Chapter 2
Controlling Sand Movement Through Mechanical Measures: China's Experience

G. Ali Heshmati

Synopsis This chapter is an overview of the measures taken to stabilize mobile sand to protect farmland, and infrastructure such as roads, railway tracks and irrigation canals. The chapter explains in detail the various proven practices accumulated from years of trial and error and derived from scientific investigation in China's extensive sandy lands.

Key Points

- China is one of the states facing serious problems of desertification in the world. The affected lands are mainly distributed in arid semi- arid and dry sub humid areas in the west part of Northeast China, North Central China and the most part of Northwest China. Shifting sand is one of the serious contributors to desertification in China.
- China has developed very successful measures to stabilize shifting sands and revegetate denuded areas. These technologies have been tested under extremely difficult conditions in China's arid north west and are now used with equal success throughout the world.
- There are two complementary measures used to fix shifting sands. One is to protect the vegetation on the sand dunes or where such vegetation has deteriorated, to plant trees, shrubs and grasses (see Chap. 3). This type is known as biological or plant measures. The other method depends on mechanical measures. These are used to set up barriers on sand dunes or to cover the surface of sand dunes by wheat straw, clay, and branches of trees, bamboo, reeds, sorghum stalks, cobblestone, and petroleum chemicals and so on. Mechanical measures have been proven to be effective in fixing shifting sand dunes. However, their success is limited to a number of years, hence; they should be complemented

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with other measures, especially the biological measures. This is where suitable desert plant species are planted immediately after the shifting sand is fixed so that permanent solutions can be attained.

Keywords Desertification • Mechanical measures • Sand dunes • Wind erosion • Land use change • Checker boards • Wind velocity • Transport routes • Infrastructure • Shapotou • Xinjiang • Gansu • Ningxia • Inner Mongolia • Tennger/Tengeli desert • Taklamakan desert • Gobi desert • Yellow river • Qilian mountain

1 Introduction

Shifting sand is one of the serious contributors to desertification in China (Ci and Yang 2010). There are two complementary measures used to fix shifting sands. One is to protect the vegetation on the sand dunes or, where such vegetation has deteriorated, to plant trees, shrubs and grasses. This type is known as the biological approach and is dealt with in Chap. 3. The other method relies on mechanical measure and is the subject of this chapter.

Sand dunes especially along the fringe of sandy desert encroachment seriously harms or threatens farmland, villages, irrigation canals, reservoirs, transportation (highway, railway), mining, etc. It is in these areas that mechanical measures are suitable as emergency measures to fight against the moving sand dunes. Mechanical measures are preferable to biological ones under these circumstances. In some extremely arid areas, subject to wind and sand movement, plants can barely survive and grow and so in order to prevent sand dune encroachment, mechanical measures must be taken. If it is desirable to plant trees, shrubs or grasses on the sand dunes in some areas, mechanical measures should be taken before planting of trees, shrubs or grasses. Otherwise the seeds or seedlings of the plants will be exposed by wind or buried by blown sand even if the soil moisture content is available and other natural factors are suitable for the plants. Mechanical measures, under these conditions, can prevent sand dunes from moving and guarantee the survival of these seedlings of the sand-holding plant species.

2 Relationship Between Mechanical Measures and Biological (Plant) Measures

In general, the service life of mechanical measures is about 3–5 years. They require regular maintenance after they are set-up. In any case, the effectiveness of desert control by biological (plant) measures alone is not satisfactory. Therefore, various sand-holding plant species should be planted after the mechanical measures. In the ensuing years, especially the first 5 years, these two measures can well be complimentary in checking wind and controlling sand (Fig. 2.1).

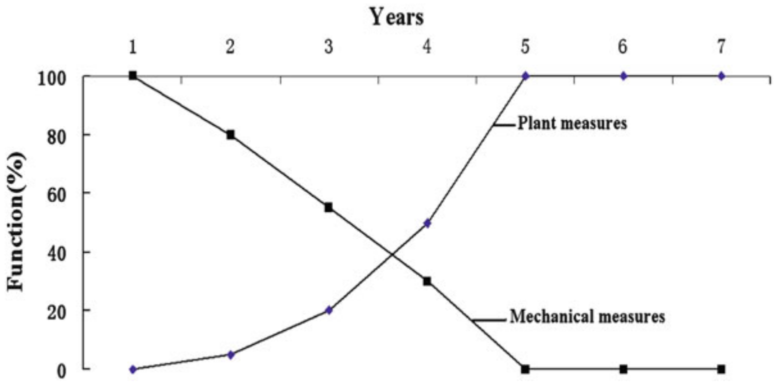

Fig. 2.1 Relationship between mechanical and biological measures

2.1 Types of Mechanical Measures and Their Uses

Modern classification of mechanical measure is generally based on the materials used, the methods of installation, the disposal pattern for the trapped sand, and the height, structure and function of the mechanical measures. Mechanical measures can be categorized into surface (covering) sand barriers and standing sand barriers. The types of mechanical measures and their functions are summarized in the Fig. 2.2.

3 Surface Sand Barriers

The movement of sand dunes needs two prerequisites. They are (1) power source – wind and (2) substance source – sand. When the wind (velocity >4.5 m/s) blows over the loose surface of the sandy land or sand dune, it will become sand-driving wind because some sand is entrained (lifted by the wind). This sand-driving wind is harmful as it will bury or damage crops or other objects. Measures to prevent such damage can be taken by covering the surface of the sand dunes. The principle of the surface barrier is to eliminate one of the above two prerequisites – substance source sand. When the wind passes over a sandy area, where a surface barrier has been set up, there will be no sand-driving wind formed.

The materials of surface barriers include straws and stalks of some crops, branches of trees, cobble stone, clay, earth, emulsified asphalt, asphalt belt and many kinds of complex polymers. The function of the barriers is to stabilize the moving sand on the spot because the sand is fixed and the passing wind is separated from the sand.

In many sandy areas of China, sections of sand dunes and oasis are distributed in a checker board pattern. These scattered sand dunes seriously threaten the farmlands of the oasis. In these circumstances, the laying of sand barriers, which are made

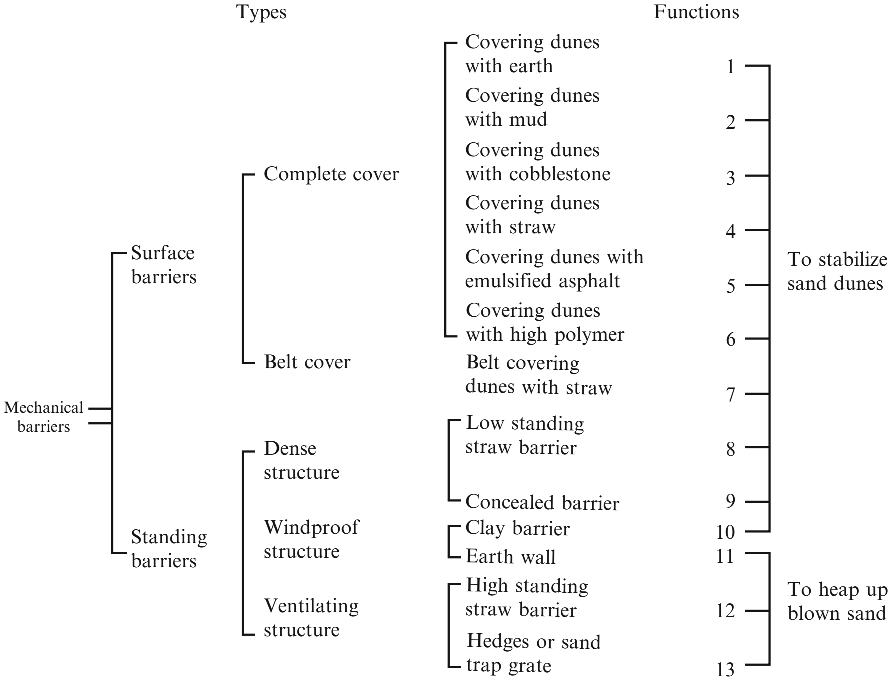

Fig. 2.2 Type of mechanical measure and its function

of local materials-straws, stalks, earth clay cobble stones among others is usually adopted. The cost of setting up such barriers is low as all the material for setting the barriers are abundant and locally available. This means that surface sand barriers can be easily utilized in such areas.

In controlling sand in some priority projects for example sand control for railway lines, emulsified asphalt has been used. However, this material is not locally available and its cost is relatively high. It is therefore not a suitable choice for general use. The following are some common surface barriers materials used in China.

3.1 Covering Sand Dunes with Earth or Mud

Local people living in the sandy areas cover sand dunes with earth or mud. The main function of the barriers is to protect agricultural production by stabilizing a sand dune that threatens adjoining agricultural land.

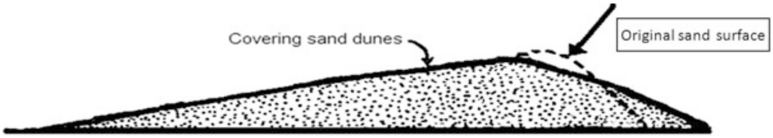

Fig. 2.3 The cross section of covering sand dune with earth

3.1.1 Technique of Covering Sand Dune with Earth

This technique uses the following steps:

- The sand top is pushed down the leeward slope to make the sand dunes gentle so that the earth can stay on the sand dunes.
- The surface of the sand dune is covered with clay or piled from the top to the foot of the sand dunes. The depth of the clay or pile covering on the sand dune is around 6–15 cm. Under normal conditions; it is deeper on the windward slope and the upper part of the sand dunes. The sand dune must be completely covered and the clay or piled soil is left loose. Some plants such as *Artemisia arenaria* and *Agriophyllum squarrosum*, can be sown after the sand dunes are covered. At the same time, several lines of trees or shrubs should be planted along the foot of the sand dunes so as to stabilize the sand dune permanently. See Chap. 3.

Covering sand dunes with mud is often practiced in areas where plants survival is problematic due to extreme shortages of rainfall. The function of the mud is to reinforce the sand surface and protect the sand dunes from erosion.

3.1.2 Technique of Covering Sand Dunes with Mud

The technique of covering the sand dunes with mud is basically the same as that of covering the dune with earth. Generally the steps of employing the earth or mud barrier are as follows:

- Cover the sand dunes with earth or damp soil
- Cover the earth or damp soil with mud alone or mud mixed with broken straws
- Daub plaster on the sand dunes from the top to the foot of the sand dunes.

A protective crust, on which there will be no plants, will be formed. Finally, trees and shrubs can be densely planted along the foot of the sand dunes. Although this method can consume a lot of man-hours it can save many useful materials and it can control moving sand dunes immediately.

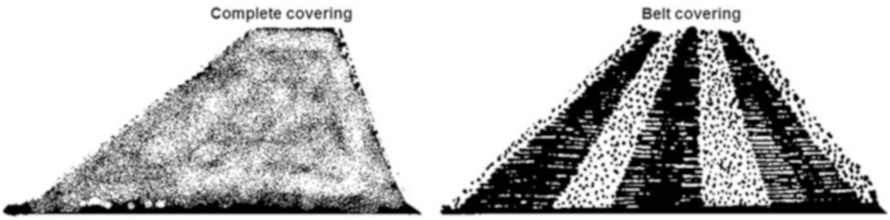

Fig. 2.4 Covering sand dunes with straw or branches

3.2 Covering the Sand Dunes with Straw or Branches

This method involves covering the sand dunes densely with straw or branches. It is usually used in areas where straws or branches are abundant. For this method, there are two types of covering sand dunes: (1) complete covering and (2) belt covering (Fig. 2.4).

3.2.1 Complete Covering

The sand dunes are completely covered with straws or branches and then sand is placed on the straws and branches, or they are held down with some big branches across them. The advantage of this type of sand barrier is that it can stabilize the sand dunes completely. Its shortcomings are that it will consume a lot of materials (approximately 370 kg of straws per hectare) and it is inimical to the growth of sand plants because the moisture conditions of dunes protected by this kind of barrier are unfavorable.

3.2.2 Belt (Strip) Covering

Here the dunes are covered with strips or belt of straws or other plant matter. The widths of the belt are varied. In general, the width is the same as the length of the straws or branches used in the barrier, that is, 50–100 cm. The row spacing is about 3 m. The run of the belt should be at right angles to the direction of the prevailing wind. In order to prevent the belt barrier from being blown away by the wind, the barrier should be covered with sand along the central line of the belt.

3.3 Covering Sand Dunes with Other Materials

In areas where clay is in short supply but cobblestone, baijang soil (clay pan or plano soil) and gypsum are abundant and available, this kind of sand barrier is often adopted.

3.3.1 Covering Sand Dunes with Cobblestones

The principle and the method of covering sand dunes with cobblestone or gravel are the same as for covering dunes with earth, but the depth of the covering using these materials is around 3 cm, not 6–16 cm.

3.3.2 Covering Sand Dunes with Baijang Soil

Covering sand dunes with baijang soil is usually used in those areas which are near a lake basin because baijang soil is commonly located in lake basin. The techniques are as follows:

- Mix the baijang soil with water
- Spread the baijang soil mixture onto the surface of the dunes. A very firm crust will be formed after the baijang soil is dry because baijang soil will cement the surface sand together.

3.3.3 Covering Sand Dunes with Gypsum

Covering sand dunes with gypsum is usually used in areas where gypsum is abundant. The establishing method is as follows:

- make plaster of paris into slabs
- crush the plaster of paris into powder
- mix the plaster of paris and sand, the ratio of plaster to sand is 7:3
- Spread the mixture into the surface of the sand dunes evenly
- Spray water on the mixture. A crust with depth of 2–3 cm will form on the surface of the sand dunes after the mixture is dry.

Among the above three kinds of barriers, the erosion resistance of the cobblestone or gravel surface is the best, and the service of the cobblestone or gravel sand barrier is the strongest. The other two kinds of sand barriers are liable to be destroyed by livestock, people or rain.

3.3.4 Covering Sand Dunes with Man-Made Materials and Chemical Stabilizers

This measure involves laying or spraying chemicals on the surface of moving sand to form a surface crust or permeate the chemical substance into the sand, then a cohesion layer will come into being, which can stop sand from drifting or moving. Sand-fixation of this kind has been trialled, especially the use of pitch emulsion, compounded chemical emulsion of wild plants, and animal's glue. Some achievements have been gained and the results showed that the method of using pitch emulsion (asphalt) is the best. However, with the high cost and lack of source, it cannot be extended on a large scale. Other materials tested are in the following models:

- In Taklimakan Desert, Chinese oil gas farms made trials of some man-made materials to cover the moving sand surface around oil gas facilities, along the expressway and tent settlements. These materials include: used plastics, poly-fiber, nylon and acrylic wire netting, oil based products and straw matrix.
- In Dunhuang, acrylic netting and nylon cloths are used to cover sand surfaces to protect the ancient Buddhist Grottoes of Magao.
- In Zhongwei County, Ningxia Hui Autonomous Region, some chemicals were adapted to fix shifting sand surfaces. The chemicals include: asphalt emulsion, OT-asphalt, ABS asphalt emulsion, OP-asphalt emulsion, Polyacylamide, Polyvinyl alcohol, Polyvinyl acetate, Hydrolytical polyacrylonitrite, and sodium silicate.

4 Standing Sand Barriers

If surface sand barriers affect one prerequisite of sand movement, standing sand barrier affect the other, namely wind. Wind velocity is reduced when any barriers obstructs the wind and some of the sand carried by the wind will heap up around the barriers when the wind velocity is reduced. The sand carrying capacity of the sand-driving wind is reduced by a big margin. According to studies on the structures of the sand-driving wind, 80–90 % of the total sand capacity of the sand-driving wind is found at the height of 20–30 cm above the ground and within this height of 20–30 cm, most of the sand is carried under a height of 10 cm above the ground. For this reason, if the standing barriers set up in the path of the sand-driving wind maintains a height of between 30–50 and 100 cm, most of the blown sand can be controlled. We can let the sand be carried by the sand-driving wind to heap up at the designated places through the setting-up of standing barriers. The dropped sand around the barriers will remain there because the wind velocity is reduced both behind and in front of the barriers, and the threat of the sand to any object can be eliminated by such standing sand barriers.

The weak wind areas formed on the leeward side and on part of the windward side of the sand barrier can allow the sand carried by the sand-driving wind to drop down and become fixed. Plantation on the bare surface of the sand dunes can be guaranteed because the standing sand barriers eliminate the sand-driving wind. Standing sand barriers, which are 50–100 cm high, are called high standing sand barriers. Standing sand barriers whose height is between 20 and 30 cm are called low standing sand barriers. Materials used for standing sand barriers, in general, are the following: straws or stalks of crops, tree branches, clay, and many other materials. Sand barriers made of any of these materials can reduce the wind velocity and heap up or stabilize the sand around the sand barriers. Standing sand barriers can

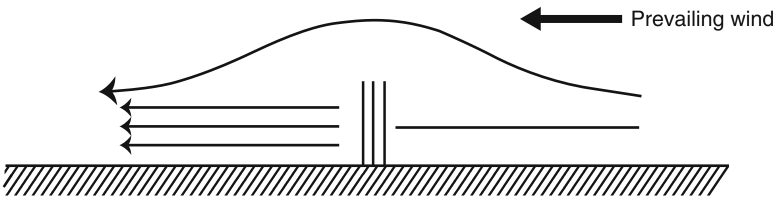

Fig. 2.5 The effect of ventilation sand barrier on sand-driving wind

be divided into different types on the basis of the materials, structure and patterns. These are *ventilating sand barriers* and *dense structure sand barriers* that have different functions in combating sand damage.

4.1 Ventilating Sand Barriers

When the sand-driving wind passes through ventilating sand barriers, the frictional drag is increased and will form separate turbulent flow and vortex flow around the barriers. The sand-transporting capacity of the sand-driving wind will be reduced because of the decrease in the kinetic energy and in the velocity of the wind through the interaction of the two kinds of flow. The sand will heap up on the windward and leeward sides of the sand barrier. The dropped sand on the windward side of the sand barrier is much less than that on the leeward side, so the sand barrier is not apt to be buried by the dropped sand. On the leeward side of the sand barrier, the mound of the dropped sand gently spreads with the wind and the mounded range. Grain size of the dropped sand is much larger than that of the windward side. So the ventilating sand barrier can act on sand-control for a long time and can stop a great deal of sand on the leeward side of the sand barrier (Fig. 2.5).

The phenomenon of sand-control differs with the different densities of the ventilating sand barriers, the space on the barrier and the level of ventilation. In general, the ratio of the area of the space on the barrier to the total area of the barrier is called the degree of density of the sand barrier. The degree of density of a sand barrier is generally regarded as the index of the sand-control efficiency of the sand barrier. When the degree of density of a sand barrier is about 25 %, it can heap up sand, on the leeward of the barrier, within a range of 7–8 times the height of the sand barrier. When the degree of density reaches 50 %, the range of the dropped sand on the leeward of the barrier is around 12–13 times the height of the sand barrier. As the degree of density of the sand barrier increases, the range of the dropped sand, the amount of dropped sand mound and the sand-control capacity of the sand barrier will rise. But when the degree of density of a sand barrier exceeds 50 %, wind erosion at the windward side of the sand barrier may occur, and under these circumstances, the sand barrier may be destroyed from the base. In order to make optimum use of sand barriers, the height, the row spacing and the degree of density of sand barriers should be determined in the light of specific conditions.

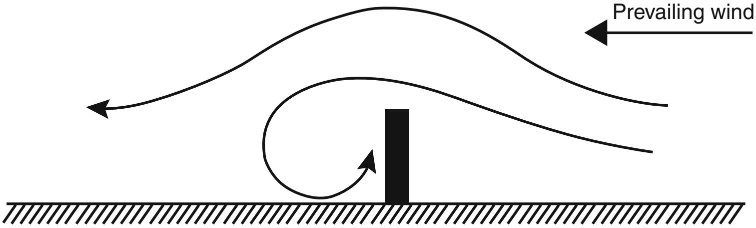

Fig. 2.6 The effect of dense structural and windproof sand barriers on sand-driving wind

The degree of density of a sand barrier suitable for a given area can be determined in accordance with the wind force and the abundance of the sand in the area. Under normal conditions, ventilating sand barriers whose degree of density is between 25 and 50 % are usually adopted in dune control. In an area where the wind force is strong and the sand is abundant, the degree of density of the sand barrier should be greater than normal; conversely, in an area where the wind force is weak and the sand not so abundant, the degree should be smaller than normal.

The sand control function of the standing sand barrier is satisfactory because it not only can stop the sand carried by the sand-driving wind, but also can stabilize the sand which is originally located around the barriers. The standing sand barriers can gradually gather many small sand dunes or sand mounds into one big dune and form a “sand-hold-back” sand dam or sand mountain. Standing sand barriers are often adopted to protect farmlands, canals, transport lines and wind gaps, which are seriously threatened by the moving sand, In order to prevent the protected objects from being buried by sand dropped from the sand-driving wind, a suitable distance must be kept between the sand barriers and the protected objects. This distance can be determined according to the degree of density and the range of dropped sand of the sand barriers.

4.2 Dense Structural Sand Barriers

A strong vortex flow will form around the sand barrier that is completely windproof or structurally dense because the sand-driving wind is raised upon the windward side and descends sharply on the leeward of the barrier when the sand-driving wind is obstructed by such a sand barrier. Because the vortex flows formed around the sand barrier affect each other, the kinetic energy of the blown sand is greatly consumed and both the wind velocity and the sand-transporting capacity of the wind are reduced. The sand carried by the sand-bearing wind will heap up around the sand barriers (Fig. 2.6).

If the sand is very abundant, the height of the dropped sand will be rapidly equal to the height of the sand barrier. In this case, the sand barrier is liable to be buried by the dropped sand, so the service life of a barrier, in this condition, is very short,

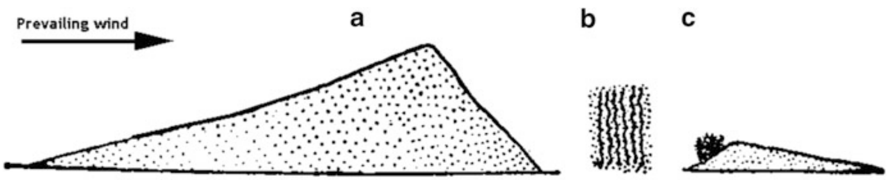

Fig. 2.7 The indication of the prevailing wind (**a**) is the initial condition after stabilizing the dune with standing sand barriers (**b**) is the location of plantings of trees and shrubs between the dunes and (**c**) the reduced size of the dune at some future time

however, the base of this type of barrier is not liable to be destroyed, and a steady surface of sand between two sand barriers will soon be formed. This phenomenon can protect the seedlings of plants seeded on the sand dunes where the sand barrier is set up. In order to avoid the seedlings of sand plant being buried by the shifting sand on the leeward side of the barrier, the plantation site between two sand barriers should be kept at a distance from the sand barrier. The low windproof or dense structural sand barriers should be installed before the planting of vegetation between sand barriers is started.

4.3 Installation of Standing Sand Barrier

Standing sand barrier are the most widely used in sand-control, especially the straw sand barriers that have often been adopted by local people to protect farmlands and irrigation canals. To protect railway lines and major infrastructure located in the sand areas, hedges of wood chips are usually used, and along the fringes of the villages or farmland, sand-protecting walls of earth are often adopted by local people. In recent years, clay sand barrier, which belong to the low windproof sand barrier type, have been widely used in desert areas. Techniques for installing various standing sand barriers are described in the following section:

4.3.1 Run of Standing Sand Barriers

The run as well as the disposing patterns of a standing sand barrier should be determined in the light of the direction of the prevailing wind, the patterns (shapes) of sand dunes and the purpose of the sand barriers. The run of a sand barrier should meet the direction of the prevailing wind at right angles. Therefore, the direction of the prevailing wind in the area that is to be protected must first be found out. According to the practical experience, there are three indicators: (A) the length of the windward slope and the leeward slope of existing sand dunes; (B) the patterns of sand ripples; (C) the run of sand plaits (Fig. 2.7).

On the work site, the run of the sand barrier can be determined in the light of the above-mentioned indicators. The windward slope of sand dunes is longer and gentle,

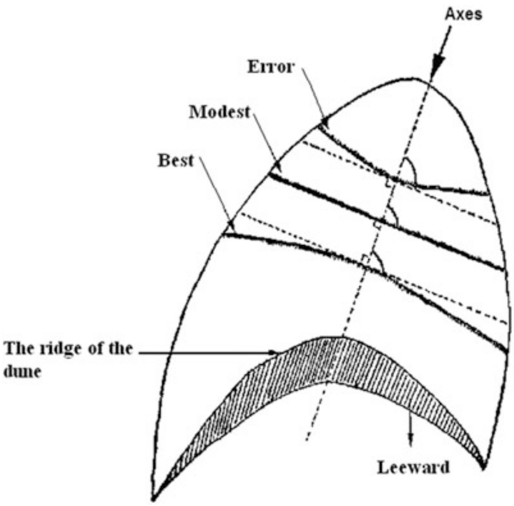

Fig. 2.8 The run of sand barrier on the windward slope of dunes

and the leeward slope is shorter and steep. From this phenomenon, the direction of the prevailing wind can be easily seen but for micro landscapes, the directions of the wind are various, and in this case we need to consult patterns of sand ripples. The run of the ripples formed by the coarse sands on the surface of sand dunes is perpendicular to the direction of the prevailing wind. These ripples can clearly show us the direction of the prevailing wind, so sand barriers can be set up along the run of the ripples of coarse sands. Ripples of fine sand formed between the ripples of coarse sands, caused by partial changes of the direction of the prevailing wind should not be regarded as indicators of the direction of the prevailing wind. In general, the third indicator, the run of sand plaits, is more reliable than the previous two. Because the spreading direction of the sand plait is identical with the direction of the prevailing wind, this direction can be recognized through an observation of the run of sand plaits.

The run of the sand barrier should be kept at right angles to the direction of the prevailing wind. When a sand barrier is planned for the windward slope of existing sand dunes, a line, which goes along the axis of the sand dune, should be first drawn in line with the prevailing wind. For practical purposes, the angle between the run of the sand barrier and this line should be more than 90° because of the distribution patterns of the wind on the sand dune. The wind is stronger in the middle (top) than on the two sides. If the angle between the run of the sand barrier and the direction of the prevailing wind is acute, the wind will be concentrated in the middle part of the sand dune, and therefore the sand barrier is liable to be destroyed in this area. If the angle is between 90° and 100°, the wind will go along the two sides of the obstruction. The effectiveness of the sand-control of this kind of sand barrier is satisfactory (Fig. 2.8).

The disposing patterns of sand barriers are mainly as follows: linear-shape, parallel lines, trellis (check) shape and fishbone shape. In an area where the direction

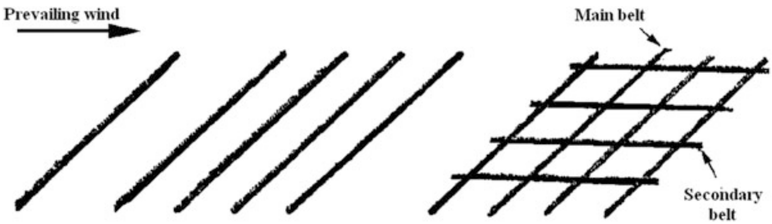

Fig. 2.9 The patterns of some sand barriers

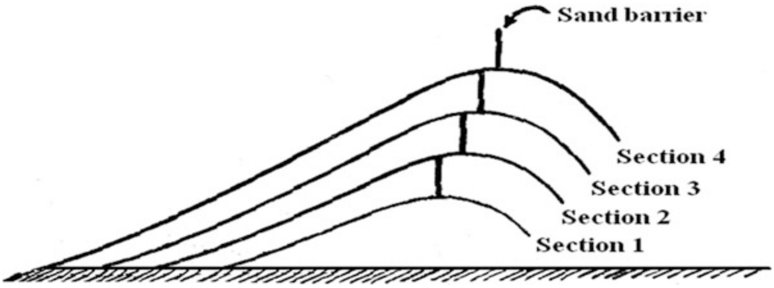

Fig. 2.10 The section of linear-shaped sand barrier

of wind is single, linear-shaped or parallel linear-shaped sand barriers are usually adopted, but in an area where side winds are strong, the check-shaped sand barriers are often used (Fig. 2.9).

Linear-shaped sand barriers are generally established in an area where the threat of sand-driving wind is serious. Its function is to hold back the shifting sand. This kind of sand barrier is called "stopping up the wind gaps" by local people. The linear-shaped sand barriers are often used as high standing sand barriers or hedges. When the dropped sand buries a sand barrier, the barrier should be raised or rebuilt. The height of the sand mound on the leeward side of sand barrier will gradually increase and the dropped sand will form a great sand dune – a great sand-blocking dam-in the end (Fig. 2.10).

Parallel linear-shaped and check-shaped sand barriers are used not only to stabilize the original sand dune on the spot, but also to hold back the passing sand carried by the sand-driving wind. These two kinds of sand barriers are usually adopted to guarantee the survival rate and growth of seedling of sand plants that are planted on the sand dunes.

All of the above patterns of sand barriers are only suitable for areas where the sandy land is gentle and the landforms are simple. For an area where the landforms are varied, other patterns of sand barriers should be set up in the light of the type, run and slopes of the sand dunes.

When sand barriers are set up on crescent (barchans or semi-lunar) dunes, the top of the windward slope of the dune should be left open so as to let the part which is

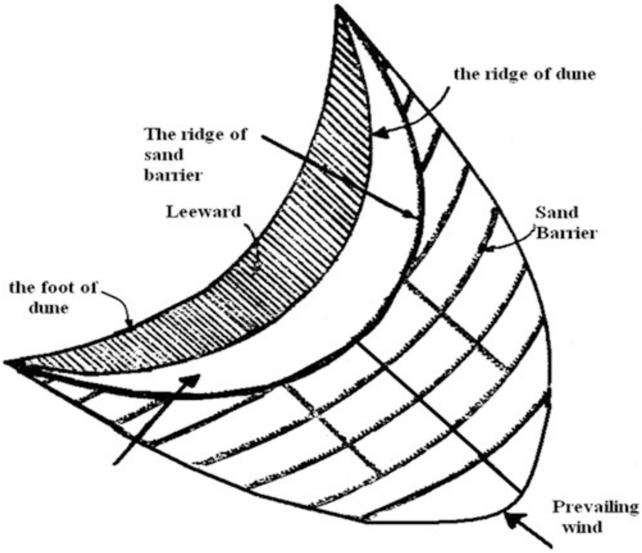

Fig. 2.11 The disposing patterns of sand barrier of the windward slopes of crescent dunes

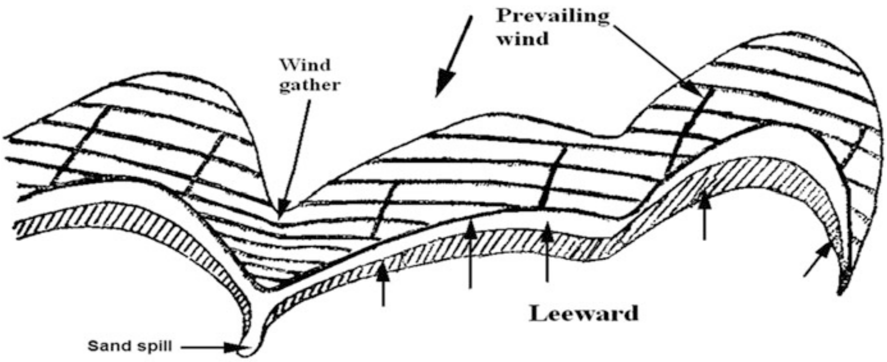

Fig. 2.12 The disposing patterns of sand barriers on the semi-lunar dune chains

not protected by the barrier be moved by the wind. The sand on this part will then fall into the leeward slope of sand dunes (Fig. 2.11).

The patterns of sand barriers on semi-lunar dune chains are more complex (Fig. 2.12).

On the various sections of semi-lunar dune chains, sand barrier can be set up in the same fashion as on individual semi-lunar dunes, but where two dunes link up, the parallel linear-shaped sand barriers should be adopted because this area is a wind-gathering area. The direction of wind here is steady and the sand-driving wind force is strong. If the material of the sand barrier is clay, the distance between two barrier

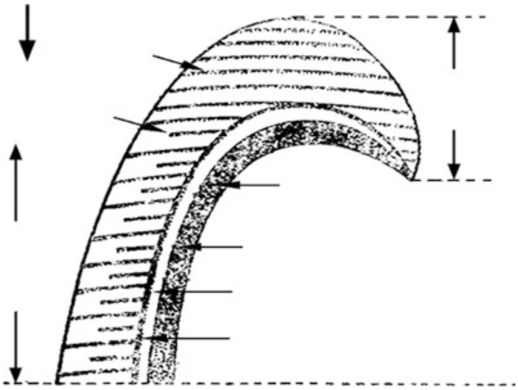

Fig. 2.13 The disposing patterns at the head of longitudinal dunes

lines should be shortened. The undulations on the semi-lunar dunes show that the winds here are various and unsteady. In such circumstances the check-shaped sand barriers should be used. The patterns of sand barriers on longitudinal dunes are illustrated in Fig. 2.13.

The disposal patterns of sand barriers at the head of longitudinal dunes are the same as the patterns on the windward slope of semi-lunar dunes. The patterns on the body of longitudinal dunes are complex. The body of a longitudinal dune can be divided into a windward slope and a leeward slope. The patterns on the windward slope of longitudinal dunes are similar to those on the semi-lunar dunes. A main sand barrier on the ridge of a longitudinal dune, along the run of the dune, should be established first. And then secondary barriers that are vertical to that main sand barrier are set up. In order to eliminate the vortex flow, the run of the secondary barriers should be inclined in the direction of the prevailing wind. To revise the distance between two barrier lines and the run of sand barriers, some short barrier lines among the secondary barriers should be set up. For the longitudinal dunes whose surface is gentle and smooth, fishbone-shaped or double fishbone-shaped sand barriers are usually adopted.

For the complicated irregular sand dunes, the fishbone-shaped sand barriers are usually used by local inhabitants of the sandy area (Fig. 2.14).

Fishbone-shaped sand barriers are composed of a main barrier and many secondary barriers. The latter consist of two kinds. One is a longer barrier from ridge of sand dunes to the foot of the dunes, and the other is a shorter barrier inter spread among the longer ones as needed to adjust the pattern.

4.3.2 Row Spacing and Standard Dimensions of Sand Barriers

The row spacing of high standing sand barriers must be appropriate for the conditions. If it is too wide, the sand barrier is liable to be destroyed by blown sand. Conversely, if the row spacing is too close, man-hours and materials are wasted. From the experiences of local people, the row spacing of sand barriers should be

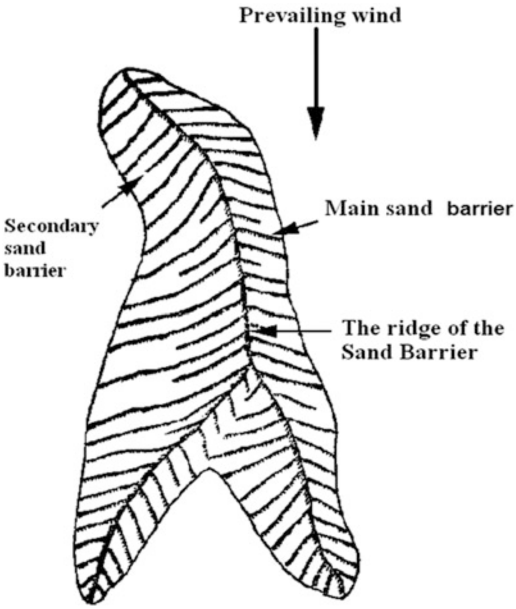

Fig. 2.14 The disposing patterns of sand barrier on the complicated irregular sand dune

smaller in those areas where the wind is strong, and on the top of the dunes. In other areas, the spacing can be increased. In general, the row spacing of sand barriers can be determined on the basis of the following factors: (1) The *height of the sand barrier*: the higher the sand barrier, the wider the row spacing; (2) The *slope of sand surface*: the steeper the slope, the closer the row spacing; (3) The *wind force*: the stronger the wind force, the closer the row spacing; (4) The *part of sand dunes*: the row spacing is closer on the top than that at the foot of the sand dunes; (5) The *structure of the sand barrier*: the denser the structure of the sand barrier, the closer the row spacing.

High Standing Sand Barrier

Under normal conditions, on a gentle slope, which is less then 4°, the row spacing of sand barriers should be 10–15 times the height of the sand barrier. Of course, the wind force should be considered in this case. When the sand barriers are set up on the windward slope, the base of the barrier which is located on the upper part of the dunes should be lower than the tip of the next barrier which is situated to the lower part of sand dunes (see Fig. 2.15).

When barriers of a given height are set up on the slope of sand dunes, the row spacing is closer for the steep slope and wider for the gentle slope. The steeper slope of the sand dunes, the closer the row spacing of the barrier (Fig. 2.16).

There is a close relationship between row spacing of sand barriers and the height of sand barriers, as well as the slop of sand dunes (see Table 2.1).

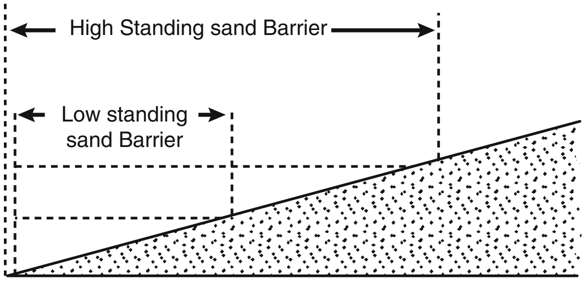

Fig. 2.15 The relationship between the height and the row spacing of the sand barrier

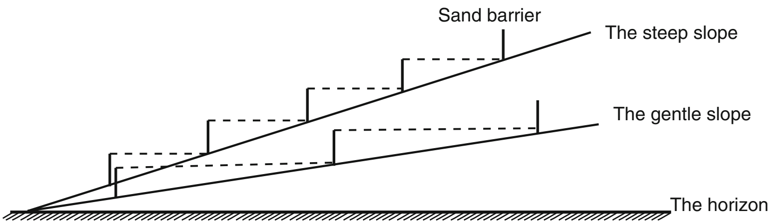

Fig. 2.16 The relationship between the slope of sand and the row spacing of sand barrier

Table 2.1 The ranges of row spacing of straw and branch sand barriers

The general height of the barriers		The row spacing for various slopes (m)		
Types	Height (cm)	5°	5°–10°	10°–15°
Low standing sand barriers	20–40	3–5	2–3	1–2
High standing sand barriers	60–80	7–10	5–7	3–4

The row spacing of clay sand barriers (or other low standing sand barriers with dense structure established for afforestation on the sand dunes) is mainly determined on the basis of the special needs of planting.

The intention of sand barriers that are set up for afforestation is that a depression among the sand barriers will form after several episodes of strong sand-driving wind and the sand will heap up around the barriers simultaneously. If the run of the sand barrier is correct, the depression will quickly become stable.

The depth of the steady depression among the sand barriers is about 1/12 of the row spacing of the sand barriers. And the deepest part is not more than 1/10 of the row spacing. The wider the row spacing, the deeper the depression.

If the height of the sand barriers is less than 1/10 of the row spacing, the sections between the sand barriers will be eroded. On the contrary, if the height of the sand barriers is more than 1/10 of the row spacing of the sand barrier, the sand will heap up in those sections. Therefore the phenomenon of sand-dropping or erosion on the surface of sand dunes which are protected by sand barriers can be determined not only by the row spacing of sand barriers, but also by the height of the sand barriers (Fig. 2.17).

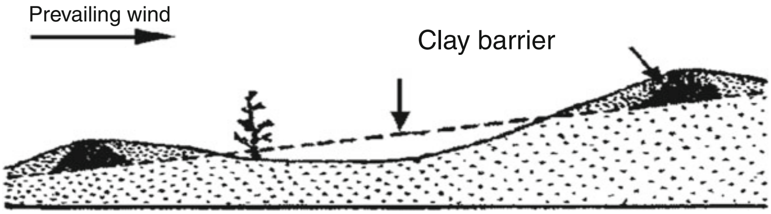

Fig. 2.17 The relationship of the stable surface of sand dune and the concave part around the sand barriers

The row spacing and the height of clay sand barriers should be determined on the basis of the above-mentioned principles.

4.3.3 The Row Spacing of Clay Sand Barriers

From the point of view of sand control, it is inadvisable to adopt too large a row spacing for clay sand barriers. If the row spacing is too large, the sand among the sand barriers will be easily carried away by the wind and a deep depression will form among the sand barriers. From practical experience, the depth of the depression should not be more than 40 cm and the row spacing of sand barriers should be kept under 10 times the above dimension. This means that the row spacing of sand barriers should be kept less than 4 m. Such sand barriers can control sand steadily and effectively. Only for areas where the wind direction is constant and the sand surface is gentle, can a row spacing of 5–6 m or more be used; In general, a row spacing of 2–4 m is usually adopted.

4.3.4 The Size of Narrow Mound Clay Sand Barriers

The proper size of narrow mound clay sand barriers is crucial to afforestation on the sand dunes because it can not only prevent the protected sand being carried away by the wind, but also avoid the sand carried by the wind from heaping up in the protected area. In order to ensure the survival and the growth of seedlings of plants which are sown among the sand barriers, the eroded depressions should be kept at less than 5 cm, and the biggest depth should not exceed 15 cm, because the depth of the dry sand layer on the sand dunes is usually 5–15 cm. Therefore the height of the clay sand barriers can be calculated in the light of the determined row spacing, the general depth (1/12 of the row spacing) of depression among the sand barriers and the biggest depth (1/10 of the row spacing) of the depression. The most common row spacing of clay sand barriers is 3 m. Under such circumstances, the depth of the depression among the sand barriers is about 25 cm and the biggest depth is not more than 30 cm. To maintain an eroded depth of less than 5 cm between the sand barriers, clay sand barriers with a height of around 20 cm and a width at the bottom of about 60 cm are often adopted. With the row spacing being shortened, the size of the clay sand barriers should also be narrowed and cut down, but if the size of the clay sand barrier is too small, the barrier is liable to be destroyed by wind, livestock or people. Under normal conditions, the row spacing and the height of clay sand barriers is 2–4 m and 15–25 cm, respectively. For different row spacing and sizes of clay sand barriers, the amount of earthwork and manpower are also different.

4.4 Installation of Straw Sand Barriers

The best seasons for setting up straw sand barriers are the end of autumn and early winter. Because the sand is moist in these periods, a lot of labor can be saved and the base of the sand barrier firmly established. If sand barriers are set up in the summer or spring, the base of the sand barrier is easily destroyed by the wind because the sand is dry in these seasons, and it is difficult to set up sand barriers on dry sandy land.

4.4.1 Installation of High Standing Sand Barriers

The heights of standing sand barriers that are made of tall and supple stalks (such as reeds and the stalks of *Achnatherum splendens*) should be more than 70–80 cm. The installing techniques of standing sand barriers are as follows: (1) dig the furrows along the designated lines. (2) put the materials-stalks-into the furrow with the tip of the stalks up and the base down. More should be in the furrow than out of the furrow. The barrier must be very dense and leave no spaces in it or it will be liable to be destroyed by wind. (3) fill the furrow with the broken stalks first and then with sand above the broken stalks on both sides of the sand barrier.

In order to make the sand barriers very firm, the filled sand on both sides of the sand barrier should be more than 10 cm above the ground level (see Fig. 2.18).

The density of the materials should be about 0.2–0.4 kg/m but if the material sources are not locally abundant, the cost of establishing the barrier is much higher. Standing stalk sand barriers can break the sand-driving wind no matter whether the wind is strong or weak.

4.4.2 Installation of Low Standing Sand Barriers

The materials for low standing sand barriers are usually as follows: grasses, shrubs, sub shrubs, branches of trees, wheat straw and other crop stalks or straw. The installing techniques can be divided into two kinds according to the different materials used:

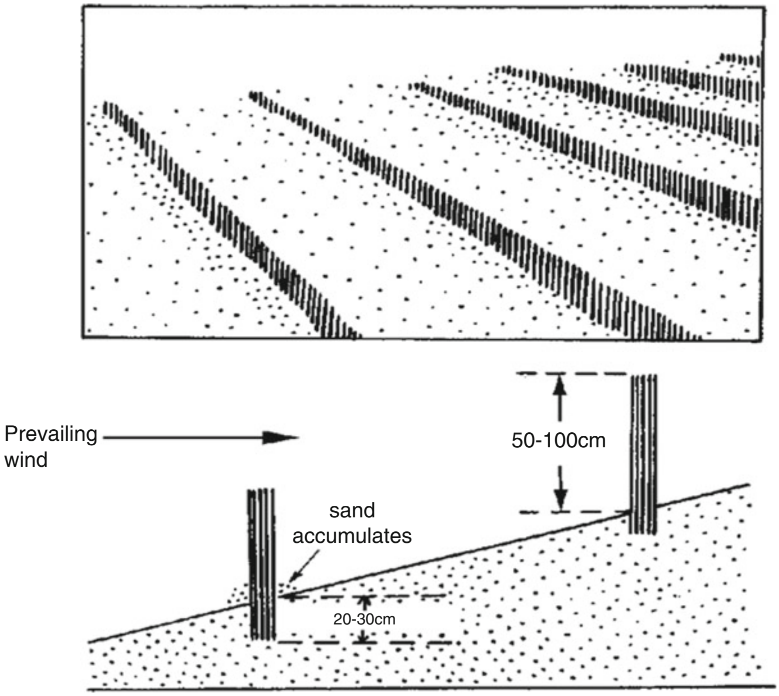

Fig. 2.18 The installing techniques of high standing sand barrier

1. Setting up in the furrow
   The materials used in this method are hard, such as the branches of *Nitraria tangutorum*, *Artemisia ordosica* and *Alhagi sparsifolia*. First, a furrow, width 15 cm, depth 20 cm should be dug. Second the materials are put into the furrow with the roots up and the tips down and the sheaves or branches are overlapped (see Fig. 2.17). It is better to keep the degree of density of the sand barriers at 20–30 %. The height of the low standing sand barriers is usually around 30 cm. Finally, the furrow is filled with sand and then tamped firm. Sometimes, in order to avoid the base of the sand barriers being destroyed by the wind, some broken straws are firstly filled into the furrow on the windward side of the sand barriers and then covered with sand.
2. Setting up by pushing down the straws
   For some soft straws, such as wheat straws, it is not necessary to dig a furrow when the sand barriers are set up. The steps for installation of such sand barriers are as follows (see Fig. 2.19):

   (1) lay the straws along the designated lines evenly and make the run of the straws vertical to the lines; (2) press the middle of the straws into the sand to a depth of around 10–15 cm with a blunt spade. Thus the two ends of the straws

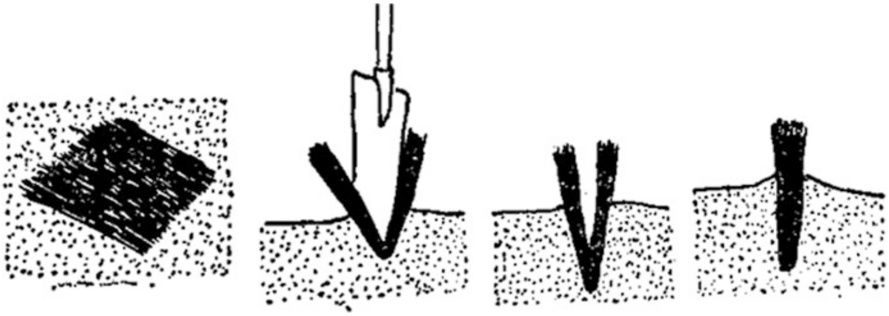

Fig. 2.19 The installer's method of soft spread sand barriers

will rise up; (3) close the two separate sides of the straws into one and tramp the base of the sand barriers on both sides with feet. The advantages of this method are that it is fast and saving of manpower.

4.4.3 Installation of Concealed Sand Barriers

The materials for concealed sand barriers are usually wheat straw, reeds or other grasses. The installing method is as follows: (1) cut the straws or grasses into 20–25 cm lengths and then bundle up the cut straws or grasses to a diameter of 5 cm; (2) dig the furrows on the sandy land to a depth which is the same as the length of the bundle; (3) stand the bundles into the furrow and then fill the furrow with sand and tramp it firm. The tips of the bundles of straws or grasses are at ground level. Such sand barriers cannot break the sand-driving wind above the ground. But they can control the moving of the sand ripples on the surface of sand dunes. When the concealed sand barriers are set up, the existing landforms can be kept although the sand is still moving. This phenomenon is advantageous to afforestation on the moving dunes. The patterns of this kind of sand barrier are usually parallel linear-shaped with row spacing of around 2 m, or check-shaped with a size of 2×3 m. For this kind of sand barrier, there is another installing method; this is digging a furrow to a depth of 15–20 cm and laying the straws or grasses into the furrow and then filling the furrow with sand (Fig. 2.20). This method can save man-hours, but its efficacy at sand-control is not very satisfactory. This method is usually adopted when the materials are broken straws or grasses.

4.4.4 Installation of Clay Sand Barrier

The clay sand barrier belongs to the low standing type of sand barrier with windproof structure. In many sandy areas, the clay sand barrier is set up first before the sand-adapted species, such *as Haloxylon ammodendron*, are planted

Fig. 2.20 Installation of materials in furrows

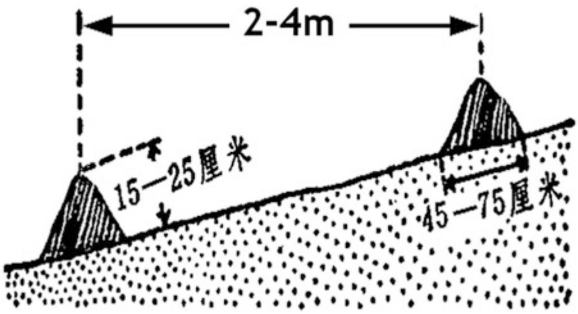

Fig. 2.21 The section of clay sand barrier. Major barriers are placed 2–4 m apart with a base of 15–25 cm in the lower slopes and 45–75 cm in the upper parts

on the moving dunes. The effectiveness of the clay sand barrier for sand-control near farmlands and irrigation canals is also very satisfactory. Clay sand barriers are widely accepted by the local people living in the sandy areas. In general, the clay sand barrier is set up at the lower part (approximate 2/3 of the slope) of the windward slope of sand dunes. Before setting up, the lines should be drawn on the basis of the direction of the prevailing wind, the shapes of the sand dunes, section of the dunes, size and row spacing of the sand barriers and so on. The narrow mounds, along the lines, are piled with clay that is taken from lowland between the sand dunes. A row spacing of 3 m and a mound of 20 cm in height are usually used (Fig. 2.21).

For the sand barriers that are established on the upper part of the slope and on the steep slopes of sand dunes, the row spacing should be shortened and the height should be raised. For areas where the ground is gentle and the sand dunes are steady, a sand barrier of smaller size can be used. The width of the mound should be kept even, or it will be destroyed by wind at the narrowed part. In order to maintain an uneven surface, lumps of the clay should be used, but very big lumps of clay should not be used because they will probably cause wind-erosion around them. Clay barriers should be examined after several exposures to strong winds. The following aspects should be examined: (1) whether the run of the barrier is correct or not; (2) whether the depressions among the sand barriers are eroded or not; (3) the angles between the run of sand ripples and the run of the sand barriers; (4) the angles between the sand plaits and the run of the clay sand barriers; (5) whether any part of the sand barrier has been destroyed.

If the run of the sand barriers is wrong, secondary sand barriers should be set up so that erosion can be controlled. If some parts of the sand barriers have been destroyed, they must be repaired immediately.

Initially, clay sand barriers can improve the moisture conditions of sandy land because the depressions among the sand barriers can collect the run-off of any rain. According to observation: with a precipitation of 25 cm in 4 days, the water permeates to depths of between 28.5 and 35.6 cm on the sand dunes protected by the clay sand barriers and to a depth of only 18.5–23 cm on bare sand dunes. The moisture contents in the depth of 0–15 cm are that, 13.35 mm for the dunes protected by high standing sand barriers, under 10 mm for the low standing sand barriers and 16–16.65 mm for the clay sand barriers. The moisture status of the sand protected by the clay sand barriers is greatly improved. The depths of the dry sand layers of sand dunes protected by the clay sand barrier and by the straw sand barrier are 8–10 and 18–20 cm, respectively, therefore for the sake of afforestation, the clay sand barrier is better than others.

However, at a later period after installation of the clay sand barrier, thin crusts will form on the sand surface because of the washing of the rainwater. This can prevent the rainfall seeping into the sand dunes. In this case, the moisture conditions of the sand dunes will have harmful effects on afforestation. Therefore afforestation should be undertaken immediately in the spring following the setting up of the barrier.

At 20 cm above the ground, the clay sand barrier can reduce the wind velocity by 27–33 %, the high standing straw sand barrier by 42 % and the low standing straw barrier by 8–17 %. At 2 m above the ground, the clay sand barrier can reduce the wind velocity by 40 % or more, and the straw sand barrier can reduce the wind velocity by 10–40 %. Therefore, in respect to the function of protecting seedlings, the clay sand barrier is better than other barriers. The cost of the clay barrier is the lowest among the various sand barriers because it only consumes manpower. The materials -the clay- are located on the low land which is just on the foot of the sand dunes. Therefore the clay sand barrier can not only reduce the cost, but also save a lot of other materials, such as straws, stalks, and branches, etc. So in many areas where a clay source is available and the straws or branches are in short supply, the clay sand barrier is the best choice.

The cost of the man-power for the clay sand barrier is around 150 man days/ha, but for covering a sand dune with earth, this cost is about 1,500 man days/ha, The cost for labor of the clay sand barrier ,the straw sand barrier and the branch sand barrier are about RMB 0.60, 1.05 and 1.05 Yuan/m, respectively. So the cost of the clay sand barrier is the lowest one. In general, the service life of the clay sand barrier, if it has been set up correctly, is around 4–5 years. The plants such as *Haloxylon persicum*, which are planted in the sand barriers, can exercise a function of sand-control very effectively within 2–3 years of planting. At this point plants can replace the clay sand barrier to control moving sand.

5 Implementation of Mechanical Measures in China – Proven Practices

In the arid part of northwest China, transport routes links are very important for the economic development of the region and to the welfare of the people. Hence, the total length of the railway lines crossing the sandy area are about 1,200 km, with wind-sand catastrophe taking place in an area of about 200 km wide and 1,000 km long, these include railway lines of Baotou-Lanzhou, Jining-Erlianhaote, Gantang-Wuwei, Lanzhou-Wulumqi, Baotou-Shengfu and there are other lines which are under construction. Effective prevention and control measures have been applied to about 50 % of the rail lines in the desert region (Chen Guangting 2005). There are lots of major highway lines passing through the arid areas and these include the highways of Xilinhaote-Zhangjiakou in Inner Mongolia that cross the sandy area of Hunsantake, Baotou-Yulin crossing the Kubuqi and Maowusu desert and the highway of Taklamakan desert. The last mentioned has been a great success but involved many challenges (Box 2.1).

Box 2.1: The Miracle of the Takliman Desert Highway

Taklimakan desert is the largest in China and the second most active desert in the world. Eighty-five percent of the area is drifting dunes, having the strongest fluxion among the entire deserts in the world. Ninety-two percent of these sand dune lines cross the mobile sand area, and are composed of all kinds of mobile dunes with different shapes and heights. The mechanical measures of prevention, stabilization, transportation, conduction, and control are all used synthetically. Building a highway in this desert marked the study of measures on controlling sands. The designers took part in the design of the road beds, especially on the wind gap or sand platforms, designing sections for transporting sands, and cleared the barrier on both sides of the lines allowing the sand flows to cross the roads and with no depositing on the road beds. In the section where the wind is uni-directional, dividing fence into sections with tangle angles creates feather rows to conduct sands. However, most of the prevention systems are sand-fences and straw checkerboards along the desert highway in Taklimakan desert. The materials used to weave fences are taken from reeds and in order to construct fences quickly, nylon webs had superseded most fence material. The widths of shelterbelts are laid out according to the positions of the aeolian sand landforms and are adapted with flexibility.

The prevention method together with the mechanical measures along the desert highway in Taklimakan desert assure that the highway remains open, accelerating oil exploration and exploitation and development in the

(continued)

Box 2.1 (continued)
hinterland. The desert highway reclamation program received a nomination for the tenth national achievements in science and technology in 1995, and received the National first prize for progress in science and technology in 1996.

The Shapotou Research station on the Yellow River (Box 2.2) developed many of the techniques that were described above and which have been applied in the protection of trans-desert transport routes. The construction of the prevention systems along the Baotou-Lanzhou railway line was awarded the National Prize on progress in Science and Technology in 1986, and this was the initial desert railway line crossing the southeast edge of the Tenggeli desert. In this area, grid dunes dominate among the types of aeolian sand landforms with relative heights of 15–20 m, and an annual average rainfall of about 185 mm, and a deep ground water level that cannot be exploited by vegetation.

Box 2.2: The Shapotou Experimental Station, Ningxia, China

Shapotou Experimental Station was established in 1956, to find ways of stabilizing mobile sand dunes of the Tengger Desert (Zhu and Liu 1989). In 1956, the Batou to Lanzhou railway was constructed through 40 km of the southern Tenggelli Desert (Plate 2). Therefore methods were required to reduce sand encroachment on the rail track. Besides planting trees as wind breaks, a procedure for establishing an artificial ecosystem on mobile dunes was derived. The process converts areas with shifting sands with less than 5 % vegetative cover to areas of fixed dunes with 30–50 % cover. Initially, a sand barrier is established, encouraging aeolian deposition. Behind the sand barrier, straw checkerboards (Fig. 2.22) are constructed which increase aerodynamic roughness, thereby decreasing wind velocity and stabilizing the surface.

The prevention systems developed at Shapotou have two essentials which are *fixation* and *prevention*. These were divided into four belts by disposition; Firstly, the belt of preventing sands on the edge, using different material, with a height about 1 m, equal to sand-fences preventing sand shifting, secondly, the belt of fixing sands with no irrigation. Straw checkerboards (1 m $\times$ 1 m) are the main parts of the prevention systems mixed with the shrubs and herbs, thirdly, the belt of trees and shrubs with irrigation and fourthly, the belt of transporting sands with pebble platforms.

The lengths of the integrated fundamentals belts are about 9 km including the section of the second and fourth belt and the rest are composed of the belts of fixation and transportation.

Fig. 2.22 A view of part of the Shapotou Desert Research Station showing the system of checkerboards made with straw to increase surface roughness and reduce sand movement

Many railways pass through the Gobi area which as a result of strong winds and scarcity of sands is saturated with sand flows, 60 % of the Lanzhou-Xingjiang lines cross the Gobi area and the Yumen sections (Hesan Lake-Wangdong, Sanshilijing-Gongchan River and Junken-Erdaogou) lie north of the Qilian Mountain. The prevention systems on this railway obtained the first National Prize on Progress in Science and Technology in 1954.

In response to strong winds, insufficiency of sand resources and the erosion abilities of sand flows, major measures were adapted which included reducing the wind velocity and shut off sandy resources and combination of prevention and protection. At the edge of the railway lines there are higher sand barriers, which include shrub branches and other materials which form a fence height of about 1.5 m. After 20 years of construction and study, by the end of 1994, on both sides of railway lines Junken-Erdaogou, Sanshilijing-Gongchanghe River, 96 km of shelterbelts of prevention have been established. The work has continued and China's proven technologies have been adopted elsewhere (Yang et al. 2005, 2011).

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