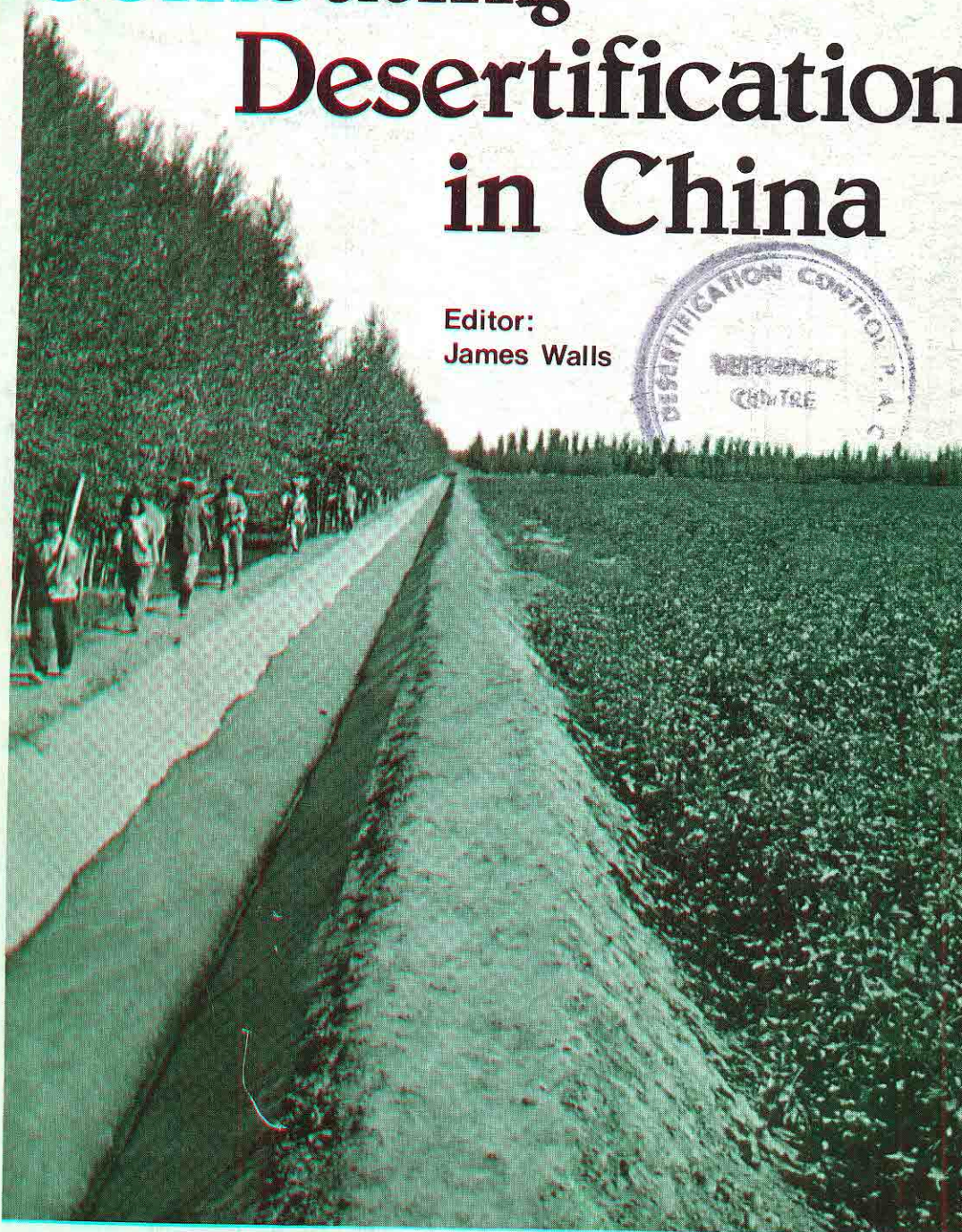


Combating Desertification in China

Editor:
James Walls



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Combating Desertification
in China



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COMBATING DESERTIFICATION IN CHINA

edited by
James Walls



A report on a seminar sponsored by
the Academy of Sciences of the People's Republic of China
and the United Nations Environment Programme

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Physical features of Deserts in China

Deserts in China are mainly distributed in the north-west and north China, a few more are found in the north-east. In the desert zone there are predominantly active dunes; in the desert steppe and steppe zone, semi-fixed and fixed dunes.

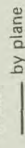
Route Followed by Participants on Field Trips

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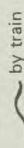


Deserts

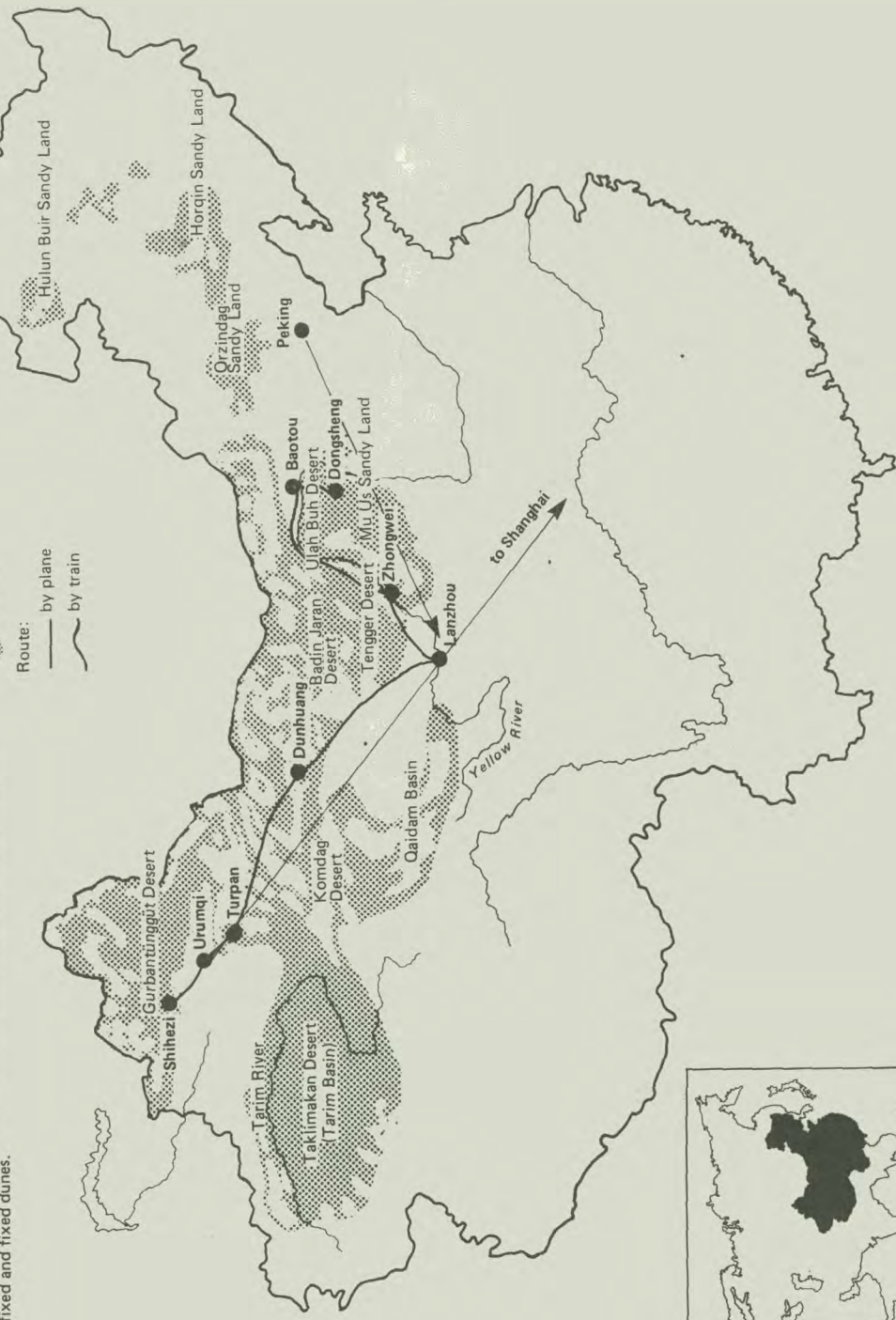
Route:



by plane



by train



to Shanghai

Preface

This collection of lectures delivered and field studies conducted during the training course on combating desertification held in 1978 at the Institute of the Desert, Lanzhou, China, represents in many ways the culmination of the UNEP/China project agreement. This project was designed to enable skilled technicians from developing countries to benefit from China's experience in combating desertification. The fruits of this exchange are now available in this volume for the rest of the world's growing number of specialists and technicians who are dealing with the pressing issue of desertification control.

For more than 20 years, the People's Republic of China has been carrying out action against desertification. By 1978, a number of significant results had been achieved, and Chinese scientists felt they had something to show to visitors.

A great deal of importance was attached to this seminar by China, the first such action to be organized jointly with the United Nations Environment Programme. As an indication of this importance, the assignment was given to the Chinese Academy of Sciences.

The seminar was conducted over a 30-day period for 18 participants from eight countries in the developing world. The training was conducted in three stages. The first part was theoretical, covering the presentation of five reports on the Chinese experience plus

country reports by the participants. The second stage was a field trip by air, train and bus covering more than 6,200 km, an undertaking of a scope that would not have been possible in many countries. The third stage was devoted to a comprehensive review of the seminar. The participants reflected on the experience and prepared their reports on it.

As all the visitors agreed, the lectures were of high quality, supplemented as they were by films and slides and augmented by a tour of the laboratories and other facilities at the research institutions.

The practical side, presented through field inspections in a variety of environments, was unique to seminars of this kind, as several of the participants remarked. Here they were given an opportunity to see the actual results of actions to combat desertification. There are few countries in which such a convincing showing could have been made.

The third stage was as significant as the others, in that the participants were asked to consider their experience and comment on it at length, to the benefit of their hosts and of all future seminars.

Another important benefit derived from bringing together skilled and experienced people from eight countries with their variety of environments, placing them in close contact with one another and with the Chinese people in a friendly atmosphere in which, for

a full month, they were continuously engaged in serious discussions on a most challenging environmental problem.

Three general observations should be made with regard to the seminar:

1) Holding such a seminar indicates the willingness of a country with skill, experience and wisdom to communicate these to others to the fullest extent possible.

2) The participants presented their own experience in combating desertification in their own countries. This provided opportunities for meaningful discussion of great benefit to all, not only to the participants for reassessing their judgements and methods, but also to the Chinese hosts, who repeatedly and modestly stated their interest in learning from others.

3) The seminar was in fact a demonstration of technical co-operation among developing countries.

The primary objective of the seminar was to strengthen national scientific and technological capability in developing countries affected by desertification. This is in accord with Recommendation 18 of the *Plan of Action to Combat Desertification*, as approved by the nations at the United Nations Conference on Desertification.

The primary objective was completely achieved by the seminar. Through publication of this volume this objective will be further served by a wider exposure of not only the knowledge and experiences exchanged at the seminar but also the very great benefits intrinsic to international co-operation which the seminar exemplifies.

Gaafar Karrar

Principal Officer, Desertification Unit
United Nations Environment Programme
Nairobi, Kenya, 2 April 1981

Introduction: China at the United Nations Conference on Desertification

In 1951, the Advisory Committee on Arid Zone Research was established within UNESCO to organize the first systematic investigations into problems affecting arid lands. As time passed, some 200 desert research institutes located in 40 countries collaborated in the production of the 30 large volumes of the UNESCO Arid Zone Research series. The agronomists and soils scientists at work on this project soon began pointing out that large amounts of productive land were being lost to agricultural use through a process they came to call "desertification". Their warnings, however, received comparatively little notice until world attention was caught by a severe drought in the West African Sahel that in the five years from 1968 to 1972 destroyed most of the livestock on the Sahelian pastures and threatened the lives of their human inhabitants.

The Sahelian drought raised many questions. Most disturbing was the possibility it invoked that the world's climate was turning drier in a shift of parameters that would affect agriculture and make it more difficult in the future to feed the earth's rapidly growing populations. This suggestion seemed to find support in the acceleration of desertification that had become evident in recent decades. By 1977, land specialists and economists were estimating that taken all together, some 5.8 million hectares of productive land were going out of use each year. This was an alarm-

ing figure. It represented an annual loss of land larger in area than the whole of Austria.

Drought in the Sahel focused public attention on this menacing situation and provided the immediate impulse to the United Nations to convoke a world conference on desertification. From 29 August to 9 September 1977, representatives of 94 nations met in the Kenyatta Conference Centre in Nairobi, Kenya, under the gavel of Daniel arap Moi, now President of Kenya, to consider what was known about this threat to human welfare, to ascertain its causes, and to approve a Plan of Action to Combat Desertification that would be global in scope.

What emerged from the United Nations Conference on Desertification was a Plan of Action that was optimistic in its outlook. It declared that if only the political will could be activated, desertification could be halted everywhere on the planet by the end of this century. Such a projection could never have been reached if a changing climate had been perceived as the cause of desertification and of its recent acceleration. A climatic shift to more arid conditions would involve processes beyond human control. But as the conference perceived it, the cause could be credited not to climate but to man. Desertification was seen as the result of bad land-use practices on pastures, on rainfed farms and in irrigated systems. Man, the victim of desertification, was

thus also portrayed as its perpetrator—a conclusion with which arid land specialists agreed.

The two weeks of intense discussions that constituted the conference had been preceded by two years of preparation, carried out by a small conference secretariat situated in the Nairobi headquarters of the United Nations Environment Programme. This was an appropriate location for work on an essentially environmental subject. It was appropriate, too, that the secretary general of the conference, the officer charged with directing the conference preparations, should have been Mostafa K. Tolba, the UNEP Executive Director.

Beginning with the conference on the environment held in Stockholm in 1972, the United Nations has held a series of world conferences on the major problems affecting mankind. The preparations for all such conferences call for the assembly of all available knowledge on the subject in question and for its orderly arrangement for the convenience and instruction of those who will attend as delegates. The recommendations approved by delegates must be based on the best and latest scientific findings and conclusions. In preparing for the conference on desertification, the Secretariat had been directed by the United Nations General Assembly to assess "all available data and information and its consequences on the development process of the countries affected". These were the customary instructions.

To Dr. Tolba and his staff, however, it was quickly evident that desertification was not a subject like others, one already organized and presented in textbooks. On the contrary, it was a subject scattered among 20 disciplines, one that would have to be structured from the ground up. It was apparent, furthermore, that the subject was not complete, that it contained gaps and lacunae, which Tolba asked his scientific advisers to fill to the best of their ability. To round out a subject that might be called "desertification" a number of extraordinary measures were initiated. These included a new model of conference documentation, in which the subject was divided into four major aspects, each to be dealt with in an

extended analysis. They included also the development of six transnational projects designed to test the feasibility of international co-operation to combat a problem that paid no attention to national boundaries. Case studies were also to be undertaken which would show desertification in action, display its impact both on natural ecosystems and the people who live in them, and illustrate measures which might be adopted to halt the process and, where possible, reverse it.

As originally proposed, three pairs of case studies were to be developed that would make comparisons possible under arid conditions (1) with warm-season rainfall, (2) with cold-season rainfall, and (3) with irrigation systems affected by waterlogging and salinization. These studies were indeed carried out in (1) India and Niger, (2) Chile and Tunisia, and (3) Iraq and Pakistan, with UNESCO serving as executing agency for all but the Chile study. Within only a few years of the conference, it was evident that these studies had become classics in the field.

At the time they were announced in 1976, the six United Nations case studies yielded a dividend that was as welcome as it was unanticipated. Six countries announced that they would carry out case studies of their own as a contribution to the desertification conference. The United States would describe a rehabilitation programme carried out on the Vale rangelands of south-eastern Oregon. Australia would present the measures undertaken to halt desertification on the sheep stations in its arid Gascoyne Basin. Iran would describe its Turan Project, the rescue of affected communities at the edge of a salt desert. Israel would analyse rehabilitation measures undertaken in the Negev. The Soviet Union would present two studies, one on the development of an integrated irrigation scheme on the Golodnaya Steppe, the other on river diversion in Turkmenia for irrigation and rangeland improvement. The People's Republic of China announced that it would present three case studies, which reached the conference Secretariat in June 1977, under the following titles:

- *Tame the Wind, Harness the Sand and Transform the Gobi.* Summary Report on the Experiences of the Xinjiang Turpan People in Combating Desertification. Office of Environmental Protection, Xinjiang Uygur Autonomous Region. (A/CONF. 74/16)
- *Control the Desert and Create Pastures.* Summary Report on the Experiences of the Uxinju Commune, Uxin Banner, Inner Mongolia, in Combating Desertification. (A/CONF. 74/17)
- *Combating Desertification in China.* Summary Report on the Experiences of the Masses in Combating the Deserts. Lanzhou Institute of Glaciology, Cryopedology and Desert Research, Academia Sinica. (A/CONF. 74/18)

If the usual pattern of atmospheric circulation prevailed in China, most of the country would be arid. Latitude 30° north bisects the country, passing just south of Shanghai, marking what is elsewhere the subtropical zone of subsiding air that creates deserts in Iran and Arabia, North Africa and northern Mexico. China, however, is blessed with the south-east Asia monsoon, a wind that moves north-westward out of the South China Sea, bringing to the land warm summer rain.

Yet the monsoon rains become less as the wind moves inland, fading away finally in China's northern regions. From the giant dunes of the Taklimakan across 3,500 km of gravelly Gobi and semi-arid rangelands, China's northlands are dry. During a century of political turmoil in China, as the case studies reported, desertification advanced unhindered across these northern drylands. With political stability restored under the government of Mao Zedong, the Chinese undertook to halt desertification and, where possible, to restore lands that had been degraded and damaged. This effort is the subject of the case studies.

An integrated set of campaigns, intensively pursued as a war against advancing deserts, is

what is shown in China's case studies. Activities are described in a variety of settings ranging from the true desert at Turpan oasis to the pastoral grasslands on the semi-arid Ordos Plateau at Uxinju. The measures undertaken include the planting of shelter belts, dune stabilization, the recovery and enhancement of soil fertility, access to ground water and the development of irrigation systems. The procedures employed were botanical. Dunes were fixed by skilful plantings rather than by mechanical means, and soil was restored without the use of synthetic fertilizers. There is little reference in the case studies to the use of machinery. Desertification was confronted in China—and sent into retreat—by that country's diligent and inexhaustible manpower.

Indeed, the case studies presented by China to the United Nations Conference on Desertification are success stories of stunning impact. They illustrate precisely what Dr. Tolba's scientific advisers had been telling him; that desertification, caused by man, can be cured by man. Such brilliant examples of desertification control naturally aroused continuing interest. It was out of such interest that one year after the Conference, the United Nations Environment Programme, directed to oversee the World Plan of Action to Combat Desertification, arranged with scientists in China to hold a Desert Control Training Seminar for Developing Countries, in which experts from three continents would have a chance to see for themselves the great advances that had been made in China in techniques to combat desertification.

The seminar was based on five documents prepared by scientists of the Lanzhou Institute of Glaciology, Cryopedology and Desert Research. The first of these provided a general overview of anti-desertification measures undertaken in China's arid north, while the other four dealt with specialized topics. Edited versions of these documents are presented here as chapters 2-7.

The Transformation of Deserts in China: A Summary View of the People's Experiences in Controlling Sand

Department of Desert Research
Lanzhou Institute of Glaciology, Cryopedology and Desert Research
Academica Sinica

20 September 1975
Revised in August 1977

Arid lands in China include gravelly gobis and sandy lands in the arid and semi-arid steppes. The term *sandy land* distinguishes dune formations in the steppe zones from those in true deserts with their different natural conditions. Occurring mainly in northwest and north China, with a few in the northeast, the arid lands cover an area of 1,095,000 km² or 11.4 per cent of the total area of China. Sandy conditions, including lands affected by wind erosion, prevail on 59 per cent of the arid lands while gravel desert occupies 41 per cent. They spread over the Inner Mongolia Autonomous Region, the Ningxia Hui Autonomous Region, the Xinjiang Uygur Autonomous Region, and the provinces of Shaanxi, Qinghai, Liaoning, Jilin and Heilongjiang.

Over the years before liberation in 1949, the people living in China's desert areas were oppressed and exploited. As their natural resources were wasted and plundered, they were forced to retreat before the advance of wind-driven sands. Since the founding of the People's Republic of China, they have embarked on the mass movement, "in agriculture, learn from Dazhai". In the spirit of self-reliance and hard struggle that typified Dazhai, the famed agricultural production brigade, a part of the Dazhai People's Commune in the Daihang Mountains of eastern Shaanxi, Chinese farmers mapped out a general programme around the principle that desertification should

be dealt with in terms of local conditions. Comprehensive measures were developed in a co-operative spirit, with scientific and technical personnel working closely with the farmers. As a result, a number of achievements were realized, the basis for sand control established, and considerable progress in animal husbandry and agriculture recorded.

THE DISTRIBUTION AND CHARACTERISTICS OF CHINA'S ARID REGIONS

The arid regions of China are mostly typical of the temperate zone arid lands and are mainly distributed in inland intermontane basins, with some 90 per cent of them concentrated in the arid zone west of 106° longitude—the heart of the continent. Most of these lands get less than 200 mm of annual rainfall, and with annual evaporation reaching as high as 3,500-4,000 mm, the aridity index is above 4.0, rising even beyond 6.0 in the desert in the Tarim Basin.

On sandy lands, vegetation cover is sparse, with shifting dunes occupying 75 per cent of the area. Fixed and semi-fixed dunes occur only in the Junggar Basin and in certain lake basins as well as along the banks of intermittent streams and on the frontal margins of alluvial fans on the deserts. Irrigated oases are distributed along the river banks on the desert

fringe, with major farming centres located on the middle and lower reaches of piedmont alluvial fans.

To the east of 106° arid and semi-arid steppes with sparsely distributed dunes and small gobis constitute only 10 per cent of China's total arid lands. As it approaches the sea, this region is more affected by the south-east monsoon. Here, annual precipitation averages 200-450 mm which, with annual evaporation of 1,500-2,500 mm, yields aridity indexes of 1.5-4.0. Vegetation grows fairly well here. Besides grasses, herbs and shrubs, trees are found growing on the semi-fixed dunes that constitute 80 per cent of the total dune area, with shifting dunes dotted sparsely here and there.

The deserts and arid lands of China are distributed over the vast area lying between 35° and 50° north latitude and 75° and 125° east latitude. Affected by local factors—precipitation and temperature, vegetation and landforms—they show distinct natural characteristics.

The Taklimakan Desert in Xinjiang, with an area of 327,000 square kilometres, is the largest in the country. It is famed for the huge size of its moving dunes, generally 100-150 m

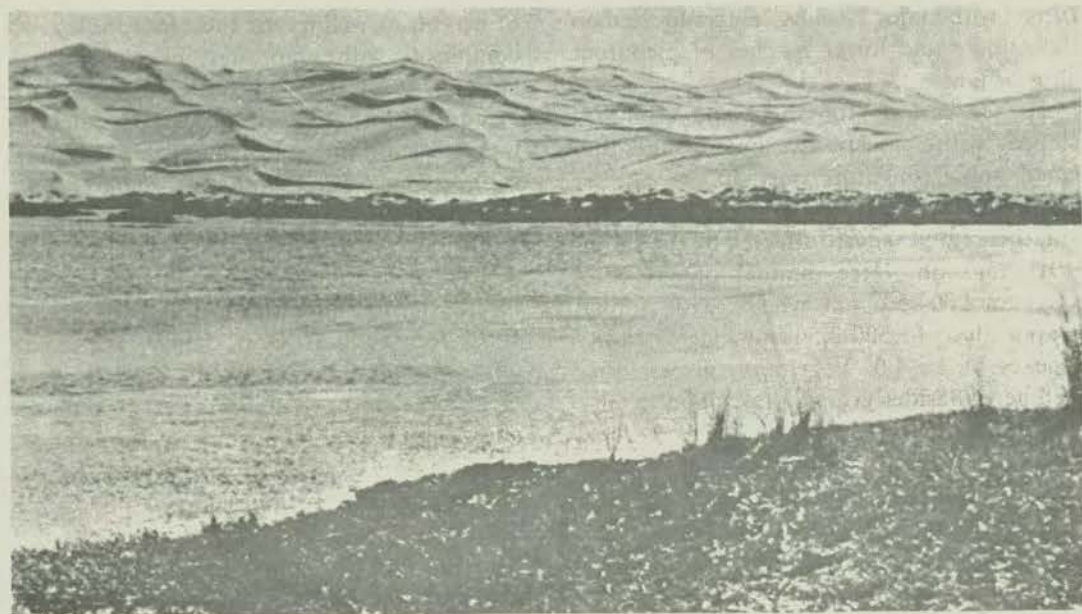
in height, as well as for their morphological complexity, with composite dunes constituting two thirds of the dune area. Along rivers extending into the interior of the desert, intermittent floods and ground water sources support *Populus diversifolia* and *Tamarix chinensis*, forming natural green belts in an otherwise empty landscape.

The Gurbantünggüt Desert is characterized by an extensive distribution of fixed and semi-fixed longitudinal sand dunes. These are covered mainly by *Haloxylon ammodendron*. Near the wind-gap to its west, this desert shows a rich display of wind-eroded geomorphic features. The Badin Jaran Desert presents a spectacular landscape of huge bare sandhills averaging 200-300 m in height and constituting 68 per cent of its total area. These are dotted with lakes. The Tengger Desert is characterized by shifting sand dunes interspersed with grasslands bordering on lake basins. The Qaidam Basin, the highest desert in the country, averaging 2,600-3,400 m above sea level, is typified by a patchy distribution of dunes amidst densely grouped wind-erosion lands that constitute 67 per cent of its total area.

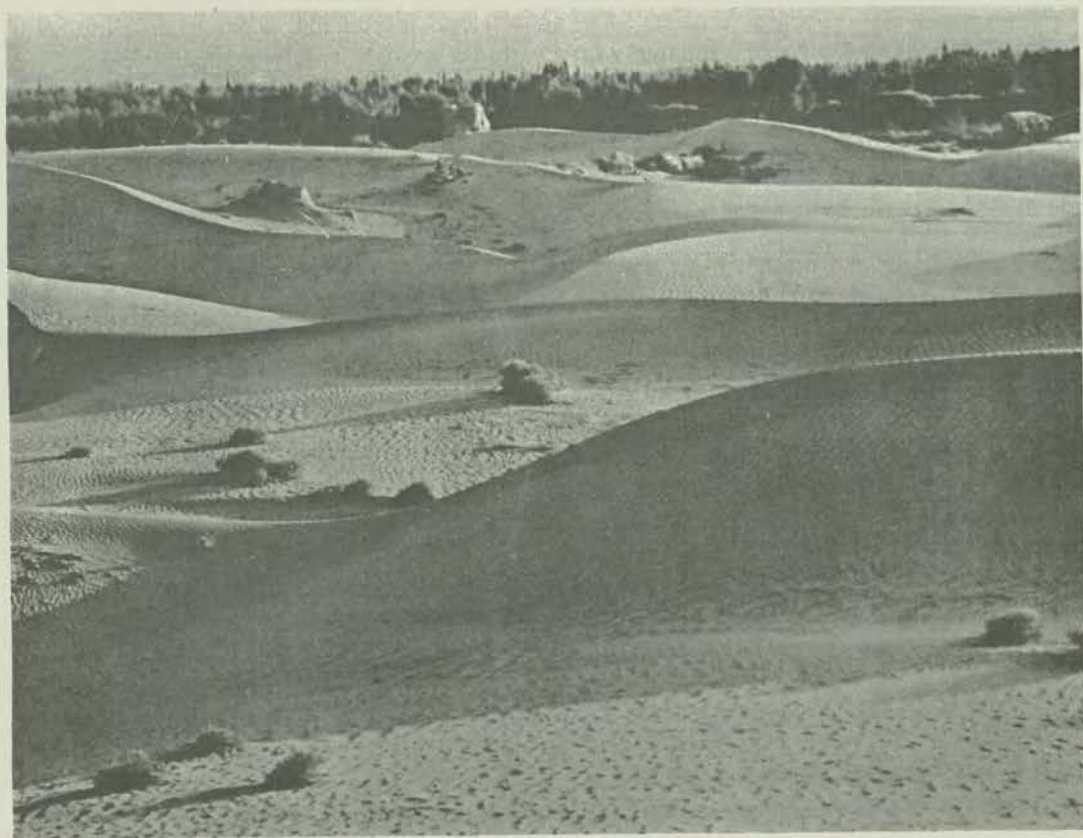
Set amidst arid and semi-arid steppes, the Mu Us sandy land is a region of varied

The Badin Jaran Desert has the highest dunes in China—generally between 200 and 300 metres high with the highest reaching 500 metres.





Above: Lakes interspersed among the dunes characterize the Tengger Desert. Below: The ancient city of Shouchang, in the western part of the Hexi Corridor, was once engulfed by the shifting sand. Through sand dune fixation and afforestation this ancient city has been brought to life again.



landscapes. Arrays of shifting sand dunes occur amidst fixed and semi-fixed dunes, lake basins and valley terraces. The Orzindag, Horquin and Hulun Buir sandy lands in the eastern steppes show a considerable number of lake basins and a predominance of fixed and semi-fixed sand dunes on which *Pinus sylvestris* var. *mongolica*, *Pinus tabulaeformis*, and other trees flourish amidst grasses and shrubs.

In combating desertification, the people living in the deserts and arid lands have developed a number of effective measures. These take account of the special features of their environments.

—In sand deserts, shelter belts of trees and shrubs are planted around oases and farmland as a protection against sand drift, while windbreak networks are planted within the cultivated areas so as to protect the crop plants. Grasses are planted in the fringes of the surrounding desert to stabilize moving sand. Where possible, surface water is used for levelling dunes.

—In sandy lands where shifting dunes occur amidst a prevalence of fixed and semi-fixed dunes, *grass kulums* are built and a rational use of pastures pursued to develop animal husbandry. The word *kulum* is a Mongolian term for enclosures of dunes, natural meadows or plots between dunes where water and soil conditions are favourable. The enclosures are constructed of barbed wire, earthen bricks or wicker fences so as to protect the land from grazing and other activities. Pastures are protected against desertification by stabilizing dunes through plantings, by fencing off ranges and by constructing protective forest belts.

—In most desert areas, new oases are developed on lake basins, on desert rims and on the banks of rivers extending into the deserts by building reservoirs to store the waters of intermittent floods, by building ditches to collect and divert runoff from snow in the mountains, and by tapping ground-water resources from alluvial-lacustrine deposits. In such oases, the land is levelled, shelter belts planted, soil quality improved and barren lands reclaimed.

—Along railways and highways that pass

through deserts, engineering measures are adopted to stabilize moving sands. Protective straw palisades are built in a checkerboard within which sand-fixing vegetation is planted. Where this is not sufficient, additional measures to fix, block or remove sand may be taken as circumstances warrant.

MEASURES FOR COMBATING DESERTIFICATION IN CHINA

In accordance with the principle of adaptation to local conditions, effective measures to control desertification depend upon what calls for protection—whether farmland or pasture, roads or railroads.

Forest and Shelter Belt Networks to Control Blowing and Drifting Sand

On the fringes of oases where irrigation is possible and dunes no higher than 10 m with depressions between them, forests for protection against sand are generally arranged in belts and patches. A loose-structured belt of trees 50-60 m wide is established along the main ditch on the fringe of the oasis. It is supported by patches of trees—usually *Populus cupidata* and *Elaeagnus angustifolia*—in the depressions between sand dunes adjacent to the belt, both watered by ground water or what can be spared from the irrigation of crops. Sand dunes are thus surrounded and partitioned off. Within the trees air currents are no longer saturated with sand, and the movement of dunes comes to a halt. Even without further measures, dunes 4-5 m high will decrease 1-2 m in height within three or four years. Trees to control sand movement have been planted on the Hexi Corridor in Dunhuang, Linze, Gaotai and other districts.

On some shifting sand dunes between tree patches, artificial barriers are being erected, composed of locally available materials, such as clay, wheat straw, stalks or gravel, increasing the roughness of the surface and checking wind velocity (see table 1). Sand-fixing plants will then be established inside the barriers. At Minqin, clay barriers reduced wind velocity

Table 1. Effects of clay sand barriers on surface roughness and wind velocity (on the western fringe of the Tengger Desert)

Type	Wind velocity value (%)	Wind velocity reduction inside barriers (%)	Roughness (cm)
Shifting sand surface outside barriers	100		0.0025
Checkerboard-shaped barriers made of clay	72	28	0.4923
Belt-shaped barriers made of clay	67	33	0.4923

28-33 per cent and stabilized the sand surface, thereby assuring the survival of the seedlings of such sand-fixing plants as *Haloxylon ammodendron*. At Shajingzi, west of the Minqin Desert, such measures turned shifting sands into semi-fixed dunes and improved the density of the vegetation cover on the dunes from an original 3-5 to 30-40 per cent.

For oases on the periphery of deserts with flat soil interspersed with shifting and semi-fixed sand dunes, forests for sand protection are generally composed of trees together with shrubs, such as *Tamarix ramosissima*. The shrubs are placed facing the desert to check wind and sand movement at the surface, while the trees are placed on the farmland side. Data obtained at Pishan, south-west of the Taklimakan, show that with a medium velocity wind, air passing through *Tamarix chinensis* has its sand content reduced by 80 per cent. The nearer they are to the sand sources the denser the shrubs should be.

At Minqin, for example, belts of shrubs are 300-500 m wide to reduce the sand content of the air, to minimize sand accumulation and to facilitate irrigation of the trees which, planted in 50 m wide belts, further check air speed and reduce its sand content. This arrangement has also been established at Yumen in the Hexi Corridor, in the new reclamation region on the lower reaches of the Tarim River and at some of the oases to the south of the Taklimakan. At Shache, Markit and other oases on the western fringe of the Taklimakan, the sand-preventive shelter belts, generally 180-200 m wide, are mainly composed of *Eleagnus angustifolia*, a vigorous tree whose dense

branches and leaves are effective in reducing wind velocity at the ground surface and lowering the sand content of the air. A medium wind will be checked in velocity by 40-57 per cent within the belt, whose protective range extends 23 times its height.

In the north-eastern part of the Ulan Buh Desert, shelter belts bordering the oases are looser and wider, averaging 300-400 m, and the trees on the side facing the desert are combined with shrubs and grasses to fix shifting sand. Within a range of 30 times the height of the trees, the average drop in wind velocity is 50-60 per cent, while 70 per cent of the sand content within 20 cm above the ground is blocked at the front edge of the shelter belt.

For the oases situated near the frontal margins of gravel gobis or wind-erosion lands where strong, sand-laden wind constitutes the main problem, the general practice is to adopt a system of alternating belts and ditches. At the wind gap in the Wuxing People's Commune, Turpan, Xijiang, the Wudaozhu shelter belt displays to full advantage this arrangement of multiple, combined belts and ditches. The ditches are dug—1.5 m wide and 4.5 m apart—before the trees are planted. This assures easy irrigation, high survival rate of saplings, water economy, and the convenient removal by water of accumulated sand. In choosing plant species, the emphasis is placed on long life, quick growth, and dwarf varieties with large crowns. Along the first windward ditch is a belt of *Eleagnus angustifolia* which has high wind and sand resistance as well as salt-alkali tolerance. At each of the

next two ditches one row of *Populus bolleana* and one row of *Ulmus pumila* are planted. Each of the two leeward ditches is planted with one row of *Populus bolleana* and one row of mulberry (*Morus alba*). This arrangement provides a stable structure having at the same time an uneven or zigzag profile at the tree-tops which cuts wind velocity. Within a distance equal to 1-3 times the shelter heights behind the belts, a medium wind is cut to 26.7 per cent of its unchecked speed, while at a distance of 7 shelter heights wind is still cut to 29 per cent. At Turpan, perimeter belts of this type are combined with shelter belt networks planted within the oasis. This combination has proved effective in protecting farmlands from strong winds and blowing sand.

Different species of trees and shrubs are for planting in different places. In the oases bordering the Xinjiang deserts, suitable tree species include *Populus bolleana*, *Eleagnus angustifolia* and *Ulmus pumila*. *Tamarix chinensis* is a well-adapted shrub. In the Hexi Corridor,

Populus cupidata and *Eleagnus angustifolia* are the usual trees and *Haloxylon ammodendron* is the typical shrub. In the Ulan Buh Desert, *Salix matsudana*, *Populus simonii* and *Eleagnus angustifolia* prevail. Long experience has shown that for fixing sand and stability of plantation a combination of several species is better than one.

Within oases, networks of shelter belts must also be planted simultaneously with the establishment of protective belts at the perimeter, and the two must be integrated into one protective system. Only in this way can full protection be achieved. Experience shows that successive shelter belts, integrated into a multiple network, have the effect of successively lowering wind velocity, as shown in table 2. At Markit, Shache, Pishan and Turpan, tight networks of narrow belts have been established.* Observations made at Turpan, where the problem of drifting sand is the most severe, show that small networks are 7.4-26.7 per cent more effective than large networks in

In the central part of the Hexi Corridor where dunes are low and water available, trees are planted to split and isolate the dunes.





Since liberation China has launched a mass movement to stabilize deserts by afforestation.

Table 2. Average wind velocity behind shelter belts as compared with open field

	Percentage
Open field	100.0
First belt	38.0
Second belt	42.0
Third belt	51.1

cutting wind velocity.

In oases on the rim of the Taklimakan, the distance between main forest belts averages 200-400 m, and between secondary belts, 300-500 m, each composed of four to eight rows of mixed trees of different heights, providing two-layer canopies. Networks of this type show a remarkable ability to break the wind, as shown in table 3. In the farmland shelter belts in the southern part of the Mu Us sandy land in northern Shaanxi, the main belts are usually composed of five to six rows of trees over a width of 8-11 m, while the secondary

Table 3. Protective effects of narrow shelter belts against wind (on western fringe of Taklimakan Desert)

Distance in multiples of forest height behind belts	Percentage of drop
Open field	0.00
1 <i>H</i>	78.92
3 <i>H</i>	61.11
5 <i>H</i>	61.11
8 <i>H</i>	50.00
10 <i>H</i>	46.30
15 <i>H</i>	25.50
20 <i>H</i>	15.70
25 <i>H</i>	15.70

belts are established in three to four rows averaging 6-8 m wide, both belts occupying a total of 7 per cent of the land. Networks of trees on the edge of an oasis where drifting sands run rampant could be composed of

Table 4. Wind-braking effects of belts of varied heights

Height of belt (m)	Coefficient of wind penetration	Relative value of wind velocity at test points behind belts with that of the wind velocity unchecked as 100							Average drop within 1-3 H behind belt (%)
		1 H	3 H	7 H	10 H	15 H	20 H	30 H	
6	0.54	84.4	51.1	57.8	77.8	86.7	95.6	100.0	20.9
10	0.52	67.5	47.5	47.5	60.6	70.0	80.0	95.0	33.2

belts with various distances between them depending on the wind velocity. Experiments conducted at Turpan show that a satisfactory arrangement establishes 15 heights between the first and second belts, 15-17 heights between the second and third belts, and about 30 heights from then on, with shrubbery along the first and second belts to form semi-closed structures.

The efficient protective range of shelter is usually expressed in multiples of belt height as their wind-blocking efficiency is proportional to their height. Under conditions in which wind velocity and penetration are similar, observations show that when shelter belts consist of six rows, the average drop in wind velocity 1-30 heights behind the belt is 32.2 per cent if $H=10$ m and 20.9 per cent if $H=6$ m, as shown in table 4.

Farmland shelter belts are preferably composed of fast-growing indigenous plus a small proportion of long-life species. In Turpan Basin, characterized by extreme aridity, high temperatures and strong winds, shelter belts are properly designed in multiple layers with a loose structure. *Ulmus pumila* and *Populus bolleana*, key species for narrow shelter belts, are planted in the centre of the belt so as to ensure the necessary height and sustained protective effect. Rows of *Eleagnus angustifolia* are planted on the belt's windward side so that in their young stage, their curved branches and luxuriant foliage will serve as shrubbery, while in their mature stage, their crowns may extend sideways to shade *Ulmus pumila*, thus permitting the key species to grow straight and tall. Trees of economic

value such as mulberries and apricots are planted on the lee side to increase the thickness of the belt. In oases along the Hexi Corridor, *Populus cupidata* and *Eleagnus angustifolia* are usually planted in interior belts. In the northern Ulan Buh Desert, mixed plantings of *Salix matsudana* prevail. In oases on the rim of the Taklimakan, economic species such as mulberry, apricots and walnut are added to belts composed of *Populus bolleana*, *Populus nigra* L. var. *thevestina* and *Eleagnus angustifolia*.

Farmland protective belts are generally deployed along ditches or roads, often with one ditch between two belts. They are mainly loose and ventilating. Experience shows that shelter belts of mixed trees and shrubs with a loose structure are effective in areas seriously vulnerable to wind and sand, while in more ordinary conditions, belts of a ventilating structure with low wind penetration are preferable within oases. According to data obtained in southern Xinjiang under medium wind velocity, a shelter belt with a wind penetration coefficient of 0.5 or so has a protective range of $23.7 H$ with a wind-breaking effect of 34.41 per cent, while the sand content close to the ground is 60-70 per cent of that outside the network. Using interior belts of this type, the farm of the 150th Corps at Mosouwan in the southwest part of the Gurbantünggüt Desert has reduced the area endangered by wind and sand from 21 per cent of the total in 1961 to 1 per cent in 1978.

Shifting sands within oases may reappear with the destruction of vegetation on stabilized dunes or with sands supplied by dry

riverbeds. The remedy can often be found as in Shache, Xinjiang, by planting trees around the dunes. In other places mechanical measures have been called for in addition to tree planting. At Jinta, Gansu, clay was placed on top of the dunes. At Minqin, Gansu, checkerboard clay barriers were constructed, inside of which sand-binding plants like *Haloxylon ammodendron* were established.

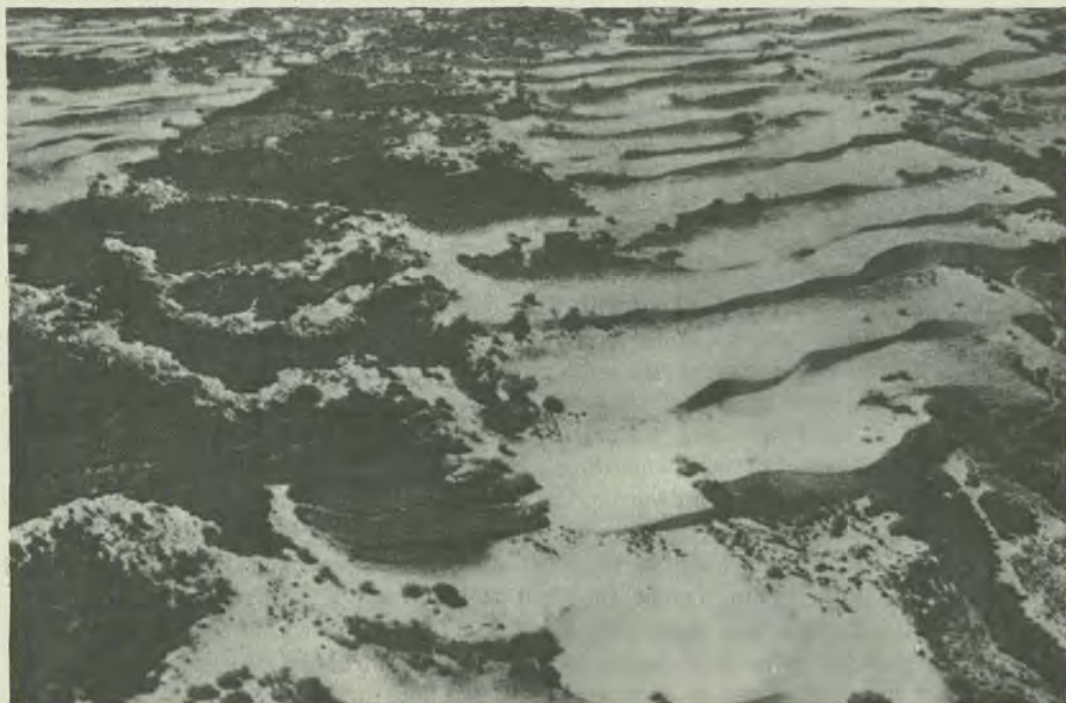
Combined Tree-Shrub-Grass Structures for Fixing Moving Sands

In the sandy lands on arid and semi-arid steppes, annual rainfall which averages 200-450 mm and sometimes reaches as much as 500-600 mm establishes favourable conditions for stabilizing moving sands with vegetation. Here tilled lands are mostly distributed on valley terraces and wet lowlands interspersed with sand dunes in zigzag patterns. Here also, the tree-shrub-grass combination has been adopted to stabilize drifting sand in a variety of ways depending on local conditions.

BLOCKING IN FRONT AND PULLING FROM BEHIND

In the Mu Us sandy land, experience shows that planting *Salix cheilophila* and *Salix matsudana* saplings or poplar cuttings in depressions between dunes, forming woodlots on the lee slopes of barchan and dune chains, has the effect of blocking moving sand in front, for the dunes are thus partitioned and contained. On the lower one third of the windward slopes, plantings are made of such sand-fixing species as *Salix cheilophila* or *Artemisia ordosica*. This has the effect of pulling the dunes from behind, since the vegetation cover lowers wind velocity at the ground surface, as shown in table 5, and thus reduces the amount of sand blown off by the wind. Observations indicate that the sand content of the air declines as the cube of the decrease in wind velocity. Less sand is blown off the windward slope to accumulate on the lee slope. At the same time, the wind will blow the top of the dune away, and as its height is reduced, trees are planted which act to continue the levelling

The Maowusu sandy land, where active dunes are interspersed among semi-fixed dunes.



process until the dunes have acquired gentle slopes. As vegetation increases from less than 5 per cent to 50-60 and even 80 per cent, the dune can be said to be stabilized. This process, illustrated in table 6, will generally take about five years. The people of the Mu Us sandy lands have applied the method with variations, as follows.

1) *Drag from behind only.* A belt of *Salix cheilophila* is planted on the lower part of the dune's windward slope to let the wind do the levelling. As soon as comparatively level stretches are formed, shrubs are planted, and planting continues until the dune area is completely level and covered with shrubs. The

lower part of the windward slopes are screened against the wind by such shrubs as *Artemisia ordosica* and *Salix cheilophila*. The artemisia will be removed after two or three years to benefit the growth of the trees, as was done on the May 7th Forest Farm in Ejenhoro.

4) *Tree-shrub-grass combination.* This is a method that developed out of "block in front and pull from behind" by adding herbs and grasses, such as *Melilotus albus*, planted in depressions between dunes, among other places, at Yangjianghao, Chengchuan Commune, Otog Banner, Inner Mongolia.

In all the foregoing methods, shrubs are planted on windward slopes to provide shelter

Table 5. Relative values between velocities at various heights of sand dunes with vegetation cover and those within 1.5 m on top of shifting sand dunes

Height (m)	Top of shifting sand dune (%)	Top of sand dune with vegetation cover (%)	Lowlands between dunes with vegetation cover (%)
1.5	100.0	90.0	52.8
0.5	87.1	57.1	34.2
0.2	72.8	54.2	30.0

method is called "chasing the wind and driving away sand with vegetation". It has been applied at Woduzaidang Brigade, Shenmu County, Shaanxi, to stabilize moving sands.

2) *Block first and pull later.* Tall tree cuttings — of *Salix matsudana* or *Populus simonii* — or the shrub *Salix cheilophila* are planted in depressions behind the lee slopes of the dunes. Since the trees block the advance of the dunes, their tops will be levelled in two or three years time, when *Salix cheilophila* can be planted on the windward slope to stabilize the surface. This method was applied extensively by the people of Ejenhoro Banner, Inner Mongolia.

3) *Mixtures of trees and shrubs* have been planted to stabilize low dunes (below 7 m) scattered over wet lowlands or undulating sandy land. Trees such as *Salix matsudana* or *Populus simonii* are planted in depressions between the dunes, while trees planted on the

Table 6. Relative values between wind velocities at various parts of barchan and that on the dune top (percentage)

Part of sand dune	Relative value of wind velocity
Lowland windward	76.7
Slope foot windward	77.9
1/3 slope windward	91.5
1/2 slope windward	94.7
Dune top	100.0
1/2 slope leeward	8.4
Slope foot leeward	27.0
Depressions between dunes	45.2
Lowland in front of windward slope of another dune	67.3

Note: Height of observation is 20 cm; dune is 5 m high.

against sand deflation. Data collected in northern Uxin Banner show that 20 cm above the surface, winds are down to 74 per cent of those blowing over unprotected dunes where *Artemisia ordosica* was planted five or six years before. Branches fall from artemisia, increasing the fertility of the soil and encouraging the growth of other herbs. At Dingbian, Shaanxi, in the southern part of the Mu Us sandy land, a crust formed on the sandy surface after *Artemisia ordosica* had been in place for three or four years, and in eight to ten years, the content of organic matter in the 0-50 cm surface layer had increased from 0.17-0.33 to 1.42-1.48 per cent.

Under the protection of such shrubs, the finer sands are no longer blown away. Within five or six years, particles of 0.01-0.05 mm diameter in the 0-5 cm surface layer had increased from an original 1.28 to 7.46 per cent.

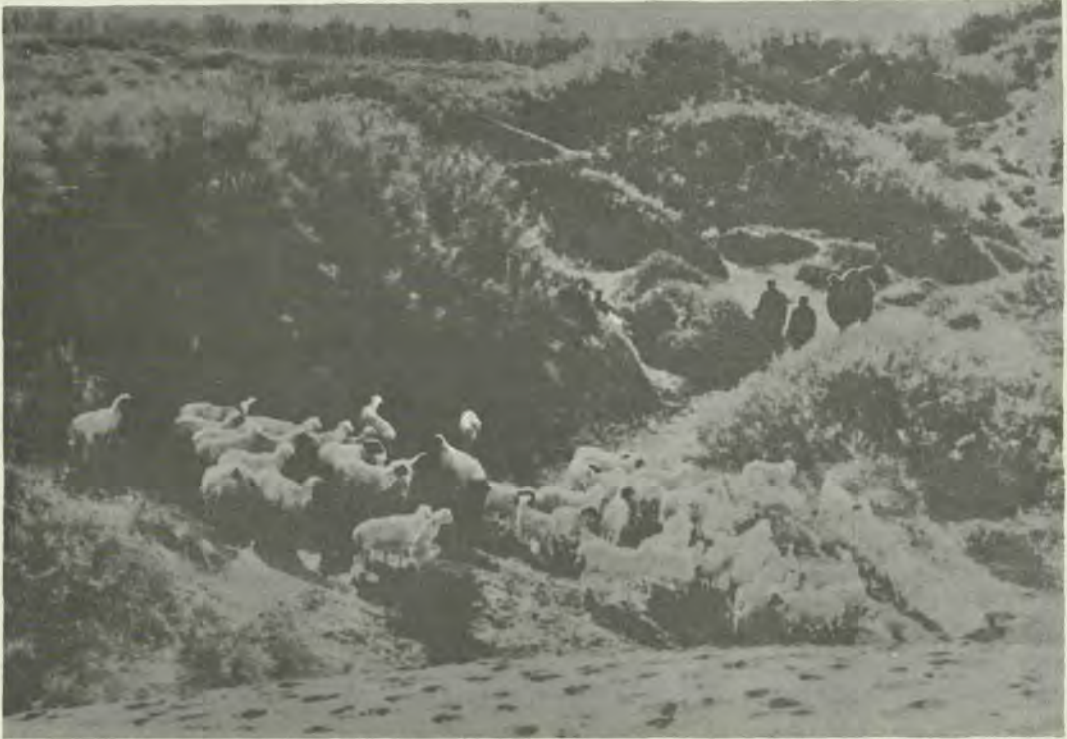
It should be pointed out, however, that the planting of *Artemisia ordosica* will tend to dry out the sand dunes because the root system absorbs a considerable amount of moisture. Data collected in late May show that on dunes planted with artemisia, the moisture content at a depth of 5-20 cm had dropped from 5.56 per cent before planting to 4.93 per cent after planting. The drop in moisture was even greater below 20 cm. This is detrimental to the growth of trees. Therefore, saplings should be planted shortly after the barriers of artemisia are in place. The artemisia barriers are best established in autumn when the moisture content of the soil is comparatively high and the wind not so strong, with the trees planted in the following spring. In some districts, the artemisia is removed after it has performed its protective function and replaced with other selected species. At Hele, Ejenhoro Banner, *Salix cheilophila* and *Artemisia ordosica* were planted in alternate rows, with the former protected by the latter. The artemisia was removed when the willow shrubs had matured and was replaced by *Pinus sylvestris* var. *mongolica* or *Pinus tabulaeformis*, under the protection of the *Salix cheilophila*. *Amorpha fruticosa* can also be used to stabilize drifting

sand and improve sandy soil. Data show that five years after planting, the organic content of the surface layer had increased by a factor of four.

TREE SHRUB COMBINATIONS FOR TRANSFORMING SAND DUNES INTO WOODLANDS

Parts of the steppe are favourably endowed with water. The best such region is the Horqin sandy land with an annual rainfall of 300-600 mm and a moisture content of 3-6 per cent in the sand strata. Under such conditions, it is possible to establish patches of trees in the depressions between dunes, while simultaneously planting sand binders, mainly shrubs, on the dunes preliminary to the establishment of the pine groves forming woodlands. Suitable species for the depressions between dunes are *Populus simonii*, *Populus pseudosimonii*, *Amorpha fruticosa* and *Salix flavida*. Where the water table is 2-3 m deep and no water-logging appears during the rainy season, *Pinus sylvestris* var. *mongolica* and *Pinus tabulaeformis* may be planted with other trees.

In the Jangutai District, Zhangwu, Liaoning Province, the measures taken to stabilize dunes began with the construction of artificial barriers on the lower two thirds of the windward slopes. Below the barriers, *Artemisia halodendron* or cuttings of *Salix flavida* are usually planted, although belts of *Lespedeza dahurica* or *Caragana microphylla* can also be used for the same purpose. Sand-fixing plants should be established after the top of the dune has been blown away. After two or three years, when the surface is relatively stabilized, is the time to plant pines between the shrubs or herbs on the dunes. Earlier planting would leave the saplings vulnerable to wind scouring or sand burial, while in later plantings the growth of pine saplings is affected by the absorption of a large amount of soil moisture by the root systems of the shrubs. Since *Pinus sylvestris* var. *mongolica* develops a strong root system in dry, poor soil with deep vertical and large horizontal roots which facilitate the absorption of nutrients and moisture, it is the



Another effective method of fixing active dunes inside oases is to protect the natural vegetation cover and plant xerophytic vegetation.

favoured species for afforestation on sandy land in arid steppes.

These were precisely the procedures through which moving sand dunes near Jangutai in the south-eastern part of the Horqin sandy land were transformed into pine-covered sandy soil with significant changes in the local landscape. The forest now has an average height of 7 m, in places as high as 10 m, with trunks an average of 12 cm in diameter and the largest 24 cm. At a height of 1.5 m within the forest, wind velocity has decreased by 78.4-81.2 per cent compared with the wind velocity in open terrain.

Experiments with Enclosures to Protect Vegetation Cover

If the vegetation cover is to be protected on sandy land, the ground surface must be protected against wind erosion and the reappearance of moving dunes, while young trees and crops must be guarded against sand move-

ment and damage from wind and wind-blown sand. Vegetation cover works within enclosures formed by the shelter belts to provide such protection.

In the northern part of the Ulan Buh Desert in Inner Mongolia, sandy lands sown to shrubs such as *Artemisia ordosica* and *Nitraria* spp. have achieved a vegetation cover of 50-60 per cent with adequate irrigation. Dunes with less than 5 per cent cover in the Ulan Buh near the Dengkou oases have become semi-fixed mounds with a 20-30 per cent coverage of shrubs.

In the oases on the fringes of the Taklimakan and along the Hexi Corridor, it has become the customary practice to plant *Tamarix chinensis* on sand dunes to turn them into shrub-covered mounds which, as experiments show, have the effect of checking the drift of sand. Observations made at Shache on the edge of the Bukuli Desert show that at the surface of a mound covered with tamarix, wind velocity is generally 40-50 per cent lower

Table 7. Changes in surface wind velocity and ground surface roughness brought about by enclosure experiment with herbal vegetation (Aitinghu People's Commune, Turpan)

	Ground surface wind velocity (m/sec)	Relative value of wind velocity (%)	Ground surface roughness (cm)	Relative value of roughness (%)
Wind eroded land outside oasis	9.0	100.0	0.0344	100
Sandy grounds with 85 per cent coverage of <i>Athagi pseudalhagi</i>	5.0	50.5	1.360	3,953

than it is on naked sand, while the sand content of the wind is 80-90 per cent less. Planting herbs on enclosed sandy land has been further developed at Turpan in recent years by winter irrigation and by sowing grasses inside the enclosed area. The result is an average increase of seven new seedlings per square metre and a vegetation cover of 60-85 per cent within three years. Shrubs suitable for enclosed areas include *Alhagi pseudalhagi* to be mixed with *Karelinia caspica* and *Crespis* spp. On undulating sand surfaces on the fringes of oases, *Phragmites communis*, *Tamarix chinensis* and *Halostachys belangerinna* are used where the water table and mineralization are both high, while *Capparis spinosa* is more suitable to wind-eroded land. A surface covered with 80-85 per cent *Alhagi pseudalhagi* is shown by observation to be over 40 times as rough as the wind-eroded surfaces outside, while the surface wind velocity is 50.5 per cent lower, as shown in table 7. This causes the coarser sand particles to settle down. The windward face of the shelter belt becomes a sand trap, minimizing sand accumulation within the shelter belt and benefiting the growth of young plants. The ability of vegetation to halt sand movement within fenced enclosures is all the more evident where water conditions are fair as in the dunes in the north-eastern part of the Mu Us sandy land. There the natural vegetation, mainly *Artemisia ordosica*, achieved a 60-70 per cent cover in four to five years time, and fine sands of a size below 0.05 mm have increased by 50 per cent while organic content has risen from an original 0.079 to 0.71 per cent.

The Grass Kulum to Block Wind and Sand and to Create Pastures

The management of sandy lands on arid and semi-arid steppes has two aspects. On the one hand, it seeks to remedy the damage caused by drifting sand and to halt movement of dunes. On the other hand, it aims to take advantage of local water, land and vegetation resources to rehabilitate pastures and develop animal husbandry. The Uxinju People's Commune, Uxin Banner, Inner Mongolia, has shown that building grass kulum is an effective measure for preventing damage from drifting sand, for protecting, managing and rationally utilizing pastures, and for building sustained high-yield fodder bases.

Different conditions in the Uxinju sandy flats have called for different treatment, in terms of which grass kulum can be classified in three types:

1) *The tree-shrub-grass combination kulum for sand control.* This type of kulum is generally built in areas of moving and semi-stabilized dunes where measures to control sand primarily make use of sand-fixing vegetation. The goal is to turn the dunes into producers of fodder.

For barchan and barchan chains of a height less than 10 m rows of *Salix cheilophila* are planted on the lee side of the dunes, in certain areas combined with such natural shrubs as *Salix microstachya* and *Hippophae rhamnoides* to form dense shelter belts as a block against advancing sand. On the lower one half to one third of the windward slopes where sand has a little moisture and the wind is not strong

enough to endanger survival, *Artemisia ordosica* is planted against the main wind direction. As the vegetation cover increases and weakens the wind force so that the sand on top of the dune is no longer carried away, artemisia is extended up the slope until the whole dune is covered and wind erosion checked, a process that requires from three to five years.

In order to prevent wind erosion gaps caused by withering of the artemisia in seasons of drought and strong wind, various precautionary measures should be taken. For instance, *Artemisia ordosica* and *Salix cheilophila* should be planted in rows, and in the first two years care should be taken to replace dead shrubs promptly with young saplings so as to leave no wind gaps. The shrubs should be protected against cutting and grazing for three years to five years after the planting so that the canopy can be closed as quickly as possible.

To control undulating dune lands and the flat sandy lands on the fringes of wet lowlands, cuttings of *Salix matsudana* are planted to form forests. Tall cuttings three to four years old and about three metres long should be planted deep, up to one third of their length. If the water table is more than one or two metres below the surface, the bottom ends of the cuttings should be immersed in water for 10 to 15 days before planting so as to improve survival chances during seasons of drought and wind. Suitable planting distances between trees and rows are 5×5 m or 3×4 m. In such cases, the canopy should be closed within three years. But if *Salix matsudana* is planted on the windward slope of dunes, the root system must be protected from exposure

to wind erosion by adding *Salix cheilophila* and by sowing grasses. In one system, three species are planted in alternate rows, with *Artemisia ordosica* protecting *Salix cheilophila*, which protects, in turn, the *Salix matsudana* saplings. This has proved to be a satisfactory way of avoiding wind and sand scourge.

2) *Grass kulums for hay and winter-spring grazing.* Kulums of this type are in general built on inter-dune lowlands and lake basins in sandy areas. They are a type extensively distributed at present, mostly on slightly saline meadow soils or on clay meadow soils, with vegetation cover composed of various types of mesophytes and hygrophytes forming meadows adapted to slight salinity. Such, for example, are *Achnatherum splendens* saline meadow, *Iris ensata* saline meadow, sedge-forb meadow, grass-forb meadow and reed-forb meadow, with the reeds consisting of *Phragmites communis*. As a result of fencing, protection and rational use, the vegetation cover improves very rapidly in grass kulums of this type, with density and height as well as coverage increasing markedly. On wet lowlands, the yield of palatable gramineous grasses such as *Aneuolepidium dasystachys* in air-dried matter is 1.37 times prior to fencing and protection. At the same time ground litter from the rank growth of grasses prevents the reappearance of moving sands while improving the organic content of soil. Enclosures are equally effective on sandy pastures, as shown in table 8.

3) *Water-grass-forest-cereal, four-in-one grass kulum,* an improvement on the second type, might be considered as a new stage of comprehensive treatment. The four-in-one is usually built in depressions between dunes where the

Table 8. Effects of an enclosure programme on sandy pasture (Uxinju Commune)

Plant community	Condition	Vegetation coverage (%)	Height of shrubs and subshrubs (cm)	Height of herbs (cm)	Weight of air-dried matter (g/100 m ²)	Years under enclosure
<i>Artemisia ordosica</i> + <i>Hedysarum mongolicum</i> -annual	Closed and under protection	60	66	4	6,979	8
	Degenerated	25	44	3	2,031	

land is flat, water plentiful and the soil mostly of sandy clay meadow rich in organic matter. These new kulums are generally developed in the following four stages:

a) Ground water is brought into use in ways that depend on local conditions. Shallow ground water can be tapped with large-mouth wells or pipe wells. The former is a ditch-like reservoir three metres deep that collects ground water by seepage and is dug with a view to expanding the irrigation area of a single well. The pipe-well will be 20 to 30 metres deep with a strong cement pipe 50 cm in diameter serving as the shaft, the wall of which is of a type that permits water percolation and prevents shifting sand from clogging the shaft. Deep water can be tapped with pumps or artesian wells, accompanied by measures to conserve the water.

b) Shelter belts of trees and shrubs—*Salix matsudana* and *Salix cheilophila*—are planted at right angles to the prevailing wind in the form of narrow belts of loose construction which not only prevent sand drift but also provide leaves and twigs for fodder. Additional sowing of plants such as *Melilotus albus* in tree and shrub patches near sand dunes helps to check the wind and prevent damage from sand.

c) Land configurations are modified, including the levelling of dunes and the filling of depressions between them. The soil after cultivation improves greatly both in weight per volume and improved porosity.

d) Selected species of pastures and cereal crops are planted, including *Melilotus albus*,

Medicago sativa, *Sorghum sudanense* and *Astragalus adsurgens*. These are not only of higher yield and nutritional value than natural range species, but they also help to improve soil quality, as shown in table 9. Cereal crops such as *Panicum miliaceum* and *Hordeum vulgare* var. *nudum* are also cultivated, and nurseries are set up. In the advanced four-in-one grass kulum of the Zhahanmiao Production Brigade, 5 per cent of the total acreage is devoted to growing selected grasses and cereal fodders, 30 per cent to improved natural hay, 60 per cent to pastures, and 5 per cent to forest land and other uses. Kulums of this type have come to play the major role in reclaiming and improving the grasslands, and are increasing at a rapid rate.

The kulums established in the Uxinju People's Commune have been effective in controlling damage from sand and wind and in rehabilitating the steppe lands.

WEAKENED WIND AND SAND ACTIVITY

After fixing moving dunes with vegetation, observation shows that the ground surface is 290 times as rough as it is on naked dunes, and both the velocity of the wind and its sand content within 20 cm of the surface have registered remarkable drops, as shown in table 10. On inter-dune ground planted with *Salix cheilophila* and hedged-in shrubs, density of vegetation cover is as high as 75 per cent and the surface roughness is 617 times that of untreated dunes. Here the reduction in wind velocity and sand content is most apparent and the effects of vegetation most obvious.

Table 9. Effects of *Melilotus albus* on soil (Uxinju Commune)

	Organic matter (%)	Nutrients (%)			Porosity (%)	Volume weight (g/cm ³)
		N	P	K		
Inter-dune grounds planted with <i>Melilotus albus</i> for 2 years	1.138	0.046	0.168	2.58	50.5	1.31
Inter-dune grounds without planting <i>Melilotus albus</i>	1.018	0.040	0.074	...	44.0	1.48

Table 10. Effects of vegetation cover on shifting sand dunes in respect of surface wind velocity and sand content in air current (Uxinju Commune)

Type of ground surface	Vegetation coverage (%)	Relative value of wind velocity (%)	Reduction of wind velocity (%)	Relative value of sand content in air current (%)	Reduction of sand content (%)
Shifting sand dunes untreated	below 5	100.0	...	100.0	...
Dunes planted with <i>Artemisia ordosica</i> and <i>Salix cheilophila</i>	28 - 50	74.3	25.7	4.8	95.2
Inter-dune grounds planted with <i>Salix cheilophila</i> and hedged-in natural shrubs	75	37.2	62.8	2.3	97.3

Note: Height of observation 0 - 20 cm above ground.

Table 11. Changes in surface soil properties after adopting vegetative sand-binding measures at Uxinju People's Commune

	Particle size <0.05 mm (%)	Volume weight (g/cm ³)	Porosity (%)	Dry aggregate >1 mm (%)	Organic matter (%)	Nutrients (%)		
						N	P	K
Shifting sand dunes	3.31	1.69	36.2	0.2	0.098	0.033	0.05	2.82
Dune stabilized with <i>Salix cheilophila</i> and <i>Artemisia ordosica</i>	15.38	1.57	40.6	7.8	0.168	0.063	0.060	3.00
Sand dunes in high forests	6.33	1.61	39.2	...	0.141	0.040	0.087	2.90

Notes: Sampling depth: organic matter and nutrients: 0 - 15 cm; mechanical composition and dry aggregates: 0 - 20 cm; volume weight and porosity: 0 - 10 cm. Years of sand fixation: 6

CHANGES IN SOIL PROPERTIES

Consider sand dunes stabilized with *Salix cheilophila* and *Artemisia ordosica*. By comparing these with untreated dunes down to a depth of 20 cm, it is seen that particles smaller than 0.05 mm have increased from 3.31 to 15.38 per cent, while the soil's weight per volume dropped by 0.12 g/cm³, porosity increased by 4.4 per cent, dry soil aggregates

larger than 1 mm in diameter increased by 7.6 per cent, and organic matter content increased from 0.098 to 0.168 per cent, as shown on table 11. Considerable changes also took place in the content of the nutrients.

IMPROVED PASTURES

The quality of the vegetation composition inside the kulum is much superior. Grasses in

the reed-plus-forb community have come to constitute 42.7 per cent of the biomass by weight and leguminous herbs 34.6 per cent, while poisonous weeds are down to 2.8 per cent compared with a striking 84.6 per cent on deteriorated pasturelands where, too, gramineous vegetation is a mere 6 per cent. Secondly, there is a marked increase in plant height, growth within the kulum averaging 11 times higher than that outside. Thirdly, the density of vegetation has increased. The reed community has achieved a cover of 90 per cent, while the sedge-forb community has reached 75 per cent, as compared respectively with 15 and 20 per cent on degenerated pasturelands. Finally, the hay yield has greatly increased. On one grass kulum begun at Uxinju in 1964, hay yield is 19 times what it is on degenerated pasturelands.

Such changes indicate that the grass kulum is a tested and effective method for stabilizing dunes, for improving soil and the growth of forage, for building up pastures and developing animal husbandry.

Engineering Measures Combined with Vegetative Methods to Protect Roads

With the development of the People's Republic of China, more and more roads and railroads are coming to run through desert areas. Routes are carefully selected so that transportation will not be interrupted by desert conditions. Depending on different local conditions, engineering measures as well as vegetative methods are employed to keep roads and railroads in smooth operation. In some cases, routes are menaced by the movement of dunes, in others by drifting sand, in still others by both. These circumstances call for different responses.

For railway lines running through steppes with drifting sand and fixed and semi-fixed dunes: Temporary engineering measures, such as building barriers against drifting sand, are undertaken during construction. Other means must be used for the more permanent protection of the roadbed, such as sodding the slopes of the roadbed with grass turf obtaina-

ble from nearby depressions between dunes, enclosing sandy areas on both sides of the road to protect vegetation and let it grow, and planting sand-fixing vegetation on dunes.

Along railway lines in the Horqin sandy land, measures to stabilize sand have been graphically portrayed by the people as follows: *Artemisia halodendron* as the sand binder; *Caragana microphylla* as a hat for the dune; *Lespedeza dahurica* as its apron on the windward slope; poplars as its boots—for the foot of the dune and for the depressions between dunes; and *Salix flavida* as its shawl for the lee slope. Thus is formed a protective system called "the right tree for the right place".

Where sufficient water is available, trees such as *Pinus sylvestris* var. *mongolica* and *Pinus tabulaeformis* may be planted on sand dunes. To stabilize sand along railroad lines, the surface should first be fixed by building straw grids or rows of vertical barriers on moving dunes and then between the barriers to establish such sand-fixing plants as *Salix flavida*, *Artemisia halodendron*, *Caragana microphylla* and *Pinus sylvestris* var. *mongolica*. Two years after such measures were undertaken on shifting sand dunes north-east of Naiman in the central Horqin sandy land, the density of the vegetation cover on the dune surface had increased from the former 3 to 30-40 per cent.

For railway lines running through desert borders where moving dunes stretch and undulate: An example of this situation can be found in the Zhongwei-Gantang section of the Baotou-Lanzhou Railway on the southeastern fringe of the Tengger Desert. Here gravel protection is provided on the slopes of the roadbed and gravel platforms established on both sides of the line. In addition, protective belts have been built on both sides of the line for distances proportional to the movement of the dunes. Thus, on the side facing the main wind direction, the belt is 500 m wide, while a belt of 200 m width has been established against the secondary wind direction. The belts consist of barriers of straw arranged in a checkerboard pattern. Observations carried out after construction

show that straw grids make the ground surface 220 times as rough as the surface of untreated dunes and the surface velocity of the wind is 23 per cent less while its sand content is conspicuously lower, 84 per cent less with a wind of 8 m/sec.

As the straw barriers check sand flow on the dune surface, sand-fixing plants within barriers have better chances of survival and growth. With the fairly stable surfaces provided by the checkerboard pattern, it is possible to introduce shrubs to stabilize dunes on their windward slopes, where a moist layer lies 3-20 cm below the dry surface with a water content of 2-3 per cent, a wilting coefficient of 0.7 per cent and water available to the plants of 1.3-2.3 per cent. This layer gets replenished during the summer-autumn rainy season. Experience at Shabodou on the Baotou-Lanzhou Railway shows that *Hedysarum scoparium* has the highest survival rate and the best growth and that *Caragana korshinskii* exhibits fairly steady growth. Next best are *Calligonum mongolicum* and *Salix flavida*. As a result of such measures, moving dunes have

become semi-fixed and density of vegetation cover has increased from a previous 3 to 14.3 per cent, in some areas to 25 per cent, ensuring the smooth operation of the Baotou-Lanzhou line as it traverses the south-east Tengger Desert.

High-lift pumping-irrigation projects have been built in the Shabodou District to pump water from the Yellow River for reclaiming sand dunes, and for making terraces and watering them for the benefit of afforestation. Years of experience have shown that rows of trees should alternate with rows of shrubs in irrigated afforestation projects. Among preferred trees are *Robinia pseudo-acacia*, *Eleagnus angustifolia*, *Populus cupidata* and *Hedyscoparium*, *Caragana korshinskii*, *Salix flavida*, *Amorpha fruticosa* and *Salix cheilophila* are the shrubs of choice. There is generally enough silt in Yellow River water that it will settle in the irrigated area and within a year form a crust on the sand, thus fixing it and offering the trees under irrigation a higher survival rate and quicker growth.



Construction of checkerboard protection to stabilize shifting sand near farmlands.



Clay deposits from the hollows between the sand dunes are successfully used to erect checkerboard protection.

A sprinkler system fed by water from the Yellow River is used to accelerate the stabilization of shifting sand along the railway.



For railway lines running through arid zones and gobis where wind and sand drift are severe threats: The Yumen section of the Lanzhou-Xinjiang Railway illustrates such a case. During construction, temporary measures were adopted such as combinations of ditches and banks. More permanent protection is provided by irrigation canals lined with rows of trees and shrubs, preferably *Populus cupidata*, *Eleagnus angustifolia* and *Salix cheilophila*, with the last deployed on the windward side to check drifting sand. The effect of this arrangement on the wind is shown in table 12. It should be pointed out that as the shelter belts here are mainly for protection against burial of the roadbed by sand, they should generally be of a dense structure. At wind gaps where the drift of sand is strong, two to three rows of barriers should be placed in front of the shelter belt to block sand encroachment. In view of the gravelly character of the gobi, care should be taken to ensure tree survival by planting the saplings in ditches in good soil which has been brought in. Water seepage should be prevented by lining the ditches with mortared pre-fabricated cement slabs. As a result of these measures, the length of the Yumen section of the Lanzhou-Xinjiang

Railway under threat has declined from an original 94.7 per cent to a current 2.7 per cent.

For highways passing through desert areas: Where conditions are favourable for sand-fixing plants, forest belts can be planted along roadways and dunes fixed by planting shrubs such as *Artemisia ordosica* and *Salix cheilophila*, with trees and shrubs properly combined. Where dunes are fixed or semi-fixed, the easiest procedure is simply to fence them and let the grass grow and provide vegetation cover. This method has been widely used on most highways in the Mu Us sandy land. In areas where vegetative fixing is not practical, great care should be taken to select favourable routes, as on river-beds in deserts, in the bottleneck sectors of lake basin sand dunes, or on open inter-dune grounds between large sand hills where the rate of sand advance is low. Meanwhile, sand damage should be minimized by streamlining the road-bed sections formed of shallow troughs and wind banks for transporting sand, by elevating the roadbed above the average height of the surrounding dunes, and by paving a solid, even and smooth surface which will easily shed sand.

In addition, comprehensive engineering measures should be undertaken on both sides of the road to fix, block, transport and guide away sand by building sand barriers on the road's windward side, by covering nearby dunes with pebbles or salt blocks obtained in the vicinity, by establishing checkerboards of reeds to increase surface roughness to reduce wind velocity and the amount of wind-blown sand, and by building banks and wind-guiding panels close to the road to prevent sand from accumulating.

Observations made on desert highways in the mouth of the Taklimakan show that streamlined road surfaces together with rows of wind-guiding panels are effective in preventing the road surface from being buried by sand. Streamlining provides a smooth flow while the panels increase surface wind velocity (at the lower exit of the panel, the wind is moving 1.6 times as fast as in front of the panel in the open field) which blows the sand across the road without allowing it to accum-

Table 12. Wind-breaking effect of railroad protection by forest against sand

	Wind velocity (m/sec)	Relative value (%)
Open field	11.4	100.0
2.5 H	6.4	56.1
7.0 H	7.7	67.5
10.0 H	9.0	79.9

ulate. To fix sand dunes and prevent them from advancing toward the road, both reed and pebble barriers are fairly effective.

BUILDING FARMLANDS BY LEVELLING SAND DUNES WITH WATER

This method is used extensively in Yulin District in the southern part of the Mu Us sandy land and in Yangbian District, where it has been turned to fullest account. Levelling out sand with water requires that water be led naturally or drawn mechanically from rivers, lakes or reservoirs to level dunes on riverbanks or on terraces so as to convert undulating ground into flat and even sandy farmlands. Since large quantities of water are required for this task, ample sources must be available and water conservation applied. In certain districts, floodwaters are used to level out sandy lands. It takes 2,450 m³ of water to level one *mu* of land, each cubic metre of sand needing 2-2.5 m³ of water. (One *mu* = 1 are = 1/100th hectare.)

Once the land is levelled, other measures for soil improvement should be taken, such as flooding, covering infertile land with "guest" soil and planting green manure. Such action should be taken in combination with water conservation projects and shelter belts to turn barren earth into fertile farmland. The experience of the Yangjiaoban Production Brigade in Jingbian County, Shaanxi Province, shows that as a result of flooding with water, tilling, applying fertilizer and cultivation, conspicuous changes appeared in the physical and chemical characteristics of the sandy soil, as shown in table 13. Before any soil improvement was undertaken, the mechanical composition of the drifting sand consisted of fine particles 0.25-0.05 mm in diameter. In the sandy layer within 25 cm of the surface, the content of fine sand was as high as 82.2-88.8 per cent, while clay particles smaller than 0.001 mm in diameter accounted for only 4.4-6.4 per cent. Following a number of years of soil improvement, the fine sand content of the surface layer had dropped to 7-17 per cent,

A bumper harvest in sight—thanks to integrated sand control measures in the oasis in the piedmont plain of the Whispering Sand Mountain, Dunhuang County.



Table 13. Changes in mechanical composition (in percentages) of sand soils after levelling out sand with water (Yangjiaoban Production Brigade, Jingbian County)

	Sampling depth (cm)	Particle size (mm)					
							Less than
		1 - 0.25	0.25 - 0.05	0.05 - 0.01	0.01 - 0.005	0.005 - 0.001	0.001
Shifting sand dune	0-5	9.46	82.23	0.66	0.52	0.60	6.43
	5-25	2.70	88.77	2.91	0.61	0.61	4.40
10 years after treatment	0-12	4.13	17.14	47.59	9.83	5.49	15.82
	12-13	2.42	7.38	54.70	23.69	2.29	9.52
20 years after treatment	0-15	1.98	7.72	54.90	7.71	7.71	20.08
	15-40	12.98	66.82	9.65	5.26	0.60	4.69

Table 14. Changes in nutritional content in sand soil after levelling out sand dunes with water

Years after treatment	Sampling depth (cm)	Organic matter (%)	Total amount of nutrients (%)			Available nutrients (mg/100 g soil)		
			N	P	K	Water soluble N	P ₂ O ₅	K ₂ O
1	0 - 13	0.214	0.026	0.064	1.57		1.1	9
	13 - 24	0.086	0.063	0.042	1.07	3.79	1.1	7
	24 - 50	0.064	0.016	0.006	1.56	2.38	1.2	6
11	0 - 26	0.706	0.042	0.076	1.66	3.70	0.9	17
	26 - 49	0.278	0.037	0.030	1.18	3.44	0.7	8
17	0 - 14	0.814	0.071	0.088	1.86	5.82	1.3	21
	14 - 30	0.788	0.087	0.082	1.94	5.29	0.8	20

while the silt content of particles 0.05-0.001 mm in diameter had increased to 63-70 per cent. The balance, or 16-20 per cent, had come to be made up of clays of less than 0.001 mm in diameter.

Just after levelling, sandy lands are poor in nutrients, averaging around 0.09-0.21 per cent and nitrogen content 0.02-0.06 per cent. After ten years of improvement, the organic content had increased to 0.7-0.8 per cent and total nitrogen content to 0.04-0.08 per cent with a corresponding increase in other available nutrients, as shown in table 14. As a result, grain yield per *mu* increased from 50-60 *jin* to 650-odd *jin*.

During recent years, new soil improvement

measures have been developed in semi-arid areas in northern Shaanxi by planting rice on new sandy lands, which not only put an end to sand drift but also improved the quality of the soil by the fine mud and organic matter contained in the water. Physical survey data on soil improvement by raising paddy rice on sandy flats were gathered by the Yuhebao Farm, Yulin County. They show that under dry farming, the soil weighed 1.697 g per cm³ with a porosity of 33.4 per cent and with 59 per cent of it composed of particles smaller than 0.05 mm in diameter. After the land had been turned into paddy fields for four consecutive years plus one year for dry crops, the soil weighed 1.449 cm³ with a porosity of 43.6 per

cent and particles smaller than 0.05 mm then constituted 77 per cent of it. As a result of applying large quantities of manure and decomposed paddy roots to the paddy soil, the content of organic matter rapidly increased and expedited the maturity of the soil, thus turning barren sandy fields into farmlands with a high and sustained yield.

In northern Shaanxi in more recent years, this method has been further developed by building canals and weirs, the latter being dams made by sand deposited from water flow, and by watering the sand in order to turn the area green. Weirs have become very popular in the steppe region, where a number of reservoirs have been built. The Yudung Canal, besides supplying water for normal irrigation purposes, discharges its surplus water on sandy fields, and in the course of six to seven years, the whole district has been basically protected from damage by sand.

**BUILDING WATER CONSERVATION PROJECTS,
RECLAIMING BARREN LANDS, AND
IMPROVING SOIL TO FORM NEW OASES**

A number of deserts are located in intermontane

basins surrounded by snow-capped peaks, whose run-off feeds such rivers as the Yarkant, Hotan, Aksu, Manas, Shule and Hei with their sources in the Kunlun, Tian Shan and Qilian mountains. By opening canals lined with pebbles or cement to prevent seepage and to lead water into the desert, and by building reservoirs on inter-dune depressions and lakes on lowlands along rivers to conserve floodwaters, barren lands on the desert's edge and along rivers in the desert may be reclaimed. Action directed toward providing water should be combined with soil improvement and the construction of shelter belts. A number of measures can be taken to improve the soil.

1) *Using floodwaters for irrigation.* Since floodwaters contain large amounts of clay and a certain amount of nitrogen, they improve the soil and increase its fertility. Test data obtained at the Dengkou no. 1 main canal in the eastern part of the Ulan Buh Desert show quantities of nitrogen as follows: in ammonia, 0.1-0.5 g/m³; in nitrous form, 0.1 g/m³; in nitrite form, 0.1-1.148 g/m³. Moving dunes along the Yellow River in the Shabodou District, Zhongwei County, in the south-eastern



A combination of irrigation works, land levelling, soil preservation and planting of shelter belts checks the shifting sands and establishes new oases in the south-western part of the Taklimakan Desert.

part of the Tengger Desert, were levelled, inundated, fertilized and cultivated. Within eight years' time, the content of organic matter had increased from 0.0778 to the current 0.657 per cent.

2) *Adding sand to improve soil structure.* In the process of flooding newly reclaimed lands, attention must be paid to limiting the thickness of the silt layer, for too much silt results in crusting, poor permeability and rapid evaporation, all of which are detrimental to plant growth. On the other hand, some barren lands are composed of clay. In either case, addition of sand is called for. According to the experience of the 150th Corps Farm, Shihezi, Xinjiang Uygur Autonomous Region, adding sand to clay can break up crusting, cause the weight of the soil to drop by 0.14 g/cm³, porosity to increase by more than 10 per cent, and the salt content in the surface layer (to 10 cm deep) to drop by 0.7 per cent. Moisture is preserved and the water content in the surface layer increased by 3.5 per cent.

3) *Cultivating green manure*, such as sweet clover, alfalfa and *Astragalus adsurgens*, is another effective way to improve the soil of newly reclaimed desert lands so as to develop agriculture and animal husbandry. Experimental data accumulated by a farm in the south-western part of the Gurbantünggüt Desert show that soil fertility was greatly increased by three years of growing alfalfa and then ploughing it under. This led to an

accumulation per mu of 57.6 jin of nitrogen, 10.9 jin of phosphorus and 16.5 jin of potassium, equivalent to the application of 20,000 jin of high quality, stable manure. It was thus highly effective in stepping up subsequent yields, cotton increasing 3.14 times and winter wheat 2.78 times. When the inter-dune lowlands were sown to alfalfa in the Pingquan People's Commune, Linze District, in the Hexi Corridor, damage caused by drifting sand was stopped and the quality of the soil improved. As shown in table 15, the organic content in the surface layer down to 12 cm depth increased to 0.901 per cent as compared with the former 0.038 per cent. Planting such green manure on newly reclaimed sands not only improves soil structure and steps up fertility but also increases the yield of fodder grass. On a farm in the south-western part of the Gurbantünggüt Desert, the area sown to alfalfa usually takes up 26 per cent of the total area under cultivation. This illustrates the importance with which this measure can be regarded as a means of improving agriculture and animal husbandry as well as guarding against wind erosion and sand damage.

4) *Remedying alkalization and salinization.* Secondary alkalization-salinization is a problem often encountered in dryland reclamation. It calls for a sound irrigation and drainage system to wash the salts out of sandy land. Since this is well known, it need not be discussed in detail here.

Table 15. Changes in content of organic matter and nutrients in soil after sowing alfalfa on inter-dune lowlands

	Sampling depth (cm)	Organic matter (%)	Total amount of nutrients (%)			Available nutrients (mg/100g)		
			N	P	K	P ₂ O ₅	K ₂ O	
Land without alfalfa	0-15	0.038	0.045	0.086	1.16	1.62	1.12	22.9
	15-60	0.557	0.033	0.138	2.05	1.74	0.50	57.6
Land with alfalfa	0-12	0.901	0.051	0.128	1.63	1.51	1.76	40.0
	12-35	0.523	0.045	0.158	1.93	3.51	1.62	51.8
	35-85	0.564	0.042	0.172	1.54	3.89	1.68	63.1

TRANSFORMATION AND UTILIZATION OF GOBIS
Gobis in China spread over vast areas of desert and dryland. They are composed of piedmont diluvial or diluvial-alluvial gravels as well as of denuded detritus. As to their utilization, gobis of diluvial or diluvial-alluvial type may be transformed into orchard or forest with appropriate measures. Experience at Turpan indicates that the following measures are necessary. First, mountain snow water or spring water is tapped for irrigation through canals lined with gravel, mortar and cement to prevent seepage. Second, loose protective networks of narrow shelter belts are built by planting trees in ditches dug along water channels or roads. In the vineyard at the

Red Willow River Farm at Turpan, for example, the protective network is composed of shelter belts each 10 m wide, with main frontal belts 100 m apart, secondary belts 200 m apart, and inner belts both main and secondary 200 m apart. The forest occupies 16 per cent of the total vineyard acreage and affords the vines effective protection from damage by wind and sand. Third, the land must be levelled and soil quality improved within the networks of protective forest. Experience shows that the preferable method consists of leveling strips of farmland along contour lines on slopes, building earth dikes before reclamation, and watering the soil so that coarse gravels accumulate against the dikes, thus building up strips of height. The next step is to dig planting ditches 5-10 m apart, each 40 cm in depth and 40-60 cm wide at the bottom. Where salt is found, it should be washed until the rooting layer is free of crystals. Pits 90-100 cm deep, 60 cm long and 40 cm wide should be dug at regular intervals on the bottom of the ditches, and these should be filled with guest soil mixed with compost. Grapevines are then established in the pits and watered. The use of guest soil, brought in from other areas, works conspicuously to improve the gobi soil, as shown in table 16. It also decreases the content of coarse particles and increases the pro-

Table 16. Effects of guest soil on organic content of vineyards established in gobi (Red Willow River Farm, Turpan)

	Per cent
Gobi soil in the open	0.44
Ground soil between rows of grapevines	1.71
Soil in planting pit	2.35

Table 17. Effect of guest soil on changes of particle composition in gobi soil (Red Willow River Farm, Turpan)

Soil type	Sampling depth (cm)	Particle composition (mm) (%)							Loss of weight in HCl washing
		over 1 mm	1 - 0.25	0.25 - 0.05	0.05 - 0.01	0.01 - 0.005	0.005 - 0.001	Below 0.001	
Pit	00-2.5	47.69	14.29	10.58	7.45	3.26	4.98	3.64	7.11
	2.4-4.15	64.95	3.87	20.79	4.30	0.31	0.50	1.22	4.06
	41.5-63	65.52	8.19	9.31	6.51	2.09	3.75	2.80	1.83
	63-100	50.93	21.16	18.45	2.29	0.25	2.13	2.99	1.90
Open gobi	00-4.5	67.75	18.20	3.71	3.53	0.51	0.83	0.96	4.51
	4.5-38	74.67	12.14	6.65	1.04	0.34	0.73	1.09	3.34
	38-47	46.40	32.16	10.34	2.13	0.59	1.91	1.95	4.12
	47-85	70.49	12.93	6.73	3.17	0.81	2.65	1.41	1.81
	85-100	76.90	6.08	8.10	1.12	0.18	2.31	1.35	3.36

Table 18. Advantages of ditch planting for the growth of trees (Pinguan People's Commune, Linze)

Trees planted	Age of seedling (year)	Age of tree (year)	Height of tree (m)		DBH (cm)		Mean diameter of canopy (m × m)
			Average	Max.	Average	Max.	
In ditches	2	5	4.2	5.2	3.6	4.62	1.2 × 1.2
In the open	2	5	2.2	2.15	0.9	1.20	0.6 × 0.6

portion of fine sand and clay, as shown in table 17.

Under normal circumstances, grapevines begin yielding fruit after three years, and in five years' time cover up to 80-95 per cent of the ground surface, thus controlling wind and sand damage. In Turpan, over 20,000 *mu* of gobi have been turned into productive vineyards.

Trees grown on gobis not only provide crops with protection but can also supply lumber. In the experience of the people in Hexi Corridor, trees are planted in gobis by establishing seedlings in pre-dug ditches—at Linze, these are 1.5 m wide and deep—which facilitate irrigation and promote the growth of seedlings, as shown in table 18. In the gobi to the north of Linze, the organic content of the surface layer to a depth of 20 cm is 0.37-0.64 per cent, up to five times as high as on unflooded ground. A six-year-old *Populus euphratica* can stand as high as 5-6 m with a

diameter at breast height of 8.55 cm, serving as a defence against sterile gobi lands. At the Nanhu People's Commune, Dunhuang, in the part of the Hexi Corridor, sand dunes levelled with floodwaters have turned barren gobi into stretches of timberland.

A review of the examples taken from the experience of the Chinese people in building new oases shows that all the methods adopted—overall planning, water conservation projects, levelling desert lands, establishing trees to provide protection against wind and sand, improvement of soil quality—link together and converge to form a unified process for re-claiming barren lands and developing agriculture. The total area of oases in the Gurbantünggüt Desert, Xinjiang, has increased 6.2 times over pre-liberation days. The total acreage under tillage in the Hotan District on the south-western fringes of the Taklimakan has tripled since liberation.

Monitoring Desertification in China

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Deserts in China have expanded due to the advance of wind-driven sand dunes. At the same time, regions that were not true deserts have become desertified. This is due to the work of man, who has disturbed the ecological balance in arid and semi-arid areas. As desertification continues, it becomes progressively more difficult to deal with. Consequently there are great advantages in treating it promptly, as soon as it appears.

Desertification is a discontinuous process. Careful monitoring is required to determine where and when it is occurring. Its strength and development are gauged against a series of selected indicators:

1) *The movement of wind-blown sand.* Wind erosion of exposed soil and the mobilization of dunes provide the main indicator for estimating the strength of desertification. A number of measurements are included within this indicator, such as the proportion of sand dunes per unit area and the velocity of their advance, the depth of wind erosion and the amount of sand accumulating on the surface of the ground. The wind is measured too—its velocity, its sand content near the surface, and the frequency of sand-carrying winds.

2) *Changes in aridity.* Climate measurements must be extended over years to determine, for example, average annual precipitation and its seasonal distribution. In this way, the frequency of drought is established. The

aridity index is regularly measured so that trend in aridity and its fluctuations can be monitored.

3) *Vegetation cover.* The proportion of the surface covered and the density of the vegetation are principal indicators of desertification. A reduction in vegetation cover usually indicates an increase in sand dune activity.

4) *Changes in soil.* Factors to be monitored include the soil's physical composition, the proportions of particles of different sizes, its organic content, and such physical properties as weight per volume, porosity and structure. In some situations, attention should be paid to the soil's chemical composition and changes in its salt content.

5) *Changes in water regimes.* These include changes in the moisture content of the soil, in the depth of the water table and in the water's mineralization rate. Changes in the chemical substances dissolved in the water should also be monitored.

It is of the greatest importance that in addition to these natural indicators, the human factor should also be monitored. What needs to be determined is whether the land is being utilized rationally. Observations should determine if utilization is adapted to the resources and natural conditions of arid and semi-arid regions, especially in transition areas between the desert and the steppe. In either cropping or animal husbandry, overutilization will dis-

turb the natural ecobalance and lead to diminished biological production. Therefore great attention must be paid to the carrying capacity of pastures and to the climate conditions in which dry farming is carried out. If rainfed cropping has been overextended or overgrazing is being practised, desertification will

appear with the natural indicators listed above.

Because desertification is a patchy process, monitoring must be continuous so that trends can be determined. Changes in desertification indicators will be detected not only by ground surveys but also by the analysis of aerial photographs.

The Development and Utilization of Surface Water Resources in the Construction of New Oases in Desert Regions

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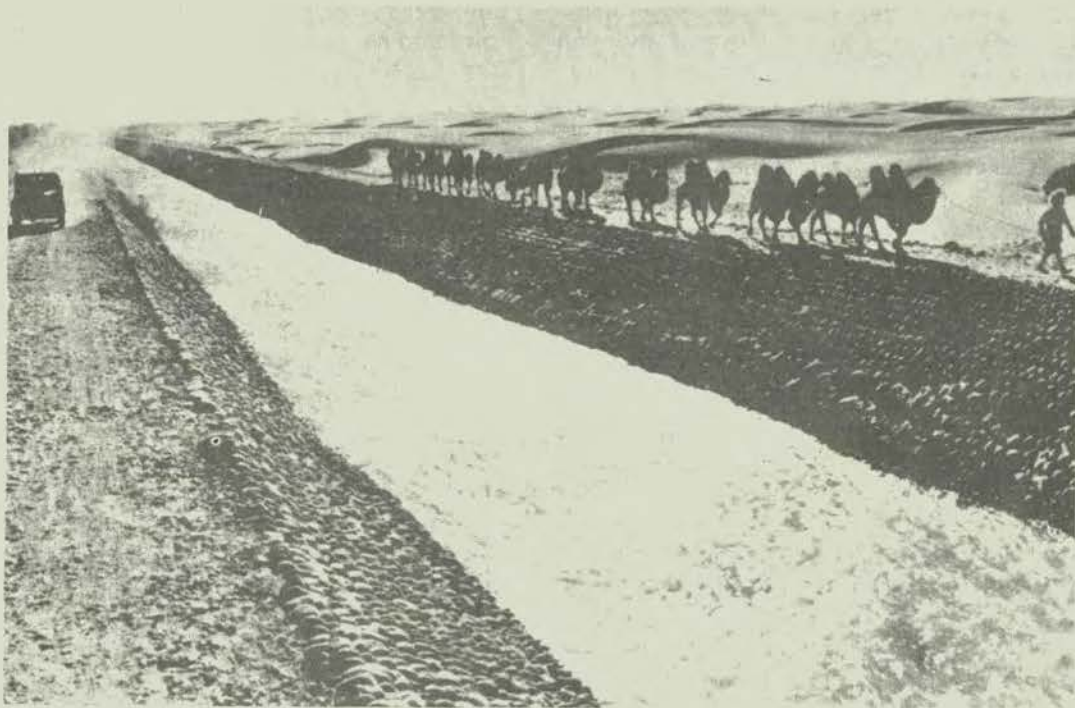
In western China, most deserts are to be found in intermontane basins, such as the Taklimakan in the Tarim Basin and the Gurbantüggüt in the Junggar Basin. In the mountain ranges around these basins, rainfall is abundant and the peaks covered with snow and ice. An important step in developing and utilizing land resources in desert areas is to make full use of these water resources. Reclamation in the basin of the Manas River illustrates the techniques developed in China for utilizing surface water to construct new oases in desert areas.

After the Manas River has emerged from Tian Shan, it flows north-westerly across the Junggar Basin through a plain composed of diluvial-alluvial piedmont fan and alluvial and alluvial-lacustrine formations. The whole landform slopes from south-east to north-west to a low point in the centre of the basin that is only 230 m above sea level although it is the heart of the continent of Asia. The piedmont fan is made up mainly of depositions of Quaternary boulders and gravels where seepage is severe and the surface gradient as steep as 5-10 degrees. As ground water reaches the surface, the frontal zone of the fan forms springs and swamps with the latter characterized by relatively serious salinization. Flowing north-west, the river leaves the piedmont to enter an alluvial plain of sand-clay and sandy clay. Here reclamation has been pursued

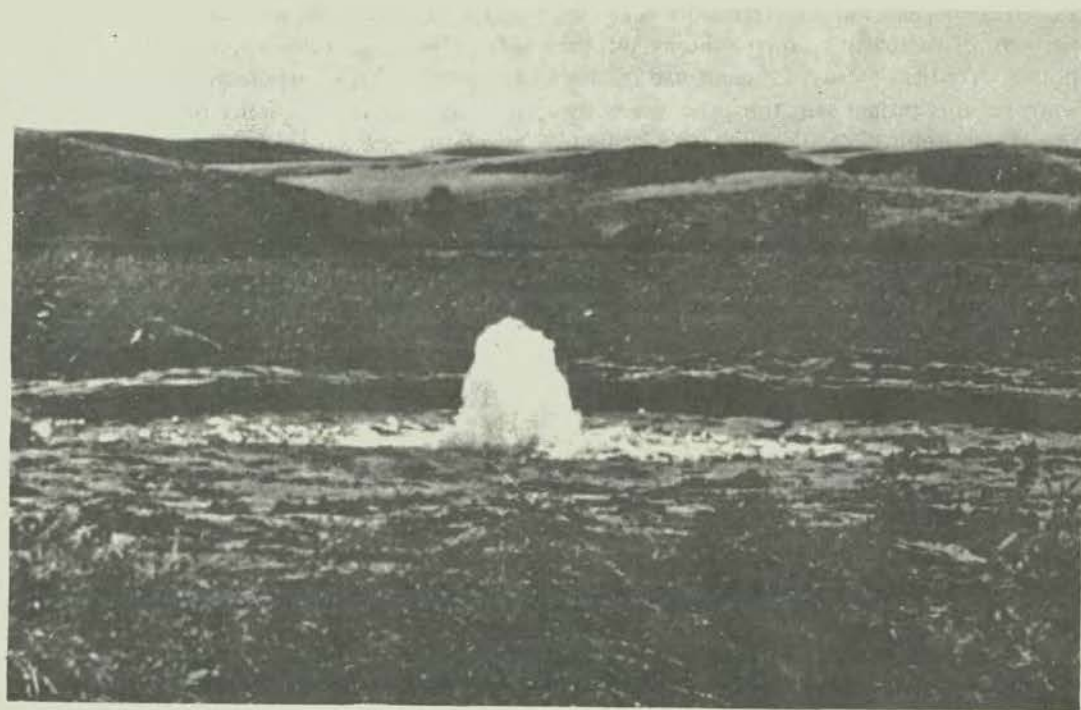
where old oases have made use of the flat relief, relatively high water table and thick vegetation. Further to the north-west, the old lacustrine plain shows a surface covered with aeolian sands of the Quaternary period. Dunes are predominantly longitudinal and of honeycomb form lying on sandy ridges, most of them so covered with vegetation that they have become fixed or semi-fixed.

If land is to be reclaimed and new oases built, an extensive and detailed survey of land and water resources is first of all required. On the basis of such a survey, a programme of water use was developed for the Manas River Basin, its resources harnessed by *diversion* via canals, *delivery* via channels lined to prevent seepage, *storage* in reservoirs, and finally, *irrigation* applied to productive fields. Following this programme, the irrigated area in the river basin has been enlarged 10 times, from about 600,000 *mu* in pre-liberation days to over 6 million *mu* at the present time.

Diversion. To achieve efficient diversion, the main headworks were built in the lower limit of the runoff area, that is, in the piedmont close to where the river leaves the mountains. Additional headworks were built on tributaries, some even in the mountains, so that the maximum amount of water is diverted into the artificial conduit. These structures were built to handle floodwaters with provisions for recollecting the seepage lost through



Above: Canal paved with pebbles to stop seepage. Below: An artesian spring in the desert.



gates and for flushing out the sand carried down from upstream. Additional diversion works were built downstream to make sure that no waters are wasted. The system's efficiency is relatively high, diverting about 70 per cent of all the waters in the basin and up to 85 per cent of the waters in the Manas River itself.

Delivery. All trunk canals carried through the piedmont fan are paved with watertight materials to prevent seepage. Paving usually consists of locally supplied gravels. Channels are lined with pebbles, with cemented pebbles, or with pebbles on the bottom and cement slabs on the slopes.

Storage. The river shows seasonal flow. To alleviate spring droughts, reservoirs of various sizes have been built on the alluvial plains to store floodwaters and winter waters. Reservoirs have been constructed mainly in places characterized by springs or where backflow might occur.

Irrigation. Before the waters were regulated, rivers and streams in the Manas Basin flowed through the twisting, braided channels typical of rivers in flat drylands. By directing the waters into canals, the system achieves a utilization coefficient that delivers more than 60 per cent of the basin's flow to the irrigation points. Needless to say, efficient use of the water requires proper irrigation practices, with the water applied regularly in the proper amount and at the proper time.

With the system in place, measures are then taken to improve the quality of the soil.

Improving Saline Soils

WASHING SALTS FROM SOILS

According to studies undertaken, the salt tolerances of the preferred crops in the reclaimed area are as follows: Total soluble salts 0.1-0.4 per cent, chlorides 0.03-0.07 per cent, hydrocarbonates less than 0.04 per cent and carbonates less than 0.007 per cent. The salt content of the soil is usually in excess of these amounts, and to get below these limits, salts must be washed from the rooting zone before planting. During this process and before these

limits are reached, salt-tolerant plants can be sown and harvested.

To desalinate the soil to a depth of 80 cm, 400-500 m³/mu of irrigation water are usually required. Too much water will often result in secondary salinization by raising the water table too high, with consequent loss of nutrients, damage to soil structure and deposition of alkaline salts by evaporation. After the salt has been removed by application of water in the correct amounts, the ground should be covered by plantings of winter wheat or of green-manure crops.

DEVELOPING ARTESIAN WELLS

These are used to expand water resources and to prevent salinization. To remove salts and prevent their return the following measures were undertaken. First, in areas of flowing springs where water quality is good and the water table high, pumps were installed to lower the water table and placed in operation either seasonally or all year round. In such settings, effective drainage must be ensured. Second, in areas where the water table was not so high but the water quality was good or could be made good by mixing with canal water, the emphasis was placed on irrigation which, when properly applied, can lower the water table. Third, where the water table was high and the water quality poor with a high admixture of salts, the water had to be desalted before it could be used. Fourth, where the water table was low and the water quality good, artesian wells were opened in the cultivated area and the water used for local irrigation with excess water being allowed to drain off naturally.

BOTANICAL LOWERING OF THE WATER TABLE

The extensive root systems and strong transpiration of trees planted in shelter belts provide an economical and effective means of lowering water tables. By intercepting water that has seeped from channels, tree roots prevent secondary salinization. For the maximum effectiveness of this "vegetative drainage", attention must be given to the rational arrangement of shelter belts and to the proper

choice of trees. If bio-drainage is its main purpose, the shelter belt should be established perpendicularly to groundwater flow so as to intercept runoff. The width of shelter belts and distance between them should be determined by volume of the groundwater flow.

As to species, fast-growing willows and poplars are preferred because of their strong transportation and thirst for ground water. Planting distances should also be measured by wind penetration and requirements for tree growth. Bio-drainage by shelter belts should be combined with cultivation, drainage and other measures for lowering water tables. If the land is not level, waterlogging may occur in low spots and forest belts alone will not be so effective in preventing secondary salinization.

Irrigation Techniques Determined by Conditions

Irrigated areas on the piedmont fan are located near the headworks and thus have adequate water supplies. The slope, however, is steep and the soil shallow and friable, poor in water-holding capacity and susceptible to erosion. Irrigation efficiency is therefore low. Frequent and shallow furrow irrigation is the technique recommended here.

On the fringe of the piedmont fan, the water table is high due to the movement of ground water. The slope is comparatively gentle and the soil moderately deep and fertile. Furrow irrigation should be combined with measures for improving the soil and with the installation of good drainage systems. Alternate furrow irrigation is used for crops during the growing season and small-bed irrigation for densely seeded crops. The width of the irrigation bed is one to two times that of the seed lines, with the length determined by the evenness of the land since uniform watering is

required. In certain places, artesian wells are used to lower the water table and prevent soil salinization. The total amount of irrigation water required will be 400-500 m³/mu.

In irrigated areas on the alluvial plain and on the desert margin, river water is still the main irrigation source. Reservoirs are provided to regulate the flow, and artesian wells are located in certain areas. Here the land is flat and the soil is deep and heavy, rich in soluble salts and with a strong ability to hold water. As the desert is approached, sand dunes appear and the configuration becomes undulating. This hinders the use of open drainage systems, so "dry drainage" is preferred, that is the use of micro-relief differences to establish soil and water regions. Salts from irrigated lands are transferred to neighbouring non-irrigated lands. Nearby lowlands are used as a natural evaporation tank.

Hydraulics for Sustained Yields

Thus in reclaiming land on the south-west fringe of the Gurbantünggüt Desert and on the north slope of the Tian Shan, people of several nationalities in the Manas River Basin have constructed hydraulic engineering works and irrigation systems and have carried out irrigation, soil improvement and the control of wind and moving sands. As a result, they have established complex units of a new type. In these new-style oases, hydraulics perform the principal tasks. A balance between water and soil resources is successfully achieved by the regulation and storage of river waters and a rational system of irrigation. Measures to improve the quality of the soil are combined with the control of unfavourable environmental factors. Agricultural production has been stabilized and further desertification prevented.

Stabilizing Sand Dunes with Vegetation

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Moving sand dunes are not uncommon in the northern parts of China. They threaten and can cause damage to farmlands and pastures, road and railroads, communications systems and population centres. To avert this threat, sand dunes must be stabilized and fixed in place, and this can be done with appropriate plantings of trees and shrubs. However, natural conditions vary in north China, and plant species must be selected with the particular locality in mind. Otherwise the objective will not be achieved.

The selection of the right species will depend on a thorough understanding of local habitats. Conditions must be known such as prevailing temperatures, wind velocity and direction, thickness of the sand layer, the composition of the underlying material, depth and quantity of ground water, dunes types and their dynamics, the water regime, the physical and chemical properties of the sand and subsoil.

Selection will also depend on understanding the botanical characteristics of the potential species. This will include knowledge of their natural geographical distribution, their biological and ecological characteristics, and their physiological indices.

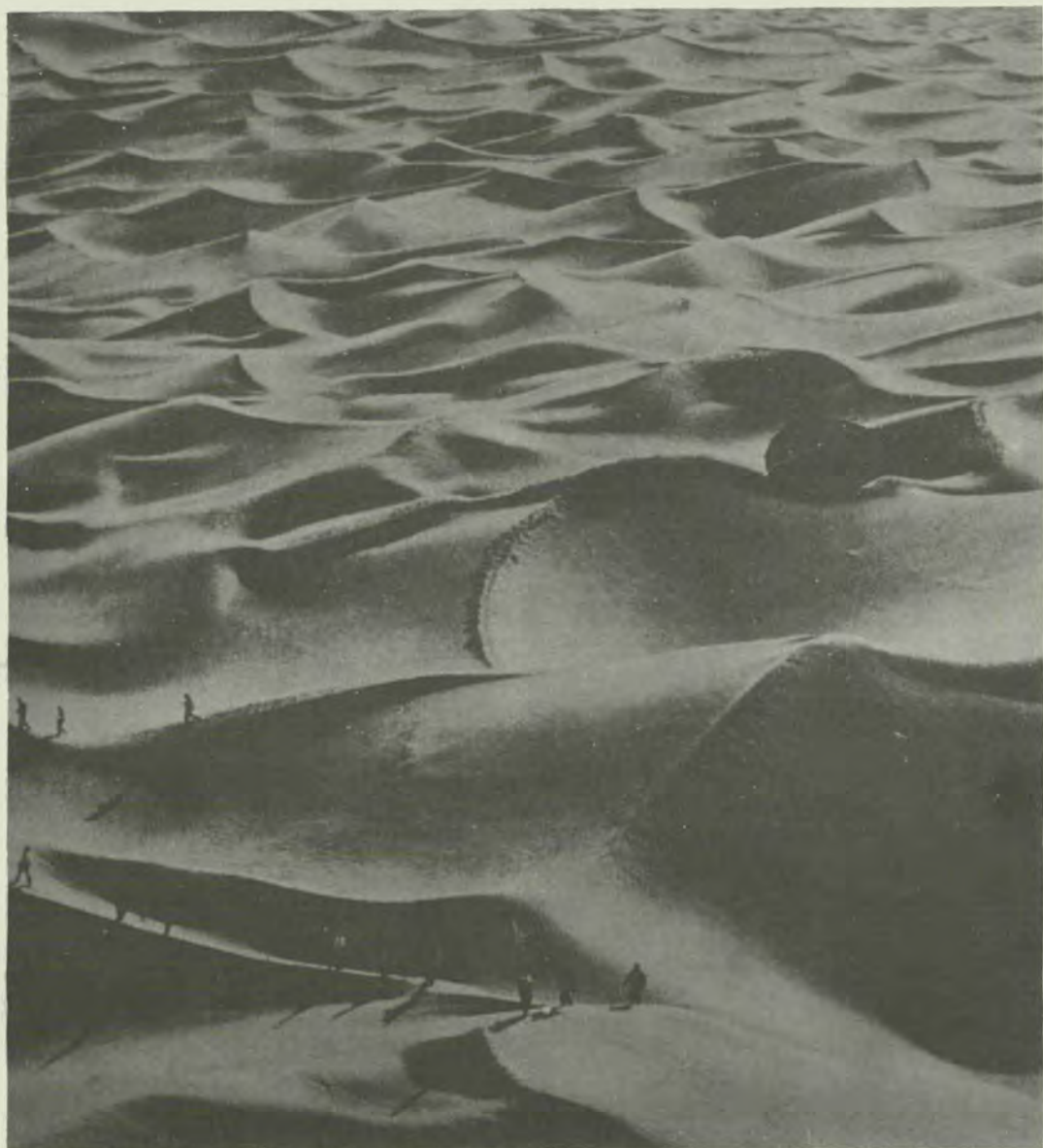
In the end there is no substitute for actual tests. Different species must be tested in experimental plantings in different natural conditions. Such experiments have been carried out in China.

SELECTION OF SPECIES IN SEMI-ARID REGIONS

Semi-arid regions include steppe grasslands transition zones from steppe to desert. They include much of the Mu Us sandy land, the Hedong sandy land in Ningxia and the south-eastern frontier of the Tengger Desert. They show an aridity index of 2-4 and annual precipitation of 150-450 mm. Fixed and semi-fixed dunes are widely distributed among them although moving dunes are also encountered, especially on the shores of lacustrine basins. The organic content of moving dunes within a depth of 10 cm averages 0.0262 per cent while fixed dunes, in contrast, show 0.629 per cent. All but 7 per cent of the particles in moving dunes are between 0.07 mm and 0.3 mm in diameter. The moisture content of dunes is higher on the windward side, reaching 2.5 per cent, with a little less moisture in the top and the least, 2.24 per cent, on the lee slope.

The vegetation on sandy lands in semi-arid regions consists mainly of shrubs and herbaceous plants of a restricted number of species. The amount of cover is low, reaching a maximum of 50-60 per cent only where water is available near the surface.

The flora is typical Mongolian, represented by such species as *Amygdalus mongolicus*, *Calligonum mongolicum*, *Zygophyllum xanthoxylon*. There are relict species in the Alxa



Active dunes.

Region among which are the evergreen broad-leaved shrubs such as *Ammopiptanthus mongolicus* and the bushy *Gymnocarpus przewalskii*. *Corispermum petelliforme* and *Stilpnolepis centiflora* grow rapidly after rain falls on moving dunes. Even as ephemerals they can create stable conditions for *Artemisia sphaerocephala* and *Hedysarum scoparium*. As the seedlings of these pioneers expand their shoots after being buried in sand, they tend to fix the dunes to

some extent.

Under the protection of *Artemisia sphaerocephala* it is possible for *Artemisia ordosica* to grow and form communities. The *ordosica* species possesses a much greater ability to stabilize dunes than the *sphaerocephala*, and under the protection of the former, perennial herbs such as *Allium mongolicum*, *Kengia mutica* (*Cleistogenes mutica*) gradually invade the area and expand the vegetation cover. This



Semi-fixed dunes.



Fixed dunes.

of course increases the consumption of water in the upper layers of the sandy soils. As the moisture becomes deficient at a depth of 1-1.5 m below the surface, *Artemisia ordosica* will begin to wither.

Sometimes, before the moisture around the intertwining root system of *Artemisia ordosica*

is exhausted, seeds of *Caragana korshinskii* may germinate and grow during the season when the soil is moist. Their roots may then penetrate quickly through the dense distributions of *Artemisia* roots to penetrate deeper below the surface.

This establishes a situation in which subsequent competitors can appear. *Ceratoides latens* sends its roots deeper than 1.5 m, and *Ceratoides* communities may replace *Caragana*. When this happens, the surface becomes harder and erosion is halted even though the cover may not generally exceed 40 per cent.

Finally, *Ceratoides* will be replaced by communities of *Reaumuria soongorica* + *Salsola passerina*. With these communities, the ground surface will be fixed even though the cover is still less since the plants are dwarf varieties and their growth is very slow. These traits make them unsuitable for selection as sand-fixing plants even though they are drought resistant.

A typical natural succession might then proceed as follows: *Agriophyllum squarrosum* + *Corispermum patelliforme* → *Artemisia sphaerocephala* + *Hedysarum scoparium* + *Artemisia ordosica* communities → *Caragana korshinskii* → *Ceratoides latens* → *Reaumuria soongorica* +

Salsola passerina communities. A natural succession of this type shows that:

1) There is great variation in annual rainfall with plants germinating best in moist years. Growth is inhibited by strong winds and moving sands. Therefore the succession will proceed very slowly.

2) In this sequence of psammophytes, only shrubs, undershrubs and herbaceous plants survive because of the limitations of water. Even survivors cannot achieve great density, and a cover of 60 per cent is considered to be the maximum.

3) The fast-growing pioneers utilize whatever water there is in the sand. Thus as the dunes begin to be fixed, their moisture tends towards exhaustion and becomes unfavourable to plant growth. In such circumstances, plants that are more drought resistant and long-lived should be substituted. In the controlled fixing of dunes, pioneers and successional plants are used in combination.



Hedysarum scoparium for stabilizing dunes.

In an analysis of sand-fixing plants carried out at the Shabodou experimental station, the following conclusions were reached:

1) It is important to study the root system of sand-fixing plants. For example, the root systems of many pioneer plants grow horizontal on moving dunes while successional plants are characterized by deep root systems. Plants with purely horizontal root systems provide small cover and cannot fix sand. Plants with vertical root systems easily suffer from wind erosion. Thus, on selecting species, combinations with different root systems should be considered so that the sand can be fixed while moisture at different layers is utilized. In natural communities, *Haloxylon ammodendron* + *Nitraria tangutorum* and *Caragana korshinskii* + *Artemisia ordosica* are examples of good combinations. Different species, of course, must be able to tolerate common ecological conditions.

2) Tests determine which trees are best for wind protection. *Eleagnus angustifolia* is indigenous to riverbanks in arid regions of China. It is adapted to a moist atmosphere but lacks resistance to drought. This species is undergoing further tests.

3) Indigenous plants are effective for stabilizing sand dunes. Among the species shown to work well are *Hedysarum scoparium*, *Caragana korshinskii*, *Artemisia ordosica* and *Artemisia sphaerocephala*.

4) Plants indigenous to dunes in central Asia are resistant to drought and wind erosion. *Calligonum caputmedusae* and *C. arborescens* are large plants with well-developed root systems. They can be introduced and cultivated.

SELECTION OF SPECIES IN ARID REGIONS

Arid and desert regions of north China cover huge areas. They include the Urad Middle and Rear Joint Banner along the Yellow River to the south of Helan Mountain, the Ulan Buh and Badin Jaran deserts, the Hexi Corridor, and the immense Tarim, Junggar and Qaidam basins. These are temperate regions with cold

winters where the aridity index can easily exceed 80. They are characterized by annual annual precipitation of less than 150 mm, in some places not exceeding 10 mm. Moving sand dunes are typical of these regions, everywhere except in the Jungger Basin, where the dunes are semi-fixed.

In the spring, *Agriophyllum squarrosum* and *Horanninowa ulicina* can be seen scattered over moving dunes. Sometimes tufts of *Aristida pennata* appear on flat sand. *Ephedra*, *Artemisia* and *Calligonum* spp. grow interspersed on semi-fixed dunes. *Haloxylon persicum* inhabits the dune top while *Haloxylon ammodendron* is dominant on the lower slopes and in saline depressions between dunes. *Tamarix* and *Nitraria* spp. tend to fix dunes into an undulating surface. *Tamarix* germinating on the tops of the dunes will soon use up the available moisture and, unable to tap ground water, will wither and die. Nevertheless, if the tamarix is cut down, the wind will get at the sand again and mobilize the dune, setting it once more into motion.

When *Haloxylon ammodendron*, *Tamarix* and *Nitraria* tap ground water, they tend to flourish with great benefit to the soil. This sort of growth should be encouraged.

Experiments conducted in test plots have led to a number of conclusions:

— Plants introduced into arid regions must be drought resistant. One such species is *Haloxylon persicum*.

— Salinity is common in arid regions. Salt-resistant plants as *Tamarix hispida* must sometimes be selected.

— Where ground water is available, plants capable of utilizing it should be considered. These include *Haloxylon ammodendron* and *Populus euphraticus*.

— Where irrigation from the ground water is possible, the plant species may be broadened appropriately. *Salix mongolica* and *Atraphaxis bracteata* are among the species that should be considered.

Conditions in true deserts are of course more severe, and climate often sets a limit to what is possible. Vegetative methods are sure to fix moving dunes if irrigation is available

Haloxylon ammodendron in the desert.



Below: Leguminous crops are planted under trees in the hollows between dunes in desert steppes to ameliorate the soil and prevent stabilized dunes from becoming active again.



and plants can be established in a checker-board pattern.

CONCLUDING SUMMARY

Most pioneer shrubs on moving dunes have well-developed horizontal root systems. The roots spread over ten times the height of the crown—or even several tens of times. Since this spread is for the purpose of absorbing thin amounts of water and nutrients, such plants cannot grow closely together. To fix sand dunes by vegetative methods, pioneer species with horizontal roots must be combined with plants that have vertical root systems so as to utilize moisture in different layers and to increase the density of the vegetation cover.

All pioneer species are typically fast growing. They need more water than successional plants. As the dune becomes fixed, they begin to wilt, to be replaced by other species. *Artemisia sphaerocephala*, for example, lives only three to five years. Under persistently dry conditions, *Hedysarum scoparium* will wilt five years or six years after being planted. When wilting occurs, deep-rooting plants must be present to hold the sand in place.

Shrubs on moving dunes will often grow 2-3 m in height. Such tall plants provide good protection against the wind but have less ability to fix moving sand than such undershrubs as *Artemisia halodendron* and *Artemisia ordosica*. Thus, a combination of species is again

recommended. Particularly effective are combinations of shrubs and grasses.

Indigenous plants have been adapted to local conditions by nature. For planting programmes, however, the natural ecological setting of each species must be considered. Some plants occur in arid regions although they are not true psammophytes. *Eleagnus angustifolia* and *Populus euphraticus*, for example, are hydrophilous plants that grow on riverbanks and are not drought resistant. This is true also of *Tamarix* spp. which grow in sand but always in moist places. Sand accumulating around the base of *Tamarix* will slowly lift the plant. When its root system can no longer reach ground water, the plant will wilt. Such species are not adapted to moving dunes with low water tables.

As successional growth approaches the climax community, the species tend to slow growing. In addition to ecological factors, selection must also take into account a plant's position in the chain of succession. Nature must be imitated by first selecting species that are fast growing. The succession can, however, be accelerated by planting later species long before they would germinate under purely natural conditions. Then again, certain stages can be skipped. In semi-arid zones, for example, the short-lived *Agriophyllum squarrosum* and *Artemisia sphaerocephala* can be dropped from sequence since their sand-fixing capacity is less than that of other, preferred plantings.

The Establishment of Forest Shelter Belts in Oases: Principles and Technology

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China's interior west of the Wushao Ling section of the Helan Mountains and north of the Tibet-Qinghai plateaux consists largely of temperate zone deserts and drylands. While the region contains mountainous terrain, much of it is made up of sand dunes, gobi and saline soils. In much of it, too, the climate is arid, with annual precipitation below 200 mm.

Oases are located on gobi lands or on the desert fringe, often drawing water from the melting of snow in the surrounding mountains. Such places wage a constant battle against drought, salinization and drifting sand. If agricultural production is to be sustained and improved in this region, measures must be taken to prevent the desertification of oases and to expand their productive areas.

The life of an oasis is based on its irrigation system. Research and experience indicate, however, that in addition to the rational development of irrigation, belts of productive forest should be established as an effective means of blocking wind and sand. Such shelter belts maintain the oasis ecosystem while becoming an essential element in that ecosystem. This can be illustrated by oases in the Xinjiang deserts.

SHELTER BELTS FOR MAINTAINING A BALANCE IN THE OASIS ECOSYSTEM

A system of shelter belts include large areas of

sand-fixing grasses and shrubs combined with trees that mark the rim of the oasis plus interior networks or grids of trees that protect the separate fields. Such shelter belts participate in the energy transformations and circulation of substances that constitute the oasis ecosystem.

As an essential part of the oasis structure, a protective network of shelter belts has effects that extend through the entire system. Among their organic functions, shelter belts transform energy to create additional biomass that would otherwise not be used. It is a biomass that is effective in countering harmful energy, as represented by strong winds and high temperatures. It helps to regulate the local microclimate by transpiration that consumes and exhales moisture. Belts of trees accelerate the circulation of salts in the soil and replenish organic content.

Shelter Belts as Wind-Breaks

In considering the effect of trees on wind velocity, more than the total wind-speed reduction must be taken into account. Some circulation of air is desirable within the limits of what is safe for plants. The optimum wind velocity should be estimated. The range of protection provided by trees— their down-wind effect — must enter the calculations. The goal is to develop forest belts that have optimum structure.

Characteristic of velocity fields behind close-structured forest belts are two closed eddy currents, one small and the other large, with a vertical range of about $0.6 H$ (H = tree height) and a horizontal range of $8-10 H$. Discontinuities appear in the air flow in front of the belt and behind it.

The windward air is forced upward to be lifted over the trees. As it flows over the tree-tops, the air speeds up, with a pronounced Venturi effect at close to $2.5 H$. A tight velocity gradient develops between the accelerated air and the eddy currents beneath within the momentum transferred downward strongly. Thus, with dense shelter belts, the leeward wind speed is restored rapidly, limiting the protective range to about 15 times the tree height. Within the range, wind speed will be reduced by an average of 39 per cent.

Loosely structured belts show a different pattern of air speed. As the air reaches the belt, part of it penetrates to form a low velocity zone near the ground surface to the lee of the trees. It forms an eddy whose curve lies between $4 H$ and $13 H$ to a height of $0.2 H$. The other part of the oncoming wind is lifted over the belt where it speeds up due to the Venturi effect. The velocity gradient, however, is weaker than with a belt of close-set structure, as in general, the velocity gradient declines with increasing porosity of the shelter belt. Up to a point, the range of protection increases with a looser structure, reaching $23 H$ with wind speed reductions of 40 per cent within the protected zone.

As is characteristic downwind of well ventilated shelter belts, the air stream separates into three components. The first is directly over the belt, with the air accelerated in inverse proportion to the belt's porosity. A second acceleration zone forms on the leeward side exactly where the tree trunks rise from the ground, but this is quickly weakened by friction with the surface. Beyond this is the low velocity zone, which extends out to where open-field conditions are gradually re-established. This pattern of air movement extends the zone of protection created by the belt.

Forest belts of ventilating structure can be

classified as easily permeated or poorly permeated depending on the species composition, the coefficient of penetration and the height of the trunks of mature trees. In easily permeated belts, trunk heights will run around 3 m and canopies of foliage are separated. The penetration coefficient will measure about 0.7 and the range of protection will be $11 H$ downwind. Poorly permeated canopies link up with each other, permitting only moderate ventilation. Here, with a trunk height of 2 m, the penetration coefficient will be 0.5, and the protected area will extend from $24 H$ to $38 H$ in a zone in which wind speed is reduced by 34-48 per cent. Belts of well-spaced trees permitting passage close to the ground but with poorly permeated growth above are widely used to protect farms in Xinjiang.

Changes in wind velocity have an influence on the protective capacity of shelter belts. A loosely structured shelter belt will reduce wind speed by 25 per cent when the wind is blowing at grade 3 on the Beaufort scale, but will reduce a grade 7 wind by 40 per cent over a longer range. If the belt permits ventilation, the speed of the air passing directly through it will increase as the wind speed rises, and the protective effect is not enhanced. A shelter belt of that type works best at moderate wind speeds. If drifting sand is a severe threat, a less ventilating structure is to be preferred, but not if the sand is blown in the wind.

The protective effect of a shelter belt is directly proportional to the height of the trees. For example, trees 8 m tall will reduce wind speed 54.7 per cent more than will trees that are 6 m tall within $20 H$, while trees 10 m tall will have an effect 95.6 per cent greater than the 6 m trees.

The angle that the prevailing wind strikes the belt makes a difference in the protective effect. In moderate wind conditions, a loosely structured belt perpendicular to the wind will reduce wind speed by an average of 39.1 per cent within a range of $30 H$. When the wind strikes the same belt at an angle 45° , the average reduction in wind speed is 43.5 per cent. The reason for this is that the angle of attack causes a change in the coefficient of penetration.

The geographic setting and specific conditions must be kept in mind while designing a shelter belt for structure and permeability. Both these qualities will change as the stand of trees matures. To maintain the shelter belt's protective effects at an optimum, control and management must be applied to the stands of trees at all stages of their development.

A system for protecting fields widely adopted in Xinjiang consists of narrow belts established in tight grids. A close spacing of belts within the oasis creates a pattern with an overall dynamic effect, with each belt presenting only a moderate wind to the next. In adaptation to desert conditions, each belt offers protection to its neighbour, enabling the trees in each successive belt to grow normally and take their place in a stable network.

Even with a narrow belt consisting only of 4-6 rows of trees with low permeability, the windbreaking effects can be remarkable, averaging 41 per cent over $20 H$ in south Xinjiang. The narrow belt must keep a density sufficient to maintain its profile. While the main species are maintained in place, ancillary species with heavier crowns are arranged around them forming a multilayer canopy typifying a well-structured shelter belt. Narrow belts closely spaced reduce average wind speed inside the oasis 20.2 per cent more than if the grids are widely spaced.

Shelter Belts as Defences against Sand

In oases confronting wind-blown or drifting sand, belts of shrubs and grasses are established on the perimeter facing the wind outside the outermost shelter belt of trees. These rings of low vegetation are wide, 200 to 500 m, and planted directly in the sand to increase surface roughness. A layer of air forms over the vegetation, decreasing the kinetic energy of the wind at the surface. The amount of friction offered to the wind is proportional to the height and density of the grass and shrubbery. Observations indicate that such belts offer 17 to 27 times the resistance of naked sand. Thus, sand-bearing winds are already weakened when they enter the forest belts.

In shelter belts in which the trees are well spaced, air passes readily through the lower part. The grid presented to the wind by the trunks of the trees creates a Venturi effect, and the surface current will speed up within the belt. This can cause wind erosion of the surface on which the trees are planted if the forest belt is unprotected by an outer buffer of grasses and shrubs. Surface sand is picked up within unprotected forest belts and deposited $5 H$ to $7 H$ behind the trees.

If the shelter belt has a structure of trees tightly spaced, and if it is exposed directly to sand-bearing winds, aeolian deposits are dropped in front of the belt and inside it. Dunes are formed, growing ever larger, and the trees will eventually be buried.

The best defence against blowing and drifting sand is provided by a belt of six to eight rows of trees at the perimeter, structured to provide surface ventilation, and itself protected by a wide outer belt of shrubs and grasses. By the time the wind strikes the trees, much of its sand content will already have been winnowed out by the buffer of shrubs and grasses. Very little sand will be deposited within the belt of trees or within a range of $3 H$ downwind. The composite system as described provides a basic solution to the problem of sand at the windward rim of the oasis.

Microclimate Effects of Shelter Belts

Farmland under the protection of shelter belts has less wind at the surface with a weakening in turbulent exchanges. There is a drop in the rates of exchange of heat and moisture in air and soil and better regulation of water consumption by growing plants. By helping to keep the water table low, shelter belts act against soil salinization. Trees help mitigate the impact of climatic extremes, helping croplands to survive seasons of drought.

Under the protection of a shelter belt, as studies have shown, surface temperatures are raised by $0.7-3.5^{\circ}\text{C}$ in the cool spring, while subsoil temperatures at a depth of 5-20 cm are higher by $0.4-1.0^{\circ}\text{C}$. In the hot summer, the air temperature at a height of 1 m can be

reduced by 0.1-2.0 °C, while the relative humidity is increased by 3-14 per cent. In winter, the surface temperature under a cover of snow can be 0.2-0.6 °C higher.

When the hot drought wind blows in the Turpan region, within three hours a sustained temperature reduction of 0.9-2.0 °C is achieved in a range of 1-10 *H* behind a shelter belt with a well-spaced structure. After the wind dies down, the relative humidity within a range of 1-10 *H* rises by 39-50 per cent in comparison with that above unprotected ground.

The presence of a shelter belt directly affects the water circulation in protected plants. In wheat, for example, the suction pressure is reduced—to 9.5 atmospheres in the lee of a shelter belt in comparison with 13.7 atmospheres outside a range of 10 *H*. Water consumption is regulated, ineffective consumption reduced, and the chances are increased that crops will survive drought

without damage.

Still other microclimatic effects are produced by shelter belts in desert regions. Since irrigation canals and ditches are shaded by the belts, surface water evaporation can be reduced by 40 per cent. Because the trees act to conserve water, the humidity of the soil within the belt and in nearby cropland may be raised by 10-13 per cent in the dry spring. Within a range of 4-12 *H* behind the belt, the transpiration of cotton is reduced by 38 per cent. When summer comes, the soil humidity down to 100 cm can be raised by 8-9 per cent.

Because of its own demands for water, a shelter belt tends to keep the water table low. For a range of 75-100 m on both sides of a mixed belt composed primarily of *Populus nigra* var. *thevestina* and *Salix alba*, the water table was found to have been lowered by 0.2-0.7 m. This helps to keep salts from accumulating on the surface.

Small meshes formed by narrow shelter belts are employed mainly in protecting farmlands inside oases.



TECHNIQUES OF CONSTRUCTING PROTECTIVE SHELTER BELTS

Structuring a Composite System

Where sand is a serious threat, the protective network should include a wide belt of grass and shrubs beyond the perimeter shelter belt on the windward rim of the oasis. Within the oasis, the network will be constructed according to the principle of "narrow belts in tight grids"

In constructing the outer shrub-grass belt, dunes and eroded areas can be surrounded by plantings to protect whatever vegetation they already contain. Irrigation will be provided by winter water or summer floods to establish a belt that is 200-500 m in width. Plants should be selected that are resistant to drought and erosion and are capable of stabilizing moving sand. These criteria permit a fairly wide range of choice, with selection carefully adapted to local conditions.

Experience shows that preferred grasses are *Alhagi sparsifolia*, *Glycyrrhiza uralensis*, *Karelinia caspica*, *Soorzonera divaricata*, *Phragmites communis* and *Achnatherum splendens*. Shrubs that work well include *Capparis spinosa*, *Calligonum* spp., *Tamarix* spp., and *Nitraria sibirica*. These can create a vegetation cover of more than 60 per cent with a surface roughness within the belt 30-40 times that of exposed sand. The surface air flow becomes turbulent inside and beyond the belt of vegetation, lessening the momentum of wind-driven sand. As a result, wind erosion is abated. These effects are evident early in the development of a shrub-grass barrier, as the vegetation begins to stabilize the shifting sand.

Besides the protection it offers, a belt of grasses and shrubs provides carefully controlled grazing and can be cut as fodder. Depending on what species are planted, herbs with medical value can be gathered as well as the materials for producing charcoal.

Protection against Sand on Ridges and High Ground

Shelter belts on high ground are composed of

tall trees intermixed with shorter varieties, planted well spaced so that light penetrates evenly from top to bottom. Each belt consists of six to eight rows of trees with a spacing between belts of 50 to 100 m. Where sand is a particular threat, the trees are bordered by belts of shrubs and grasses. Perennial grasses and sand-tolerant crops can be planted in the open space between belts.

Drought-resistant trees that provide good wind protection are desirable for shelter belts established on high ground. These include *Eleagnus oxycapa*, *E. moorcroftia* and *Ulmus pumila*. Where sand is a severe problem, shrubs such as *Tamarix* spp. and *Hippophae rhamnoides* should be planted on the windward side of the trees. Where the surface consists of undulating dunes, techniques such as "block in front and pull from behind" should be applied to level the land.

Narrow Belts in Tight Grids

This is the most widely used system for protecting the fields inside the oases of the Xinjiang deserts. These central sections of shelter belts play a major part in regulating the oasis microclimate and in maintaining a stable ecosystem.

Internal shelter belts are accompanied by roads and irrigation ditches. They are usually constructed of well-spaced structures with good surface ventilation. They are narrow, consisting of four to eight rows of trees. The distance between belts is usually 250-300 m, but in extremely dry situations with a serious sand problem, the distance between belts is made even tighter, typically 120-200 m.

State farms, communes and brigades in newly reclaimed areas work to expand their productive farmlands by extending their forest belts and transforming the desert. Communes inside oases work to improve their fields a parcel at a time while designing and establishing a system of shelter belts.

Plans for afforestation must be closely coordinated with capital construction in the fields and must include attention to more than merely trees. Ditches and roads must also be laid out and fields formed in convenient

shapes and sizes. A typical field in a tight grid system will be 13 hectares in size. Designs should strive to reduce the areas occupied by shelter belts to the minimum, so that water used and other costs will be reduced while maximizing the land available for crops.

Poplars are the species most commonly used in internal shelter belts. Whatever species are selected, they must be drought resistant and long-lived while offering an intrinsic economic value. Belts call for a mixture of species, with the trees planted in furrows or ditches. Selection also calls for careful attention to local conditions and for species that are well adapted to such conditions.

EVALUATING PROTECTIVE EFFECTS

The effects of a shelter belt on the micro-dynamics of the atmosphere are what enable it to provide protection. To calculate the protection that a line of trees should provide, the following formula is employed:

$$P = K (HM/D)100,$$

in which P is protection in per cent, H the average height of the trees, M the range of protection downwind, D the distance between belts, and K a constant representing the inverse of the permeability. A closely spaced structure with no ventilation will be $K = 1$, while no belt at all will be $K = 0$. A well-spaced structure providing good ventilation will be $K = 0.7$.

Northern Xinjiang on the slope of the Tian

Shan is characterized by strong sand-bearing winds and an aridity index of 4-10. Open grids in this region marking off fields as large as 50 hectares provide 50-60 per cent protection, and the protection is higher for smaller fields, which means shelter belts more closely spaced. Experience indicates an optimum field size at 13-20 hectares, surrounded by narrow belts of 4-6 rows deep, separated by 250-300 m distance between belts.

In southern Xinjiang, aridity rises to an index of 20-60. On the average, the wind blows at Beaufort 6 or higher for 31 days in the year with sandstorms on 14-35 days in the year. Salinization and alkalization are added to problems that create severe conditions in which to carry out agricultural production. Here, shelter belts are 4-8 rows deep and spaced 250-300 m apart, creating fields of 15 hectares. The distance between belts should be reduced to 150-250 m.

In Turpan below a wind gap through the Tian Shan and in other places in both northern and southern Xinjiang, aridity rises to 70 and the wind blows at Beaufort 8 or higher for 21-42 days in the year. The conditions can be destructive to agriculture. Networks creating fields of 15 hectares show protective efficiencies of 67 per cent after the trees have matured. This suggests that belts of 6-10 rows of trees should be spaced more closely together, creating fields no larger than 10-13 hectares. Yet even with its present system of shelter belts that are spaced widely, Turpan is expanding the area it maintains under cultivation.

The Utilization and Improvement of Pasture in China's Steppe Zone, Taking the Ordos Plateau as an Example

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China's semi-arid steppe regions are mainly located in the central and north-eastern parts of the Inner Mongolian Plateau between 35° and 50° north latitude and 105° and 120° longitude. They cover 8.6 per cent of the total area of the country. They include such areas as the Ordos Plateau, Xilin Gol, Hulun Buir and the Horgin, Orzindag and Mu Us sandy lands. The steppes are undulating plains at 1,000-2000 m above sea level with sandy lands interspersed among them that consist mainly of fixed and semi-fixed dunes, although shifting sands occur in patches among them, especially on lake basin lowlands.

The mean annual temperature is 5-7° C in the semi-arid steppe regions. It is somewhat lower in the north-east, as in Manzholi and Xilin Hot, where the average is 1.4° C and is warmer in the south-west, as at Lanzhou, which enjoys an annual average of 8.1 to 9.1° C. Half the year is frost free. Annual precipitation averages between 250 mm and 400 mm with the rainfall occurring in a markedly seasonal pattern. As most of the rain arrives with the south-east monsoon, 60-70 per cent of the precipitation is concentrated in the period from July to September in the form of heavy downpours. The 20-30 per cent of the annual rain that falls in the months of April through June is usually too thin to be of much use. According to statistics collected over the years, it seems almost a rule that a severe

drought occurs once in six years, followed by two years of good rain with a lighter drought in the third year. The aridity index for the region is between 1.5 and 2.5.

Ground water is sustained almost entirely by rainfall. The depth of the water table depends on topographic factors, varying from 10 m or more in higher ridges to 1-2 m in lowlands. The water is of good quality, with a mineralization rate of 1 gram per litre.

The soils of the steppes are mainly chestnut mollisols deposited by water and wind. Dark castanozems occur in the east with lighter types in the west. Lowlands contain bogs and meadow soils, with light meadow castanozems.

The Ordos pasturelands are situated in an arid and semi-arid transition zone in the western part of the steppes. The flora of the region is characterized by marked variety because of varied conditions with their distinctive water and energy budgets, topographical features and human activities. According to incomplete information, the Ordos contains 495 species of plants, among which Compositae, Gramineae, Leguminosae and Chenopodiaceae predominate. The commonest vegetation is composed of perennial herbs. Pastures, on the other hand, are characterized by fodder types, mostly xerophytic dwarf shrubs and undershrubs. Because of the prevalence of sandy lands in the Ordos, the vegetation is psammophytic, featuring undershrubs such as *Artemi-*

sia ordosica and shrubs like *Caragana microphylla* and *C. intermedia*. The natural pastures in the Ordos region have the following characteristics:

—They are basically suitable as grazing lands but offer little in the way of grasses suitable for-mowing.

—Most of the pastures are better suited to the needs of goats and sheep than of horses and cattle.

—The productivity of the pastures is highly seasonal in both quantity and quality. The highest yields occur in the autumn when pastures offer three to four times as much fodder as in spring. As a result, livestock experience an annual physical cycle, becoming "strong in summer, fat in autumn, thin and feeble in the spring". This cycle varies greatly from year to year, with animals in their worst condition in drought years.

—Pasture soils are for the most part sand and sandy loam, with sand particles constituting 80-90 per cent of surface horizons.

—In the west and north, the pastures are on higher ground. In the eastern part of the Ordos, pastures are also on lowlands interspersed with moving dunes. In the south, pastures are mainly on lowlands composed primarily of fixed and semi-fixed dunes.

THE PROTECTION AND IMPROVEMENT OF NATURAL PASTURES

Controlled Grazing

The Ordos region has a history of over a hundred years of sedentary grazing. Instead of the former nomadic styles, pens for livestock, wells and pastoralists' settlements are established in certain fixed places. Today, two fundamentally different grazing systems are encountered: uncontrolled free grazing and controlled rotational grazing.

Uncontrolled free grazing around the settled areas with little attempt to direct the movement of animals is characteristic of practices that are now being discarded. Such practices in the past have resulted in the degradation of

pastures that are trampled and grazed all year round.

Controlled grazing, on the other hand, produces even pressure on the pastures surrounding the flock point. It is considered a reliable way of avoiding or reducing desertification.

Contrasting examples can be taken from the Otog Banner to illustrate the consequences of the two grazing systems. Both involve flocks of goats in similar environments, grazing on sandy lands fixed by *Artemisia ordosica*.

Flock A has been in existence for only 16 years, during which time it has grazed freely. As a result, the surrounding pastures are severely degraded, with the vegetation cover thinning and the variety of plant species sharply reduced. Certain plants, such as *Cynanchum komarovii* and *Agriophyllum squarrosus*, are an index of degradation, indicated by their increasing dominance. Here, 87 hectares of pasture have turned into shifting sands.

Block B has been established for over 80 years, lasting through three generations of pastoralists. Yet the pastures surrounding the settlement point are undergrazed. They show good vegetation cover abounding in a variety of species.

The herdsmen of this family conserve the surrounding pastures by taking different directions each day, both in going out and coming back. Thus, the grazing is alternated around the central point. Watering is also done in a controlled way. Goats are never permitted free access to the well, so that no pressure is placed on the pasture around the well.

Pasture Rights and Plot Rotation

Only a few years ago, the pastures were not mapped and the right to use them was not assigned. People competing for their use were not motivated to manage them properly or to improve them. In recent years, however, the work of mapping the pastures has been done and rights to them assigned.

In the Shudiban and Jiujeng districts of Jingbian County, Shaanxi, for example, each pastoralist unit began to work out plans for mapping their pastures as soon as the right to

use them had been confirmed. They all agreed on a system of rotational grazing within the area assigned to them, dividing their pastures into three or four sections to be grazed at predetermined times. Within one or two years after the inauguration of the rotational system, as surveys indicated, vegetation had increased as much as 4.4-4.7 times and flowering and fruiting plants denser by 3.2-3.3 times. These are ranges, with the sheep showing increased body weight and higher wool yield under rotational grazing, not only because of the improved pasture but also because they do not have to walk so far to get it.

A precise system of rotational grazing has been developed on narrow pastures confined to lowlands. These pastures are divided into a number of small sections. In the morning, the sheep are brought to graze in a plot that has already been grazed twice. At noon, they are transferred to a plot that has been grazed only once before. And in the afternoon, they are moved to an ungrazed plot. This process continues until all plots designated for grazing have been grazed three times. Under this system, sheep show a 3 per cent increase in body weight and an 18.5 per cent increase in wool yield. At the same time, 40-50 per cent of the pasture is kept free of grazing to allow its vegetation to recover from being grazed three times.

Enclose and Care Programme

On lowland pastures, the government has advocated an "enclose and care programme" as a fundamental means of halting degradation and improving fodder yields. The programme can be applied with relative ease to the lowlands where soil and water conditions are favourable, and extended widely. It has shown remarkable results. The pastures in Otog and Uxin banners, for instance, have shown marked improvement following enclosure. Vegetation has increased in cover and height, with palatable grasses showing the highest increase.

Enclosures have also resulted in considerable improvement to the soil. The amount of litter is higher, protecting the surface against

soil erosion. Texture has become finer and the nutrient content has increased.

The programme has subsequently been extended to pastures on sandy lands and higher ground. These pastures, with less access to ground water, are drier and more vulnerable to wind erosion. Experience shows that even under these more unfavourable conditions, enclosures produce excellent results.

Enclosures are not intended to prevent grazing for any extended period of time. What is intended is to prevent grazing during the growing season. In the autumn, enclosed fields can be mowed when they are dense with such fine grasses as *Leymus secalinus* and *Calamagrostis pseudophragmites*. The mown fields then offer their stubble for grazing in winter and spring. Pastures not suitable for hay harvesting are "rested" during the growing season to permit the generation and accumulation of nutrients and spring grazing. Thus in addition to rehabilitating pasture ecosystems and maintaining them in equilibrium, enclosures contribute to a programme of balanced feeding throughout the year.

Reseeding and Planting

The pastoralists of the Ordos have acquired a good deal of experience in reseeding grasses and planting fodder shrubs to raise the productivity of degraded pastures, to the great benefit of stock farming in the region. The selection of species for sowing and planting is determined by local conditions.

Lowland pasture covered with sand can be greatly improved by reseeding with legumes. The favoured selection is sweet clover in white and yellow varieties. In the Uxin area, clovers are planted together with *Salix mongolica* to improve the soil between dunes.

Reseeding can improve the productivity of a pasture by 3-7 times. In depressions between the dunes that have been reseeded, hay yield has reached the equivalent of 9,487 kg per hectare. The people of Uxin have combined plantings of sweet clover with weeding out the poisonous *Oxytropis glabra* that infests the region. The growth of clover helps to reduce the presence of this harmful plant.

On semi-arid higher ground composed of fixed and semi-fixed dunes where the water table is low, *Caragana* spp. provide the principal fodder shrubs used to improve the pastures. A similarity of morphological and bio-ecological characteristics prevails among the three species most commonly planted—*C. microphylla*, *C. intermedia* and *C. korshinskii*. What makes this genus so useful is:

—*Resistance to heat and cold.* Studies have shown that *C. microphylla* is undamaged by exposure to temperatures ranging from -39°C to $+55^{\circ}\text{C}$.

—*Resistance to other extreme conditions.* *Caragana* spp. are universally recognized as among the most drought-resistant plants in the region. The genus is also resistant to wind erosion, sand burial and attack by hailstorms. The drought tolerance of *Caragana korshinskii* has been established by studies of its physiological indices—content of bound water, ratio of bound to free water, water suction pressure and water-holding potential. These studies show it to be superior to such drought-resistant plants as *Oxytropis aciphylla*, *Artemisia ordosica*, *Artemisia sphaerocephala*, *Hedysarum scoparium*, and much superior to

mesophytes.

—*Long growing period.* From budding to defoliation, the growing period of *Caragana* lasts for 200 days in the year. Although in winter the vegetation of the pasture turns yellow and withered, *Caragana* remains green.

—*High nutritive value.* *Caragana* is attractive to stock. Goats, camels, sheep and cattle are all fond of eating its flowers, leaves and green branches. Its pod wastes make excellent feed for sheep. The pastoralists of the Ordos have a good opinion of *Caragana* and consider it a nourishing plant. Analysis reveals it to be rich in protein, minerals and carotene, as shown in table 19.

—*Adaptability.* *Caragana* thrives in a wide range of ecological conditions. It grows in all the Ordos environments except on the larger moving dunes and in lowlands where the water table is high and saline-alkaline conditions prevail. It is found everywhere on higher ground, on sandy or loess ridges and in sandy lands composed of fixed dunes.

—*Long life.* *Caragana* survives for 40-75 years.

—*Easy to work with.* *Caragana* produces seeds. The yield of seed depends on pasture

Table 19. Nutrient composition of *Caragana microphylla*

	Phenophase	
	Growing (%)	Fruiting (%)
Moisture	14.95	12.26
Crude protein	22.48	16.84
Ether extract	4.98	3.22
Crude fibre	27.85	35.25
Nitrogen-free extract	22.36	26.50
Crude ash	7.38	5.93
Calcium	2.16	2.99
Phosphorous	0.52	28.70
	(ppm)	
Carotene	28.70	23.50

management and the density of the plants and ranges from 20-30 kg to hundreds of kilograms per hectare. Under good conditions, *Caragana* has yielded 562.5 kg per hectare. The plant survives and grows very well whether sown as seed or planted as seedlings.

Because of its favourable characteristics, *Caragana* has been extensively reseeded and planted on higher ground, loess ridges, semi-fixed sandy lands and on dunes that still show mobility. It has become an important weapon for improving pastures and stabilizing sand.

Before 1956, for instance, the Xiejiagou Production Brigade in Jia County, Shaanxi, was so short of pasture that it could run only 95 head of sheep. Between 1956 and 1974, the Brigade planted *Caragana microphylla* on 413 hectares. By the latter year, it was running 1,600 head of sheep. In all of Jia County, *Caragana* has been planted on 5,133 hectares. This has been of great significance in conserving water and soil, stabilizing sand and improving conditions for livestock.

RENEWAL PRUNING OF FODDER SHRUBS

Certain shrubs and undershrubs, such as *Caragana* spp., *Salix* spp. and *Artemisia ordosica*, have a great bearing on the feed balance for livestock farming. Yet when they reach a certain age, these shrubs tend to become exhausted, begin to droop and lose their vigour both for propagation and productivity, and are increasingly subject to attack by diseases and insects. Experience has shown that these plants can be renewed by pruning. If they are pruned close to the ground surface, their vigour will be restored and they will yield a new round of productivity. Studies have shown that pruning increases the yield of *Salix mongolica* by 132 per cent, of *Salix microstachya* by 127 per cent, of *Caragana intermedia* by 150 per cent, of *Artemisia ordosica* by 103 per cent and *Hedysarum mongolicum* by 33 per cent.

THE CONTROL OF MOVING SANDS FOR PASTURE PROTECTION AND EXPANSION

Shifting sands are widely distributed in the

Ordos, forming 30 per cent of its total area. Moving sands are a constant menace to pastures and can even bury them entirely. To protect pastures and develop stock farming, great efforts have been undertaken both to combat sand movement and convert dune-lands into useful pasture. These are considered to be two of the fundamental tasks of the region.

Most of the moving sands are situated in semi-arid zones. Here, favourable water and energy conditions offer a good chance of combating sand movement by vegetative means.

Controlling Dunes on Their Windward Slopes

Crescent sand dunes are found scattered sparsely among the region's lowlands. They are usually low, no more than 7 m in height, each occupying an area of 1,000 to 7,000 square metres. They are a phenomenon indicative of an early stage in the formation of extensive moving sands. Crescent dunes can send them marching at a rate of over 8 m a year. As they advance, they bury the pasture in front of them. The soil left behind in the wake of these dunes takes at least three years to respond to rehabilitation. Indeed, these dunes cause immense damage to pastures and must be listed as a top priority in programmes to combat sand.

Another severe problem is presented by chains that advance at a rate of 4-6 m per year. The "blocking in front" method is usually adopted to level barchan dunes, that is, to plant *Artemisia ordosica* or *Salix mongolica* on the lower third of the dunes' windward face and let the wind blow the top away. As vegetation develops, the wind is prevented from blowing sand off the windward slope, and its velocity is decreased there. *Artemisia ordosica* can reduce wind speed by 60 per cent when it is blowing at 3.7-6.4 m per second, and decrease by 85 per cent its ability to pick up sand from the windward slope. A Venturi effect over the top of the dune will speed the movement of air and help blow the top away. Within a year, a wind-eroded level 6-8 m in width appears in the dune above plants, or at a place one-third of the way up from the bottom.

Artemisia ordosica or *Salix mongolica* are established in these eroded levels. The process continues for several years until, after several successions of plantings, the dunes are fixed in a pattern of shallow undulations.

Changes also take place in the soil on the stabilized windward slope. Five years after first plantings, the windward surface has acquired a fragile, cloddy structure. The soil has dropped in weight and increased in porosity with an increase in dry soil aggregates. It has also increased its content of nutrients. The vegetation cover on originally naked dunes has reached 28-50 per cent with a dry-matter production of 225-615 kg per hectare.

V-shaped plantings are generally used to establish *Artemisia ordosica*. *Salix mongolica* is planted in bow-shaped layerings or in "erosion preventing squares". All such methods establish the plants in groups. Isolation of plants must be avoided, for single plants are not resistant to wind erosion.

Two other forage plants are effective for fixing sands: *Hedysarum scoparium* and *H. mongolicum*. They can be sown on shifting dunes, saving the trouble of planting, and they eventually create good stands of hay. They are resistant to wind erosion and burial by sand, are fast growing and generate vigorously. They are also high in proteins, minerals and carotene. If they are free of grazing, fields of *Hedysarum mongolicum* will yield 1500 kg of good hay per hectare.

Controlling Depressions behind Leeward Slopes

The low area behind the leeward slope of a moving dune generally extends for some little distance. The width of such spaces depends on the size and shape of the dunes. If barchan chains are 5-10 m in height, for example, the depressions behind the dunes will generally be five metres in width. It is not always advisable to plant or sow in the depressions since new vegetation there can easily be buried by sand. If they serve to stop the advance of dunes, however, several rows of *Salix mongolica* can be planted in those parts of the depressions where sand burial is least likely.

Since soil and water conditions are good in

the depressions, *Salix mongolica* will flourish there. The plant resists burial by its strong and spreading root system. As the sand advances, the plant will little by little "climb" the dune and end up by blocking any further advance.

As the dunes become semi-stabilized and the danger of sand burial recedes, the depressions provide the first places in which vegetation can take hold. The vegetation established in depressions is referred to by the people as "three storey pastures". That is because they are composed of trees, shrubs and grasses. To provide protection as quickly as possible, afforestation is carried out with tall cuttings of *Salix matsudana* as the main species. These willows have in recent years been supplemented by poplars—*Populus simonii* and *P. canadensis*. The principal shrub in use is *Salix mongolica*, although in exceptional circumstances, *Salix microstachys* and *Amorpha fruticosa* have also been used. Legumes have included white and yellow varieties of sweet clover, and in recent years, alfalfa and *Astragalus adsurgens*.

Three-storey pastures established in depressions usually show good productivity. Typical yield will be 3,000 kg of browse and fine hay per hectare, although yields have been recorded as high as 5,000 kg per hectare.

KULUMS FOR FODDER AND GRASS CULTIVATION

Projects originally carried out to protect grasses in enclosed lowlands were less elaborate to begin with. They have subsequently displayed a marked development, advancing from extensive to intensive management. Indicative of their evolution has been the introduction of cultivation and planting into the construction of grass kulums, concentrating primarily on the sowing of improved fodder grasses. At the same time, attention has been paid to diversify their economies. As a result, kulums have evolved into distinct types.

The Forage-Grass Kulum

The kulum intended for the cultivation of

forage and grass is generally built on a relatively small area within convenient distance of a stockbreeding unit. Its purpose is to provide fodder to livestock, these being mainly flocks of sheep.

Kulums of this type are usually established in places favourably endowed with water—on valley terraces, for example, or on moist lowlands between dunes where rainfed cultivation is possible. They must be manageable with the minimal amount of human labour that typifies stockbreeding. After enclosure, it is the common practice to sow grain crops for one or two years while clearing out noxious weeds. After that, improved grasses are seeded and planted. Proper management is expected to produce a yield of 7,500–10,500 kg of alfalfa per hectare one year after sowing.

Water-Grass-Forest-Cereal Four-in-one Grass Kulums

Kulums of this kind are extensively established in the Ordos region, most of them built on lowlands with favourable soil conditions and possibilities for easy management. Major efforts have gone into constructing them. The measures to be undertaken to establish a four-in-one kulum are as follows:

1) Water resources are developed and utilized. As is characteristic of semi-arid regions, the annual precipitation shows great variation. The rain, when it does come, is concentrated in late summer during the second half of the growing season. Because of the unreliability and seasonal quality of the rainfall, high and stable yields cannot be obtained without artificial watering.

Most of the surface water resources in the region are located in mixed agricultural and pastoral areas in the south. Elsewhere in the region, irrigation must rely on ground water. At the present time, pipe wells and large-mouth wells are used to bring ground water out from under shallow layers below the surface. A large-mouth well is in fact an open pond where ground water is allowed to collect. A pipe well taps water at a depth of 20–30m.

Although large-mouth wells are inexpensive to construct and produce water at preferred higher temperatures, they take up too much ground for the amount of water they supply and are subject to evaporation. Pipe wells, on the other hand, produce great amounts of water, which is preserved from evaporation until it is used. One pipe well, for instance, yields more than enough water to irrigate 3.3–5.3 hectares. In some exceptional cases, efforts have been made to supplement the water supply by bringing in boreholes or artesian wells that tap water more than 100 m below the surface.

Because the soil is usually sandy with poor water-holding capacity, irrigation canals have to be paved to prevent seepage. This can be done with sod, clay or pre cast concrete slabs. Tests show that canals lined with tamped clay work well against seepage and are inexpensive to construct. To increase water conservation, plastic sheets have been used in recent years to line canals, and sprinkler irrigation has been installed.

2) Protective shelter belts of trees and shrubs are established. To halt moving sand dunes and prevent damage from drifting sand, shelter belts are planted, usually of *Salix mongolica* supplemented with tall cuttings of *Salix matsudana*, in the form of a loose structure that permits ventilation at ground level. Other trees are included in shelter belts to provide variations in the height of their canopies of foliage. Commonly used are species of poplars and elms. Shrubs, planted to the windward of the trees, include *Caragana* spp., tamarisk and *Amorpha fruticosa*.

Shelter belts not only block the wind and prevent sand drift, they also provide leaves and twigs for fodder. Shelter belts of *Salix mongolica* and *Salix matsudana* yield an amount of green browse and undergrowth that is equivalent to 6,375–7,000 kg of dry matter per hectare.

3) The land is levelled and the soil improved. Irrigation requires level fields, but the land available for kulums may have an undulating surface because it previously contained dunes. If so, it will be necessary to complete the

levelling of former duneland and fill in depressions between dunes. In such a case, too, the soil will be too sandy, and clay will have to be mixed with it to improve its physical properties. Not only will better soil raise the crop yields, it will also conserve water. A water saving of 23 per cent was recorded in Otag Banner after the land was levelled and the soil improved.

4) Superior species of forage grasses and grain crops are then sown. At first, four-in-one kulums provide supplementary fodder for livestock. As time passes, they are expected to develop into man-made pastures of high quality.

White sweet clover is commonly sown in the region. It yields 3,525-6,375 kg of hay per hectare in the sowing year, and 5,250-12,000 kg per hectare in the second year, when it also produces seeds at a rate of 1,875 kg per hectare.

In recent years, a cultivated type of *Astragalus adsurgens* has registered good adaptability

and high yields. Under irrigation, it yields 7,5000 kg of hay per hectare in the sowing year and 27,500 kg per hectare in the second year. The protein content of this hay reaches 16.5 per cent.

The chief grain crops sown in the region are millet and naked barley, with maize cultivated in some places. Millet and barley show yields per hectare of 6,000-7,500 kg, with straw providing another source of supplementary fodder during winter and spring. The harvested field may be used for grazing.

5) Activities are finally enriched by developing diversified economies. Nurseries are established for the cultivation and testing of seedlings and cuttings. Apiculture is developed to provide honey and facilitate the pollenization of plants. Fruit trees and vegetable plots are added to the four-in-one kulum. Medicinal herbs are grown. Veterinary services become available. A wide range of human interests comes to be served in a community based on the sustained yield of the kulum.

A Seminar in China

In China, the appropriate place to hold a Desert Control Training Seminar is at the Lanzhou Institute of Glaciology, Cryopedology and Desert Research. It is here that the Chinese Academy of Sciences has placed its principal focus of research into means of combating desertification.

The Institute is located in the city of Lanzhou, capital of the Province of Gansu in China's arid and semi-arid north-west. The city itself suffers no shortage of water since it is located on the upper course of the Yellow River. Historically, it was a site on the Silk Road, where the eastbound traveller saw that

A three-in-one scientific expedition team.



at least he was leaving the deserts of Central Asia and entering a region made fertile by deep deposits of loess soil.

Scientists at the Institute responded to the UNEP suggestion that they offer a seminar to a group of selected experts from developing countries that have severe problems of desertification. The purpose of the seminar would be to familiarize the visitors with techniques of combating desertification that might have application in their own countries.

Such a purpose would, however, require the participants to travel. The arid lands of China are vast, and China's best successes in combating desertification are widely spaced. The agenda developed by the scientists in Lanzhou called for the seminar to open with a week of lectures and discussion at the Institute, including scientific exchanges between the hosts and their guest. This would be followed by three weeks of travel by air, train and bus, adding up to a total of more than 6,200 km. The first week would take the travellers eastward to Inner Mongolia and the Ordos Plateau and then back to Lanzhou, with stops at the following sites:

— By train to Zhongwei County at the edge of the Tengger Desert in the Ningxia Hui Autonomous Region. Visits to the Shabodou Experimental Station operated by the Lanzhou Institute. Inspection of sand control around the railway line.

— By train to Baotou on the Yellow River in the Inner Mongolia Autonomous Region.

— By bus to Dongsheng in the northern part of the Ordos Plateau. Inspection of rangelands and reclamation projects in the vicinity of Dongsheng. (A scheduled visit by bus to the kulums and pastures of Uxinju had to be cancelled because of stormy weather.)

This eastward swing was followed by a day and a half of discussion in Lanzhou on anti-desertification methods framed in terms of what had been seen. The inspection tour then resumed, with the visitors taken westward to north-western Gansu and the deserts of Xinjiang, with stops at the following sites:

— By train through the Hexi Corridor to

Liuyuan in north-western panhandle of Gansu Province.

— By bus to Dunhuang. Inspection of afforestation and oasis protection carried out by the Nanhu People's Commune. Inspection of sand dune stabilization carried out by the Mingshan Brigade.

— By train to Turpan in the Xinjiang Autonomous Region. Inspection of windbreaks and sand control carried out by the Five Star People's Commune. Visits to transformed gobi areas, now the sites of vineyards and forests.

— By train to Urumqi in the Junggar Basin.

— By bus to Shihezi Municipality in the Manas River Basin. Inspection of large farms on which a variety of projects had been undertaken to transform the desert into productive cropland. Visit to water conservation works on an irrigation canal linked to the Manas River system.

— By bus back to Urumqi. This completed the field tour.

From Urumqi in the heart of Asia, the participants were flown to Shaanghai and Hangzhou for an interval of sightseeing before going back to Beijing, the nation's capital, where they had arrived in China almost a month before. Here they would conduct a summing up of their experience and prepare their reports on the seminar.

Upon their arrival in Beijing, the participants were fêted at a reception in the International Club by ambassadors of their countries. Here they were welcomed to China by Ju Gebing, the distinguished Vice-President of the Directorate for Environmental Protection.

Dr. Ju's welcome was answered by Gaafar Karrar speaking for the United Nations Environment Programme and its Executive Director, Dr. Mostafa K. Tolba. On leave from his position as Permanent Secretary for Animal Husbandry and Health in the Ministry of Agriculture, Sudan, Mr. Karrar had participated in the United Nations Conference on Desertification as officer in charge of the feasibility studies. Subsequently assigned to the Desertification Branch set up in UNEP to monitor the Plan of Action to Combat Deser-

tification, Mr. Karrar has since become Principal Officer of that Branch. His duties involved him in the preparations for the seminar in China.

When the participants arrived at the Lanzhou Institute in Gansu Province, they were greeted by Jang Jinye, Chairman of the Scientific and Technical Commission of Gansu Province and Director of the Research Institute. His warm words of welcome also received a response from Mr. Karrar. Excerpts from these four speeches are offered here.

WELCOME TO CHINA

Dr. Ju Gebing

The deserts of China cover an area of more than a million square kilometres. For more than 30 years since the founding of the People's Republic of China, work has been done and some results achieved in the control of desertification.

But still we would have to say that our work has just begun, that there lies before us an arduous and long-term task. . . to control the desert and make it serve the people. This seminar has brought together experts and responsible officials from a number of countries and provides us with a good opportunity for discussion, for an exchange of experiences. It gives us a chance to remedy our weak points by learning from each other. On our part, we wish to ask your advice, and to learn from you.

This is the first time that our country has held a seminar in association with UNEP. The places you are going to visit are in remote regions of our country. It is the first time that they have been opened to foreigners, for conditions there are still poor. Although great efforts have been made for your visit because of the great importance attached to this seminar by local authorities, the conditions you will encounter are still not the best. I mention this to prepare you, and in the hope that you will understand.

Our Government is also greatly concerned with this seminar, that it has been organized in association with the United Nations, and this is shown by our assigning it to the

Academy of Sciences.

Finally, allow me to propose a toast to the health of our foreign guests, to all the envoys and comrades here.

ON BEHALF OF UNEP

Gaafar Karrar

I wish to convey to you the heartfelt greetings of Dr. Mostafa K. Tolba, Executive Director of the United Nations Environment Programme, and his wishes for success of this seminar.

On behalf of UNEP and of our colleagues who have assembled here from around the world, I can say that we are most pleased by this chance to visit your great country. Much has been heard about what you have done, but few from elsewhere have yet had an opportunity to see it. It is a paradox that the smaller countries are more frequently visited by the people of the developing world than this great nation which contains one quarter of the human population and occupies one twelfth of the earth's land surface.

We all know that this is a nation with a distinguished tradition, a history of high civilization and great achievement. This is an occasion, however, for turning more toward your accomplishments with the problems of the present day. Two examples should suffice for my short address. The first is your spectacular success in answering a basic human need by resolving the problem of human settlements. The second is the control you have achieved over schistosomiasis, bilharzia, a most debilitating and serious human disease.

Yet in still another field your achievements are of special concern to the international community and to my colleagues in this seminar. This is the control you have achieved over desertification, over this serious environmental problem. Your accomplishments here can serve as an example to other countries threatened by this process.

The People's Republic of China contributed actively to the preparations for the United Nations Conference on Desertification. And here we are today coming to your coun-

try for a further contribution—for training to be given to specially selected officers and experts from countries actively engaged in the fight against desertification.

We are most grateful for your interest in holding this seminar and for your willingness to transmit your experience without reserve.

WELCOME TO LANZHOU

Dr. Jang Jinye

You come to China from far away, bringing us the friendship of peoples from various countries in Asia, Africa and Latin America. On behalf of the people of Gansu Province, of the scientists and technicians of the Institute, allow me to extend a warm welcome to you.

In recent years there have been a number of exchanges among us, those of us who live in the third world, in different fields of culture, the economy, science and technology. In Lanzhou, we are happy to see those of you who are old friends and just as pleased to be making new friends. To all of you, I am sure you will find that your visit will further promote friendship between China and your countries, among all of us who are scientists and technicians.

Friends, the problem of desertification has aroused concern in countries the world over, and most especially in third world countries. Since the founding of the People's Republic of China, some gains have been made by us under the leadership of Chairman Mao Zedong and the Communist Party of China. Yet our present work is only a first step. Much remains to be done, and our responsibilities are still grave and difficult.

This is the first time that we have attempted to run a seminar of this kind. Undoubtedly shortcomings and mistakes will appear. We will welcome your suggestions, just as we look forward to learning from your experience in every respect. Friends, our seminar opens tomorrow. I wish it every success! Just as I wish all of you health and extend my best

wishes to your work!

AGAIN ON BEHALF OF UNEP

Gaafar Karrar

On behalf of the Executive Director of the United Nations Environment Programme and of my colleagues, the participants in this seminar, I wish to thank you for your hospitality and for the splendid arrangements you have made.

This morning we were shown your Institute and were highly impressed. This Institute played a fundamental role in the preparation of the three Associated Case Studies which were presented by China to the United Nations Conference on Desertification. From these studies we know you have great achievements to show, hence our coming to you. This is the place where a living demonstration could be seen of what is called for in the Plan of Action to Combat Desertification, that call to action approved by the Conference. By this I mean that here, backed by a genuine political will, the available scientific knowledge was applied and enthusiastically carried out by a fully participating public. And all this continuously fuelled by a non-stop flow of research results from your famous Institute.

We look forward to the success of this seminar and can safely say today that we are assured of its success. So let us turn our thoughts seriously to the subject of follow-up. What we will do later will to a large extent depend on your evaluation of what is done here and on the reports of the participants in the seminar.

A period of seven years—until 1984—has been set for initial and immediate action against desertification. By 1984, which could well be a year of stocking, the People's Republic of China and your Institute will, I am sure, have established an excellent and honourable record of national achievement and international assistance programmes. You have already begun to lay solid foundation for that huge task.

The Seminar's Participants

Those participating in the Desert Control Training Seminar for Developing Countries included experts from most of the major fields directly involved in efforts to control desertification. The selections were made with this in mind so as to enrich the discussions that would be held. Another fundamental criterion for selection was that the participant be an official or scientist actively involved in current campaigns to reclaim degraded land. Those finally selected were the following:

ARGENTINA

Juan A. de Anchorena, agronomist, Head, Department of Ecology and Range Management, INTA Bariloche Field Experimental Station

Alberto d'Hiriart, agronomist, Head, Department of Soil Management and Conservation, INTA Field Station, San Luis Province

David Lee Anderson, rangeland science specialist, Head, Department of Ecology and Management of Natural Pastures, INTA Field Station, San Luis Province

EGYPT

Mahmoud Abdel Moniem Kassem, agricultural engineer, The Desert Research Institute of the National Research Centre

Dr. Abdel Rasheed Shehata, research specialist, The Desert Research Institute of the National Research Centre

INDIA

Dr. R.P. Dhir, soils scientist, responsible for compiling and interpreting data on natural resources for developmental and planning agencies

Dr. Ishwar Prakash, animal ecologist, Coordinator, National Programme for Rodent Control, Central Arid Zone Research Institute

Dr. M.L. Purohit, sociologist and production economist, Division of Economics and Sociology, Central Arid Zone Research Institute

NIGERIA

M.A. Oyebo, Senior Forestry Officer, Federal Ministry of Agriculture, Lagos

PERU

Dr. Juan Arturo Flórez Martínez, specialist in ecology and pasture management, Universidad Agraria la Molina

Dr. Carlos López Ocaña, specialist in the ecology of arid zones, Arid Zones Research Centre, Universidad Agraria la Molina

Carlos Zamora Jiménez, specialist in soils science, director of investigations into natural resources

SOMALIA

Ahmed Salim Awad, specialist in forestry science, Director of Science, Director of Forestry Services, National Range Agency

Omar Addo Warsame, specialist in forestry science,
Director of Range Services, National Range Agency

SUDAN

Mohamed El Amin Ahmed Babikir, specialist in
soil conservation, Regional Director for Natural
Resources, North Kordofan Province

Abdelhamid Mohamed Ali, specialist in range,
science, Senior Range Management Officer, North
Kordofan Province

Ali Ahmed Saleem, specialist in forestry science,
Head, Shelter Belt Section, National Forest
Administration

Study Materials Prepared for the Seminar

The heart of the learning experience provided by the seminar consisted of field visits to projects demonstrating control of desertification. Inspection could not be undertaken, however, until adequate background had been provided on the innovative techniques that the participants were to use. Thus, one week of instruction and discussion was conducted at the Lanzhou Institute for Desert Research in advance of the field trips.

This short course of instruction was centred on five documents prepared by Institute scientists. The first of these provided a general overview of anti-desertification measures undertaken in China's arid north, while the other four dealt with specialized topics. Edited versions of these five documents are presented in what follows, providing the interested reader with a survey of the new approaches China has undertaken to halt the degradation

of its drylands and to reclaim desertified soil. The wide-ranging projects directed toward these purposes are part of a larger design through which the People's Republic of China, with its enormous population, has become self-sufficient in food production.

The five documents given to the seminar's participants form chapters 2 and 4-7 of this volume.

A summary version of the first document, entitled *China's Deserts and Preventive Measures of Desertification*, was also circulated among the participants. Slightly different in content, it contained the materials extracted here as chapter 3.

In addition, the participants were given a handsome volume entitled *China Tames Her Deserts: A Photographic Record*. The photographs appearing in this book were taken from it.

Reports on the Seminar

Both staff and participants reported on the seminar, their comments appropriately constituting a conclusion since the participants wrote their reviews on 20 September in Beijing, as they prepared to board their flights for home. The Lanzhou Institute delivered an official report on the seminar to the United Nations Environment Programme. This was prepared in December 1978 by the Institute's Deputy Director, Ju Zhengda.

The participants were all experts, and Dr. Ju was struck by the spirit that animated their exchanges among themselves and with their hosts. "It is safe to say that the seminar achieved its basic objective," he reported, "that of learning from each other, sharing experiences, promoting friendship—all in the interest of improving the technology of desert control."

The visiting scientists all agreed that they had been shown techniques of combating desertification that they could take home with them and apply in their own countries. "Therefore the seminar met an immediate need for education and training," Dr. Ju said. At the same time, it was highly instructive for the scientists of the host country.

"It is worth pointing out," Dr. Ju said, "that this training seminar provided an excellent opportunity for Chinese scientists to understand the problems of desertification and the technology of combating it as seen in other developing countries." Group discussions were welcomed by both host and visiting scientists. As Mr. Kassem of Egypt remarked,

"The exchange of knowledge among Chinese and other scientists had its merits, and was useful to all. I hope that similar activities will be organized in the future."

The visitors were unanimous in praising the hospitality of their hosts and the skill with which they had organized a complex of classroom exercises and precisely scheduled field trips. Mr. Lopez Ocaña of Peru summed up the general reaction as "a great experience", one in which the host scientists had demonstrated "that economic development and environmental protection are fully interrelated". It was against that background that the visitors offered suggestions for improving future seminars.

— Simultaneous interpretation is needed. The delays caused by old-style interpretation interrupted the rhythm of the discussions.

— Participants should be selected earlier so as to have adequate time to prepare professional presentations of the situations in their own countries. As it was, only the participants from Peru had sufficient notice to prepare a thorough professional presentation including films and slides.

— The written materials given to the visitors were judged to be excellent, but insufficient. Visiting scientists of high professional attainment wanted also general studies of China's climate, topography, soils and biota.

— Field trips exhibited completed projects. Several of the visitors suggested that it would have been valuable to have seen work in progress, at stages before success was achieved.

Dr. Ju suggested that the curriculum was too long and the field trips possibly over-scheduled. Whatever shortcomings the seminar had, they stemmed, as Dr. Ju said, from "the lack of organizational experience". It was true that the seminar set a precedent and broke much new ground, so to speak, taking the participants to areas unvisited by foreigners since the establishment of a new order in China. In any case, as all agreed, it was a rich learning experience and one of a new type—in which scientists of developing nations became of service to one another. The participants had much to say about it.

Juan A. de Anchorena, agronomist from Argentina, thinking of the livestock industry in his own country, particularly regretted that the scheduled visit to the reclaimed pasture of Uxinju had to be cancelled because of weather. (The seminar took place during the season of the monsoon.) Stationed at Bariloche in Argentina's south-west, he was concerned to identify techniques that might be transferred to arid Patagonia. These included sand dune control through afforestation and the planting of shrubs, improved grazing systems, the introduction of superior plants for dune control and pasture improvement, and the possibility of developing irrigated oases by using snow melt.

Alberto d'Hiriart, agronomist from Argentina, would have liked to receive a copy of each country's report. He contrasted China's reliance on manual labour with the use of machinery in Argentina. He thought it possible that some of the same plants used in China to stabilize moving dunes might fulfil the same purpose in Argentina although studies would be needed "to adapt the technology to conditions present in Argentina". He found a particular advantage in that "personal contact was established between scientists of different countries which will permit a continuing interchange of research findings on subjects of particular interest".

David Lee Anderson, rangeland specialist from Argentina, also regretted that weather had interfered with the field studies in pasture management and animal husbandry. He thought the seminar could have been even longer, with five more days devoted to field experience. He pointed out that the participants were shown "unconventional and largely un-

known" methods for controlling erosion and degradation which was "extremely useful" although their application to Argentina will have to be studied in the context of Argentina's comparative lack of manpower. "Argentina", he said, "has not experienced erosion and degradation on the large scale of China. This is due chiefly to Argentina's relatively short history of exploitation and lack of demand on the total of natural resources. However, it is alarming that after so few years, some areas in Argentina are becoming desertified due to man's influence. "We can learn a valuable lesson from China and take the necessary preventive measures to arrest the process before it becomes too late in our country."

Mahmoud Abdel Moniem Kassem, agricultural engineer from Egypt, mentioned that versions of many of the techniques shown the participants were already being applied in Egypt, a land whose water deficiencies are much more severe than China's. These included windbreaks around oases, artesian wells, and canal irrigation drawing on water backed up by the Aswan High Dam. He suggested the possibility of tapping the deep aquifers in the Nubian sandstone formation in Egypt's arid south-west. He asked that the next seminar give more time to group discussion. At the same time, he was full of praise for the techniques that had established checkerboard protection against sand on the railroads and had extended fruit orchards on to gobi lands. He said that a new desert research station will be established in Egypt's New Valley, and that he would recommend that it be equipped with a wind tunnel such as he was shown at the Lanzhou Institute.

Dr. Abdel Rasheed Shehata, scientist at the Desert Research Institute of the National Research Centre in Cairo, spoke also of the problems of his country, which nowhere except on the northwest coast receives as much as 100 mm of annual rainfall. He agreed with most of the participants that the ratio of classroom time to field trips was proper for a seminar of this type. But like his fellow countryman, he too wanted more time for informal group discussion. He would also like to have been brought up to date on the Chinese experience with solar energy. He considered the seminar to have been professionally enriching

and to have provided the professional participants with information "suitable to our experience and responsibilities at home".

Dr. R. P. Dhir, soils scientist from India, would like to have received more detailed descriptions of the climatic, geomorphological, soil and biological features of China's deserts and drylands as background materials for the discussions. Additional data would also have been useful, as he suggested, on the procedures shown to the group, such as treatment specifications in oasis development vis-a-vis environmental conditions, water requirements of shelter belts, growth rates of tree species, and methods of dealing with salinization. He commented favourably on using the wind itself to level dunes, combining shrubs and trees to halt sand movement, and the concept of bio-drainage. The field tours merited his "highest appreciation" showing as they did "very vividly how by mobilizing human resources to apply technologies developed through experience, productivity and stable oases are possible in every harsh climatic environment".

Dr. Ishwar Prakash, animal scientist of India, had an opportunity to visit the Institute of Zoology of the Chinese Academy of Sciences in Beijing where he discussed issues of rodent control, a serious problem in India's drylands, with the Director and other scientists. On the field trips he was interested to see how desert areas can be reclaimed by using water resources and a vast human effort without resorting to expensive technology. "At home in the Indian Desert, we have the same problems of moving dunes, deteriorating ecosystems, and so on. . . To combat them, a number of technologies have been evolved and standardized by us, some of which have found their way to the field." He noted that India also has well equipped universities and institutes. "But we lack one thing that China has in abundance—water! We don't have water in our deserts. However, projects are on their way to exploit underground water and to bring water from distant regions." He agreed with his colleagues, Drs. Dhir and Purohit, that the arrangements for the seminar were flawless.

Dr. M. L. Purohit, sociologist and production economist of India, drew on his own professional background to suggest that the

seminar would have been enhanced with more attention to people, that relations between people and vegetation, between people and the environment, are after all what create desertification. A tremendous effort over the past 20 years has produced huge works, such as windbreaks and shelter belts that have to be seen to be appreciated. Such projects could be developed in any country where the tillers of the soil could be mobilized en masse the way they have been mobilized in China. "And even so, the area reclaimed is very little as compared with the total desert terrain of China." Much that he had learned he could apply at home "to increase the people's participation in carrying out huge projects, to evaluate the multiplier effect among peasants severely affected by sand movement and erosion. . . As a human ecologist, I find the experience of this country useful in helping me to probe more deeply into people's problems, to activate their participation in combating desertification as if they were on a war footing."

M.A. Oyebo, Senior Forestry Officer of the Federal Agriculture Ministry, Nigeria, said that "the field trips were strenuous but very interesting in that most of the participants, myself included, were for the first time seeing effective measures for combating desertification". This was the case at the Nanhu People's Commune in Gansu Province where, Mr. Oyebo was informed, 54 km of irrigation canals had been dug since 1956, topsoil brought in from 2.5 km away, to create afforestation on 1,000 hectares with over 6 million trees. "The volume of timber on this once barren field is now 15,000 m³, grassland covers 2,000 hectares, protected farmland produces about 6,000 kg of fruit annually." He commented, "the situation in most of the Chinese desert areas is unique, with the water table generally shallow." To transfer the technology to Nigeria would be to bring it where "it is not uncommon to find the water table at 300 m or more. It costs a fortune to sink a borehole in this region. Water is therefore a great constraint in land reclamation in our arid area." Nevertheless, there was much he could take home with him, including the concept of the kulum and the advantages of mixed shelter belts, combining shrubs with trees under certain conditions. Perhaps most important: "It

was imprinted on our minds that landforms consisting predominantly of sand dunes should not be written off as unproductive, but that with the correct use of labour, water and the right species of trees. . . . such areas can be transformed into agricultural land."

Dr. Juan Arturo Flórez Martínez, ecologist and pasture management specialist from Peru, found the seminar important to him even though visits to pastures were cancelled by bad weather. "On other occasions, I learned the modern technology for control of desertification from lectures. Here, for the first time, I saw a real demonstration of practice in the field. What we were shown looked humanly impossible, and yet the Chinese people did it, many hands making light work." To combat desertification in Peru requires improving saline soils in irrigated coastal valleys, afforestation in the highlands and good management of croplands and rangelands. The reclamation of desert areas on the coast of Peru was similar to what was seen in China "with this substantial difference: we don't have enough water".

Dr. Carlos López Ocaña, Peruvian specialist in the ecology of arid zones, mentioned that at each place, the visitors were kindly invited to sample the products grown on reclaimed land. He was convinced that "the methodology learned during the seminar in China can be applied to the coastal desert in Peru", which also has a problem of moving dunes and sand encroachment on farmlands, canals and communications lines. China's success, however, was due to access to water, which is very scarce on the coast of Peru, and to "a great effort made by well organized human populations. This will be very difficult to achieve in Peru." Nevertheless, "we will make use of the experience obtained in this seminar in several ways. The experience will be transmitted through conferences and will enter into lectures and thesis work at the university. A project on sand-dune fixation will be planned, implemented and executed through our Centre (Universidad Agraria la Molina). We will try to coordinate action with the University of Piura on the northern coast, where moving dunes and sand encroachment give rise to important social and economic problems."

Carlos Zamora Jiménez, soils scientist from Peru, reported that "without any question, the great achievements in China in combating

desertification are on the practical side more than in the theoretical and research aspects. The opposite situation dominates many of the countries of the third world—a great amount of research and theoretical teaching in the universities with few achievements in the field." He was pleased also to report that the government of Peru has taken concrete steps to halt desertification by establishing the appropriate legal machinery, by carrying out a systematic inventory and evaluation of natural resources (in which Mr. Zamora is involved), and by undertaking specific projects. The latter include the improvement of coastal irrigation and an aggressive policy of afforestation on the steep slopes of the Andes. He foresaw the need to strengthen effective co-ordination among the various ministries and organizations involved in the problem of desertification so as to create an effective machinery for the elaboration and implementation of national programmes.

Ahmed Salim Awad, specialist in range management from Somalia, was favourably impressed by methods of establishing shelter belts and of stabilizing moving dunes, but wanted to see such work actually going on, to see, for example, sand dunes being levelled with machinery of flooding. Inspection of nurseries, too, would have helped in deciding which methods were applicable in his own country. While the Chinese had had great practical success in using indigenous plants, they should also be testing exotic species in a systematic research programme. An example of what he meant was provided by Somalia, "a semi-arid country with erratic rainfall and a problem of soil salinity". Locally, dunes were being fixed with the indigenous *Opuntia* cactus, a plant with little economic value. Investigations led to tests with exotic species, specifically *Acacia cynophylla* and *Eucalyptus* spp., and these trees, with their higher economic value, proved much more effective. The planting programme will be expanded with the use of exotics.

Omar Addo Warsame, forestry specialist from Somalia, agreed with his fellow countryman that for all its success, the Chinese programme might do even better with carefully directed research. The Chinese had made great use of what they had available—water, manpower and indigenous species of plants and trees. "Among other things, research

would permit the introduction of exotic plants suited to the local climate to see if they might do better. The planting techniques actually adopted showed a high mortality rate in certain areas. As I understand it, this was because plants grown in the nurseries were not transplanted until they were one year old, when they suffer a mortality rate of 30-40 per cent. It might be advisable to transplant earlier, that is to say, after two months." This was the sort of question that a stepped-up research programme would direct itself toward and an example of the sort of interchange that went on continually during the seminar. The Somali scientist was sure that "every one of the participants had learned techniques that they could pass on to their own people".

Abdelhamid Mohamed Ali, range management officer from Sudan, found that some of the measures used by the Chinese to control desertification—such as checkerboard enclosures, shelter belts and windbreaks—were also in use in Sudan. "Some measures, however, are more developed in China, particularly the creation of new oases and forest and shelter belts. Therefore the seminar was most useful—and not only to learn the experience of China, but also that of other nations." The techniques observed could be brought back and applied against desertification of Sudan's rangelands, with special thought to the rangelands of Kordofan Province, which come under Mr. Mohamed Ali's supervision. Account must be made, however, "of the differences in situation and environmental conditions between rangelands of Sudan and those in China".

Mohamed El Amin Babikir, soils specialist from Sudan, reported that the laboratories at Lanzhou Institute were well equipped for studying both plants and soils. The movement of chemicals in soils could be investigated by spectography. Most impressive, however—as it seemed to the other participants—was the wind tunnel for determining the effect of trees and vegetation on wind dynamics. The instrument was described by this scientist as 37.78 m long, capable of producing wind speeds varying from 2 m/sec to 40 m/sec. "With added equipment," he suggested, "the wind tunnel

could be adjusted to study living plants and their behaviour, such as rooting habits, under the influence of wind at different speeds and under varying degrees of temperature and humidity." Such research would have application in Sudan, where conditions are quite distinct from those seen in China. "There are no water resources except for a few deep wells used to water the livestock of nomads. Temperatures are high and relative humidity very low, resulting in the dessication of living plants. People in China are well organized and remarkably disciplined. The inhabitants of Sudan's drylands are nomadic tribes, and they are very independent. However, techniques developed in China would still be of great value in any future desert control work in Sudan."

Ali Ahmed Saleem, forestry specialist from Sudan, concluded that the techniques developed in China had universal application. Their effectiveness was demonstrated by the fine stands of willows and poplars that constitute the shelter belts. China, like Sudan, has experienced desertification resulting from "unscrupulous tree clearance for the expansion of mechanized dryland farming, particularly in marginal conditions". Also in the Sudan, "shelter belts are commonly used on farmlands, along canals and around reservoirs and villages. It is also worth noting that sand dunes in western Sudan have been stabilized by the checkerboard method." Mr. Saleem said that the seminar was "successful and informative. . . of definite help to me in the performance of my duties and responsibilities". Like the other participants, he said that the arrangements made by the host scientists were superb. He wished to thank them, as did the other participants, and to express his gratitude also to UNEP for arranging this remarkable event.

There was no doubt that the statements supported the conclusion reached by Dr. Ju Zhengda in his report to UNEP. This was "that the training seminar has strengthened friendship among countries confronted with similar environmental problems, that it will be helpful in promoting unselfish co-operation in solving a problem of common concern".

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