.

Rainwater flows laterally through the subsurface of the steep slopes of sand dunes and runoff can concentrate at the foot of dune slopes, creating soil moist conditions, which have enhanced the growth of *Tamarix aphilla* planted at the foot of steep dunes in the Negev desert. Runoff, however, seldom occurs on the gentle slope surfaces, resulting in uniform dry soil conditions with little vegetation coverage (Arbel *et al*., 2005). A similar trend is observed for *Populus bolleana* planted in the shifting sand dune area in Yinchuan City (Yoshikawa *et al*., 2006). Most of the trees growing in a flat lowland show a die-back phenomenon and are smaller than those growing on a steep slope. When performing afforestation in sandy arid lands, it is important not to plant trees according to regulations, but to plant in consideration of micro-topography.

5.2 Site preparation

Poor site preparation and post-planting maintenance have been significant contributors to planting failures (Harrington *et al*., 2004). The first dry season is clearly a bottleneck for the survival of introduced seedlings (Rey Benayas, *et al*., 2005). Consequently, in arid land systems, site preparation centers on improving moisture supply to the seedlings and reducing overall moisture loss by eliminating weeds to mitigate environmental stress. Water balance studies on the dry sloping land of the Loess Plateau have shown that about 5%-10% of the precipitation is lost as runoff, 45%-50% is transpired by plants and 45%-50% evaporates (Zhang & An, 1997). Microcatchment water harvesting and moisture conservation techniques (*e.g*., tillage and mulching) are valid practices for use in increasing water use efficiency for tree growth (Tabor, 1995; Gupta, 1995; Ojasvi *et al*., 1999).

One of the most popular traditional methods of microcatchment in China is fish-scale hollowing (Fig. 10). Seedlings are planted in a hole girded by a semicircular ridge with the upper tips touching the contour line. The plastic sheet mulching method devised to increase water harvesting efficiency has been effective at ensuring the survival of seeds and seedlings in Lanzhou City, Gansu Province. A planting hole is

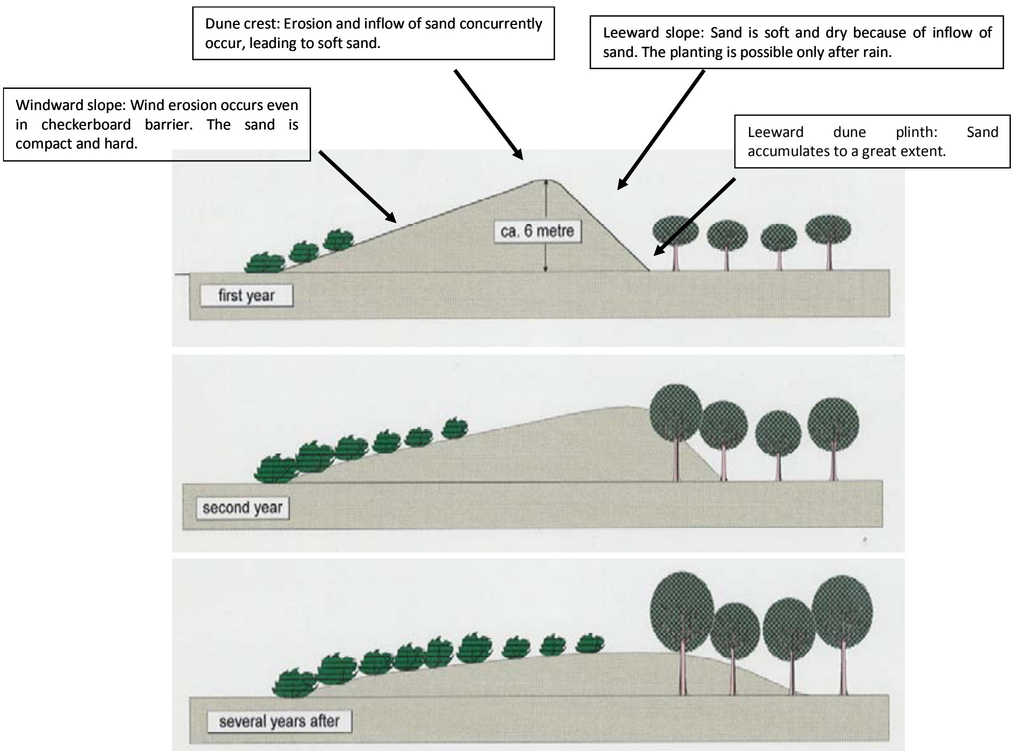

Fig. 9 Micro site conditions on a sand dune and planting procedures to stabilize a shifting sand dune.

Fig. 10 Fish-scale hollowing.

Fig. 11 *Salix psammophila* growing luxuriantly on a sandy hill in the Mu-Us sandy land.

covered by a big plastic sheet with a sufficient margin and seedlings or seeds are planted in a bore at the center of the sheet.

5.3 Inter-specific competition

Advanced vegetation and weeds proliferating in dry habitat strongly compete for water with introduced woody seedlings (Rey Benayas *et al*., 2005). In the Mu-Us sandy land, to analyze the effect of advanced vegetation on newly planted seedlings, four tree species, *Pinus sylvestris* var. *monogolia*, *Populus alba*, *Ulmus pumila* and *Euonymus alatus*, were planted on shifting sand dunes dominated by *Salix psammophila*, a tough native shrub tree. Almost half of the ground surface was covered by dense patches of this willow shrub (Fig. 11). As a result, half of the newly planted seedlings had to grow in competition with the advanced willow shrubs. To ensure adequate tree establishment, supplemental irrigation was provided throughout the first growing season. For all four tree species, the survival rate was lower in and near the clumps of predominant willows than in areas free from competition, indicating high inter-specific competition for resources, particularly soil water and radiation (Fig. 12). Therefore, the proper elimination and/or the control of advanced vegetation is necessary to mitigate a harsh environment and attain new ecosystem services when changing species composition.

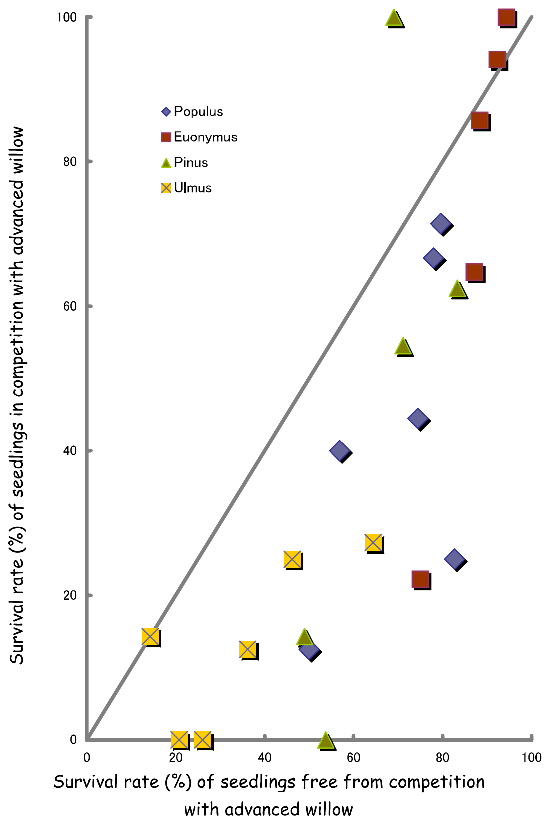

Fig. 12 Relationship between the survival rates of seedlings growing under competition with advanced willows and those growing free from any competition.

6. Conclusion

Afforestation and reforestation of drylands have been considered as an effective tool to restore species diversity and improve soil quality. Therefore, land manager likely wants to rehabilitate fast. But the restoration of dryland needs time and money to some extent, and some of the enthusiastic projects in drylands are failed by low cost/benefit ratio in the short-term, unreliable climatic variation, and absence of proven techniques that land users can prefer to adopt. Unfortunately, our technology of planting trees in dryland is still inadequate because of a short history of combating desertification. Precise evaluation of the effects of revegetation trials and its prompt feedback for improving planting procedures are indispensable to build up long term management systems. Although exotic tree species have been dominating the reforestation projects in drylands, the impacts of both indigenous and exotic forest trees on the natural native flora must be evaluated by the long term monitoring on tree growth and environmental changes. Such assessment would help in selecting the most suitable species for revegetation.

Moreover, planting trees are not always the best way to rehabilitate the degraded dryland, because any trials even for reforestation in deforested area must have serious effects on the fragile arid environment and sometimes the misleading of revegation should cause a retrieval sterilization of degraded lands. Therefore, the restoration programs must be devised without any exclusion of countermeasures against land degradation, and be designed for rehabilitating the deteriorated ecosystem based on both ecological principles and socio-economic benefit.

Acknowledgments

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Ken YOSHIKAWA

Ken Yoshikawa is a Professor at the Graduate School of Environmental Science, Okayama University. He received his M.S. and Ph.D. in Forest Ecology in 1981 from the Graduate School of Agriculture, Kyoto University. His research has focused on stress tolerance of trees growing in harsh and degraded habitats and, especially since 1987, he has been conducting applied researches on combating desertification in China based on forest ecology and tree physiology. During more than 30 years of professional activities, he has participated in many research projects closely related with environmental restoration, and as a results, the localities of his research are widely disseminated throughout the world from East Siberia, Mongolia, northern, western and eastern China, Asian countries (Viet Nam, Indonesia), Middle Eastern countries (Oman, Saudi Arabia, Egypt) and Kenya. From 1994, he has been a Guest Professor at the Inner Mongolian Agricultural University, China. He has published many books, including "Challenge to Combating Desertification in China" (Chuou Kohronsha) and "Arid Environment and Its Restoration" (Kyouritsu Shuppan). He has been serving as Vice Dean of the Graduate School, Okayama University, working on the education for sustainable development.

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