

## Soil and Water Conservation in Arid and Semi-arid Areas: The Chinese Experience

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**Abstract:** In China, soil erosion is a serious environmental problem and a major threat to the sustainability of agriculture and economic development. The total area subjected to soil erosion covers 3,670,000 km<sup>2</sup>, i.e., 38.2% of the total land area. For a long period of time, particularly since the founding of the People's Republic of China in 1949, the Chinese government has paid a great deal of attention to issues of soil and water conservation to promote economic development and better environmental management. This paper reviews soil and water conservation techniques adopted in arid and semi-arid regions of China and discusses the problems and perspectives for soil and water conservation strategies. The effective measures for wind erosion control include vegetative, engineering and chemical methods as well as land management practices, and measures for water erosion include transform topography, tillage and crop rotation management, mulching and rainwater harvesting system. Success in soil and water conservation often requires a combination of various measures, and it needs to be integrated within a comprehensive agricultural management system. In order to gain the potential ecological and economic benefits from soil and water conservation, policy and funding support are also necessary. In addition, further research is needed to assess the ecological, social and economic impacts of soil and water conservation system from a plurality of perspectives.

**Key words:** Soil erosion, China, soil and water conservation, wind erosion, water erosion.

Conservation of the environment and sustainable utilization of natural resources are major issues of concern within the international community (Li *et al.*, 1999). Land degradation is a serious environmental problem world-wide and a major threat to the sustainability of agriculture and economic development. In the case of China, the total area subjected to soil erosion has reached 3,670,000 km<sup>2</sup>, i.e., 38.2% of the total land area, of which land area subjected to wind erosion accounts for 1,880,000 km<sup>2</sup> and water erosion accounts for 1,790,000 km<sup>2</sup> (Feng *et al.*, 1999; Chen, 2000). In recent decades, much research and practical measures in

soil and water conservation have been carried out in north China to rehabilitate degraded lands and improve agricultural productivity. The objectives of this paper are to review soil and water conservation techniques and experiences adopted in arid and semi-arid regions of China, and to discuss the problems and perspectives for soil and water conservation strategies.

### Wind erosion control practices

#### *Wind erosion in north China*

The vast expanse of arid and semi-arid lands in China is subject to very severe

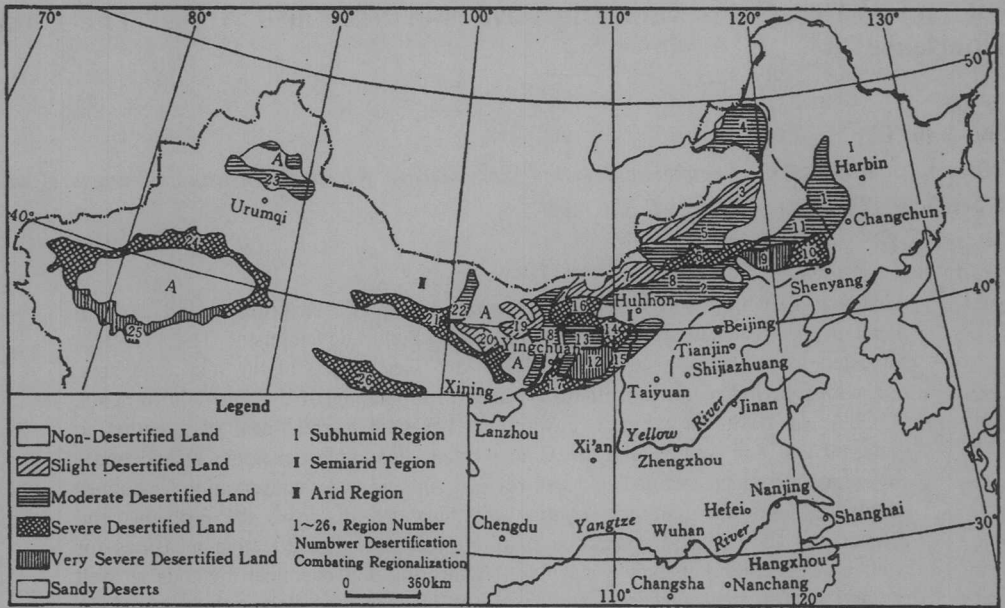


Fig.1. Sketch map of desertified lands in North China (Source: Wang *et al.*, 1999)

soil erosion by wind (Zhu *et al.*, 1989). It has been estimated that 53% of the land area of China is arid and semi-arid (Huang *et al.*, 1997), and much of this land lies in north-west China (between 32°N and 48°N) including Shaanxi, Gansu and Qinghai Provinces as well as Ningxia Hui and Xingjing Uighur Autonomous Regions. Wind erosion mainly occurs in the following three regions of north China (Wang, 2000a): (1) semi-arid agropastoral region, (2) semi-arid undulate grassland, and (3) arid oasis margin and lower reaches of inland rivers. A sketch map of desertified lands in north China is presented in Fig. 1.

Due to strong winds during the long, dry winter and spring seasons and sparse vegetative cover, dust storms occur frequently in north China. Moreover, the frequency and intensity of dust storms are increasing as a result of the dialectical relationship

between climatic change and human disturbance. Wang (2000b) reported that, there were 5 dust storms in the 1950s, 8 dust storms in the 1960s, 13 dust storms in the 1970s, 14 dust storms in the 1980s and 23 dust storms in the 1990s. Desertified land expanded at a rate of about 1570 km<sup>2</sup> y<sup>-1</sup> from the end of the 1950s to the mid-1970s, 2100 km<sup>2</sup> y<sup>-1</sup> from the mid-1970s to the mid-1980s, and 2460 km<sup>2</sup> y<sup>-1</sup> from the mid-1980s to the mid-1990s. Up to now, desertified land area covers 370,000 km<sup>2</sup> (Wang, 2000b). Dong *et al.* (1999) estimated that organic, nitrogen and phosphorus nutrients in topsoil are lost as a result of soil erosion by wind at a rate of about 55.9 million ton y<sup>-1</sup> in the whole country, an equivalent to 17,000 million RMB Yuan damages. These facts demonstrate that China is facing serious challenges in controlling wind erosion.

### *Soil conservation practices for wind erosion*

For a long period of time, particularly since the founding of the People's Republic of China in 1949, the Chinese government has paid a great deal of attention to issues of soil conservation to promote economic development and better environmental management. Measures taken include vegetative, engineering and chemical methods as well as land management practices.

*Vegetative measures:* Shelterbelts are a major vegetative method for controlling wind erosion in China. Shelterbelts are belts of vegetation planted across the prevailing wind direction to reduce the velocity of winds across farmlands or around buildings (Bhimaya, 1976). A shelterbelt management system called "forest net" is being used widely in the Three-North region (North, North-west and North-east) of China (Li *et al.*, 1999). It involves planting trees in a grid pattern so that each plot of farmland is surrounded by trees. The main purpose is to shelter agricultural crops against wind. As a monsoon climate prevails over much of China and the direction of harmful winds regularly changes, most of the shelterbelts established around farmland plots are very narrow networks with small meshes. An effective form of shelterbelt is a 5 m belt with 2 to 4 tree rows combined with shrubs, which gives a wind penetration coefficient of 0.4 to 0.5 (Hunag *et al.*, 1997; Li *et al.*, 1999). The distance between tree belts varies with climatic conditions. The average mesh size of this network is about 13 to 16 ha in arid and semi-arid areas (Zhao, 1994). Studies (e.g., Huang *et al.*, 1997) indicate that shelterbelts are effective in

protecting farmland from severe wind and sand encroachment, and for producing high-quality timber in the central and northern plains. A shelterbelt network can reduce wind velocity by 1 to 2 m s<sup>-1</sup> (Li *et al.*, 1999). Furthermore, shelterbelts can improve the surrounding microclimate. A shelterbelt network can increase relative air humidity by 5 to 10%, and increase annual mean temperature by 2 to 5°C (Song, 1981, 1990). It is estimated that farmland protected by tree shelterbelts covers 10.7 million ha and accounts for 45.7% of all arable land in north China (Huang *et al.*, 1997). Intercropping trees with farm crops is another form of vegetative measure to reduce wind erosion and improve crop production. Wei (1995) reported that intercropping apricot with cotton and grass in the sandy land reduced soil erosion by 25 to 60%. Also air-seeding was successfully used to generate grasses and shrubs to stabilize shifting sand dunes in north China (Dong *et al.*, 2000).

*Engineering and chemical measures:* In desert areas where natural conditions are not suitable for vegetative measures, engineering measures are introduced. The popular engineering methods in China include fences, straw checkerboards, clay barriers, gravel barriers, sand-transporting boards, feather-like sand-conducting fence arrays and sand-separating ditches. In north China, the engineering measures are mainly used to protect the transportation lines crossing desert. This has been successfully practiced in the Shapotou Section of Bao (Baotou) - Lan (Lanzhou) Railway, Naiman Section of Jing (Beijing) - Tong (Tongliao) Railway, Yumen Section of Lan (Lanzhou) - Xing (Urumqi) Railway and the Desert

Highway in Taklimakan Desert. A photograph showing straw checkerboards along both sides of highway for oil-field transportation in Taklimakan Desert is presented in Fig. 2. Straw checkerboards (1 m long, 1 m wide and 0.15 to 0.20 m high) can increase 11 to 217 fold surface roughness compared to bare sand dunes (Zhu *et al.*, 1998), reduce wind velocity by 20% and decrease sand transport rate by 99% (Shapotou Desert Science Research Station of Lanzhou Institute of Desert Research, 1990), and thus effectively controlling blowing sand. Furthermore, straw checkerboards can trap airborne dust. Under the interaction of raindrop impact, micro-organism activities and dust deposition, a biological crust can be formed on the top sand layer (Li *et al.*, 2000). A wind tunnel simulation study has shown that soil surface crust can reduce soil erosion

by 63 to 89% compared with flow sand (Li, 1997). Therefore, soil crust in straw checkerboards is also an important factor for effective erosion control. Another successful example of engineering methods for controlling blowing sand erosion is to use nylon fences, straw checkerboards and gravel mulch barrier combination to protect the Mokao Grottoes in Dunhuang, Gansu Province (Qu *et al.*, 2000).

Chemical methods for stabilizing loose shifting sand are limited to small areas in China because of their high cost. Research is being conducted to reduce these costs.

*Land management measures:* Land management practices used on farmland include striped and alternated cultivation, residue management, zero tillage and mulching. In most areas, the importance of land management is ignored. A good example

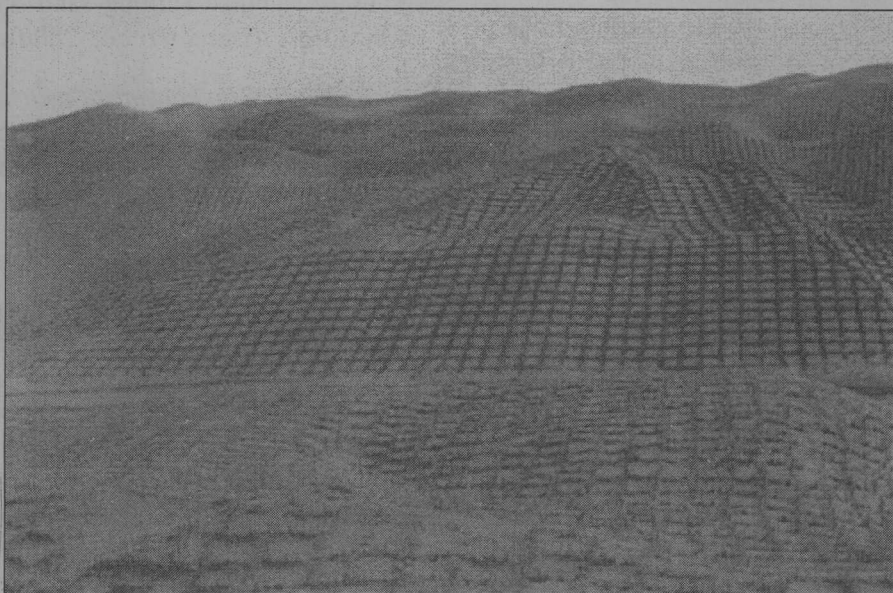


Fig. 2 Straw checkerboards in Taklimakan Desert along both sides of the desert highway (Photo, X.Y. Zhang)



Fig. 3. Gravel mulches in Gaolan County near Lanzhou City, Gansu Province.

of preventing soil loss due to wind erosion is by proper land management in the Gonghe Basin of Qinghai Province (Dong *et al.*, 2000).

A special land management strategy for soil and water conservation is the use of gravel and sand to mulch fields in north-west China. Gravel mulches are known locally as sha tian or sandy fields in Chinese, and have been widely used by local farmers for over 300 years to ensure high and stable crop yields (Li *et al.*, 2000a). Such fields are concentrated in Gansu Province as well as adjoining counties in neighboring Ningxia Hui Autonomous Region and Qinghai Province. At present, 118,000 ha of such fields are distributed in Gansu Province. The mulching gravel or pebbles (5-16 cm thick) are fluvial materials of the Yellow River. The construction of gravel-mulched fields, fertilizer application, and tillage pattern were described in detail by Gale

(1993) and Wang and Sun (1986). A photograph showing gravel mulches in Gaolan County near Lanzhou City, Gansu Province is presented in Fig. 3. The effect of gravel mulch on water conservation has been accepted by local farmers, and many studies show a pebble or gravel mulch to be effective in reducing evaporation and runoff, improving infiltration and soil temperature and maintaining soil fertility (Li, 2000; Li *et al.*, 2000a). However, the effectiveness of pebble mulch in controlling soil erosion by wind is often neglected. Li *et al.* (2001b) reported that gravel or pebble mulch had two functions in controlling wind erosion: first, it can prevent soil from being eroded by wind; second, it can trap windblown dust. According to the wind tunnel simulation experiments and field studies, pebble-mulched fields can reduce wind erosion rates ( $\text{g m}^{-2} \text{min}^{-1}$ ) by 84 to 96% and trap 1.6 to 1.8 times

more windblown sediments than non-mulched fields. The effects of gravel mulch restraining soil deflation were also studied by Li (1997), Liu *et al.* (1999) and Xue (2000), who stated that gravel mulches can increase surface roughness, and thus can effectively control wind erosion.

*Comprehensive management schemes for soil erosion by wind:* Due to the fact that the natural conditions are complex, and often vary widely between regions, the corresponding measures for controlling wind erosion are different in different regions. For example, sand damage control along roads is characterized by linear protection; point protection predominates in the mining sites and residential areas; while the farmland and rangeland require wider protection. Hence, the practices to be adopted should not be confined to one measure. Success in controlling soil erosion often requires a combination of various measures. Zhu *et al.* (1998) summarized the practical experiences in different natural zones in China, and proposed the following wind erosion control patterns: (1) Mulch-Fixation-Blockade-Protection pattern. This pattern is suitable for use in the oases of arid zone. This mode consists of establishing sandbreak forest around the oasis, planting farmland-protective forest network inside the oasis, fencing off the outer fringe of oases to protect natural vegetation, erecting sand barrier on the sand dune surface and establishing patchy forest in the inter-dune depressions. (2) Fixation-Blockade-Transport-Diversion pattern. This is suitable for use in localities where there is railway or highway passing through the dense moving sand dunes. The pattern is

to erect straw checkerboard barriers along both sides of the road and establish high sandbreak palisades at the outer edge. The roadbed section should be streamlined, and road surfaces as well as road embankment should be compacted. (3) Protection-Fixation-Closure-Readjustment pattern. This is suitable for use in farmland and rangeland of semi-arid area. The pattern consists of setting up forest network around farmland and rangeland, stabilizing sand dune in surrounding area by excluding livestock to protect natural vegetation or planting shrubs and grasses, and readjusting the land use structure. (4) Blockade-Fixation-Closure pattern. This is suitable for use in industrial and mining sites or along transport lines in semi-arid zone. This pattern consists of establishing living plant fences around the objects to be protected, setting up patchy forests in the interdunal depressions, and planting trees and shrubs in combination with protecting natural vegetation in the surrounding areas.

## Water Erosion Control Practices

### *Soil and water loss in the Loess Plateau*

In China's semi-arid regions, severe soil erosion by water mainly occurs in the Loess Plateau. The Loess Plateau of north-west China is situated in the upper and middle reaches of the Yellow River (33°43'-41°16'N and 100°54'-114°33'E). It covers a total area of 624,000 km<sup>2</sup>. Annual precipitation ranges from 200 to 750 mm, with 70% rainfall falling between June and September, often in the form of heavy thunderstorms. This not only causes tremendous amount of erosion, but also problems of inadequate availability of water for crops. The major

soil type in the cultivated land area is sandy loam of loess origin, which is loosely structured and highly susceptible to wind and water erosion (Chen *et al.*, 1996).

In a large area of the Loess Plateau where no water resources are available for agricultural irrigation, the most widespread land-use system is rainfed farming. Rainfed cropland occupies about 80% of the total cultivated land (Shan, 1993). Crop production in the region is only 25 to 33% of the potential productivity, and water use efficiency is between 0.5 and 0.6 kg m<sup>-3</sup> due to water stress (Li *et al.*, 2001a). Since the beginning of the century, particularly over the last several decades, the rapidly growing human population has placed heavy pressure on productive soil resources, forcing farmers to convert more and more forest land and grassland into cropland and at the same time to increase cultivation of steep erodible slopes (Fig. 4). Consequently, this

has led to an increase in the scale and severity of soil erosion and a reduction in soil fertility, which are major threats to the sustainability of agroecosystems in the region. It is estimated that each year, on average, 40 million tons of nitrogen, phosphorus and potassium nutrients are lost from the region through soil erosion (Feng *et al.*, 1999). The Loess Plateau suffers from the most severe soil erosion in the world, affecting 45% of the plateau, with an average annual soil loss of 3720 t km<sup>-2</sup>. This is 14 times that of the Yangzi River region, China, 38 times that of the Mississippi River region, USA, and 49 times that of the Nile River region, Egypt (Liu, 1999).

#### *Soil and water conservation in the Loess Plateau*

There are always strong links between measures for soil conservation and measures for water conservation. Many measures are



Fig. 4. Typical landscape of cultivated sloped land in the Loess Plateau.

directed primarily to one or the other, but most contain an element of both (Hudson, 1987). Reduction of surface runoff by structures or by changes in land management will also help to reduce erosion. Similarly, reducing erosion will usually involve preventing splash erosion, the formation of crusts, or the breakdown of structure, all of which will increase infiltration, and thereby assist water conservation. Therefore, soil conservation and water conservation practices in this paper are discussed at the same time.

China has a history of over 3000 years of soil and water conservation. During this long period, the Chinese people developed various conservation methods to meet the demand for increasing production and stabilizing the environment. The soil and water conservation methods adopted in the Loess Plateau are summarized as follows:

*Transforming topography:* In the Loess Plateau, sloping farmlands cover 44 to 62% of the total land in the hilly and gully region and 39-58% in the tableland region (Liu, 1999). Therefore, altering the topography is the basic technique to prevent soil and water loss. This includes techniques such as land leveling, the construction of terraces, contour furrows, ridge and furrow systems and fish-scale pits (semi-circular bunds). The purposes are to retain surface runoff and increase *in-situ* infiltration by mechanical methods. Some studies have indicated that, level terraces can reduce runoff by 92.4% and soil loss by 87.6-95.0% as compared to sloping land (Zhao, 1996), graded terraces can reduce runoff by 77.3-91.7% and soil loss by 98.0%, and contour furrows reduce runoff by 25.7-40.5% and soil loss by 33.7 to 56.1% (Jiang, 1998). A photograph

showing terrace, semi-circular bunds and rectangular bunds for soil and water conservation in the Loess Plateau is presented in Fig. 5.

Ridge and furrow systems consist of shaping the soil surface with alternate ridges and furrows along the contour to retain runoff, enhance infiltration and improve the microclimate. This technique is simple, cheap, replicable, efficient and adaptable, and it has a great potential for application in the arid and semi-arid regions. It can be used on both sloping land and dry flat land. There are various forms of ridge and furrow methods of soil and water conservation practices that have been developed in the Loess Plateau. This technique is often combined with mulching, strip cropping and rainwater harvesting to maximize utilization of rainwater. Basically, there are three types of ridge and furrow systems, i.e., bare ridge and bare furrow, plastic-covered ridge and bare furrow, and plastic-covered ridge and gravel-, straw- or film-covered furrow. The bare ridge and bare furrow system is suitable for use in the high rainfall zone. In one study, the slope land was formed in a pattern of 25 cm ridges and 25 cm furrows alternately along contours, then a 5 cm diameter hole with a depth of 35 cm was drilled in the furrows 25 cm apart for runoff infiltration. Crops were planted in the furrows. This method has brought about a soil moisture increase of 54.8 mm in the 0-200 cm soil layer in comparison with conventional cultivation. At the same time, wheat yields increased by 27.7%, surface runoff was reduced by 52.8% and soil loss was reduced by 53.5% as compared to conventional cultivation methods (Zhang *et al.*, 1994).

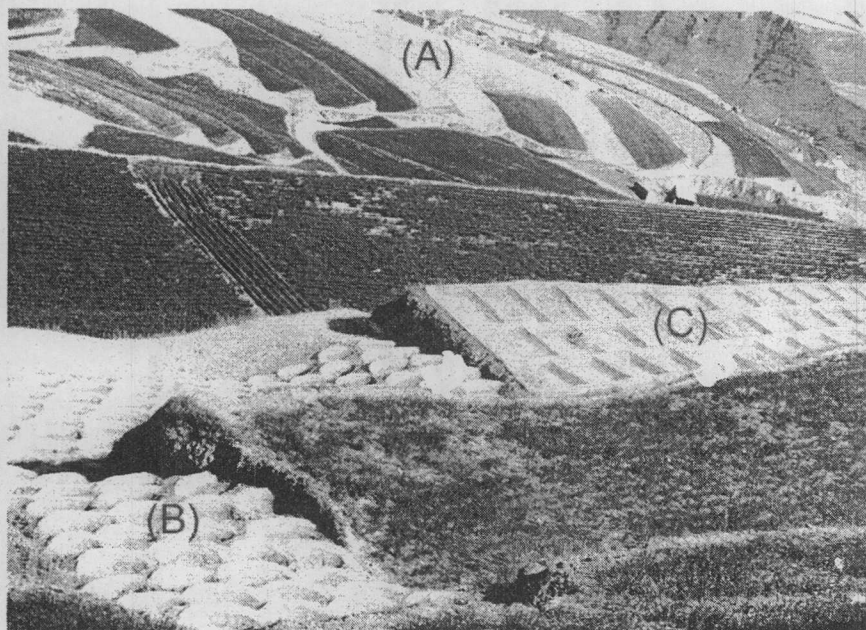


Fig. 5. Terraces (A), circular bunds (B) and rectangular bunds for soil and water conservation in Zhuanglang County, east of Gansu Province in the Loess Plateau.

The plastic-covered ridge and furrow system is suitable for use in the regions dominated by light rain of low intensity (Li *et al.*, 2000c). Li *et al.* (2001a) and Li and Gong (2001) studied the effects of ridge and furrow rainfall harvesting (RFRH) system with mulches on corn production in the drier part of the Loess Plateau. In the RFRH system, plastic-covered ridges serve as a rainfall-harvesting zone and stone, straw or film mulched furrows serve as a planting zone. The results indicated that corn grain yields in the PRFRH system can increase by 60 to 95% in drought and average years, 70 to 90% in wet years, and 20 to 30% in very wet years. For corn and winter wheat, the optimum ridge/furrow ratio was about 1:1 in the 300 mm rainfall area, 1:2 in the 400 mm rainfall area and 1:4

in the 500 mm rainfall area; and for millet, the optimum ridge/furrow ratio was 1:3 in the 300 mm rainfall area. The most effective ridge size for crop production seems to be 60 cm in the Loess Plateau. The PRFRH system has several advantages. First, it can make better use of light rain by harvesting rainwater from plastic-covered ridges, thus improving the availability of water to crops. Second, plastic-covered ridges can increase soil temperature. Third, this system can reduce wind velocity and thereby control wind erosion. Fourth, the ridge and furrow configuration can improve aeration and light radiation. Fifth, organic matter and fertilizer can be concentrated in the planting zone for improving the availability of nutrient for crop growth and thereby improve the effectiveness of fertilizer utilization. A



Fig. 6. Corn grown in the plastic-covered ridge and furrow system with a ridge/furrow ratio of 2:1 (120 cm wide ridge and 60 cm wide furrow).

photograph showing corn cropped in the RFRH system with a ridge/furrow ratio of 2:1 (120 cm wide ridge and 60 cm wide furrow) is presented in Fig. 6. Similarly, Jin *et al.* (1999) reported that an integration of ridge and furrow configuration and plastic mulch increased cotton water-use efficiency from 0.49 to 0.76–0.86 kg m<sup>-3</sup> in the Hebei Plain of north China. Deng (1999) reported that an incorporation of plastic-covered ridge and bare furrow system with strip cropping was an effective method to increase crop production. In his experiment, winter wheat was planted in the plastic-covered ridges (75 cm wide) and corn was planted in the bare furrows (65 cm wide). The grain yields of intercropped corn and wheat increased by 40% as compared to those of a corn monoculture and increased 2.7-fold as compared to a wheat monoculture.

*Tillage practice and crop rotation:* Ploughing and racking is a traditional means of retaining soil moisture in the Loess Plateau. Some studies have indicated that deep plough can increase soil moisture by 5.9 to 7.5 mm in the 0 to 30 cm soil layer, or by 30 mm in the 0 to 200 cm soil layer (Zhu and Li, 1997). Contour cultivation can decrease runoff by 19.2 to 39.0% and reduce soil loss by 31.2 to 67% in comparison with conventional cultivation methods. Strip cropping can retain runoff by 60.5% and decrease soil loss by 65.7% (Guo, 1991).

Following and crop rotations are also common practices in the Loess Plateau. Crop rotation can reduce runoff by 60.8% and reduce soil loss by 65 to 68% as compared to monocultures (Guo, 1991).

An assessment of soil conservation effectiveness between wheat monoculture and 7 rotations (rapeseed, corn, potato, pearl millet, linseed, alfalfa and sweetclover) indicated that the rotations performed much better than continuous wheat cropping in conserving soil and water resources (Li *et al.*, 2000a, Li *et al.*, 2001). Li *et al.* (2001) recommend two alternatives for winter wheat rotation: first, cultivate winter wheat followed by a 3-month legume fallow crop in year 1 and then a summer crop cultivation in the next. This system provides a soil cover during both erosion-prone rainy periods while leaving the soil bare for about 7 months (October-April) every 2 years. Another alternative is to cultivate winter wheat followed by a 15-month legume crop cultivation in the first two years and then a summer crop cultivation in the third year. This system allows the soil to be covered during three rainy periods while leaving the soil bare for about 7 months every 3 years. As most of this 7-month period is winter with low rainfall (snow) and temperatures below 0, not only is soil evaporation very low, but the risk of erosion is also low.

*Mulching:* Water balance studies on the dry sloping land of the Loess Plateau has shown that about 45 to 50% of the precipitation is lost as a result of evaporation (Zhang and An, 1997), and much work has been done to reduce evaporation in farmlands of the region. At present, plastic film mulching is widely used in the Loess Plateau to conserve soil water. Straw mulching has not been used on a large scale so far due to farmers' needs for straw as fodder and fuel. Gravel mulching is only used in the low rainfall zone of the

Loess Plateau (discussed in the previous section). Studies have indicated that plastic film can decrease soil evaporation by 30.8 mm as compared to the non-mulched soil, and increase soil moisture storage by 10 to 12 mm in the upper 20 cm soil layer. Straw covers can bring about an evaporation reduction of 12 to 42 mm and an increase of soil moisture of 27.5 mm before crop sowing. Gravel mulch can reduce evaporation by up to 40% and decrease runoff by 96% as compared to the non-mulched soil (Li, 2000).

*Rainwater harvesting:* Rainwater harvesting is an old technique for water conservation in China. Various forms of water harvesting have been used throughout the centuries. One very old but still common flood diversion technique called "warping" (harvesting water as well as sediment) has been extensively applied in China's loess areas since the Spring and Autumn period (2700 years ago). In Dongzhiyuan of Gansu Province and north of the Weihe River, Shanxi Province, rainwater cisterns and jars as well as ponds have been in use since the Ming Dynasty (over 600 years ago) (Huang, 1998; Li *et al.*, 2000b). But a growing awareness of its potential for improving crop production arose with widespread droughts in the 1980s followed by serious shortages of drinking water and crop failures. Rainwater harvesting was first practiced in Gansu Province, and aimed at solving drinking water problem for human beings and livestock. Since 1995, rainwater harvesting has been promoted by the government as a solution to the problem of water shortages for agricultural production and has been termed rainwater harvesting agriculture (RHA) (Cook *et al.*,

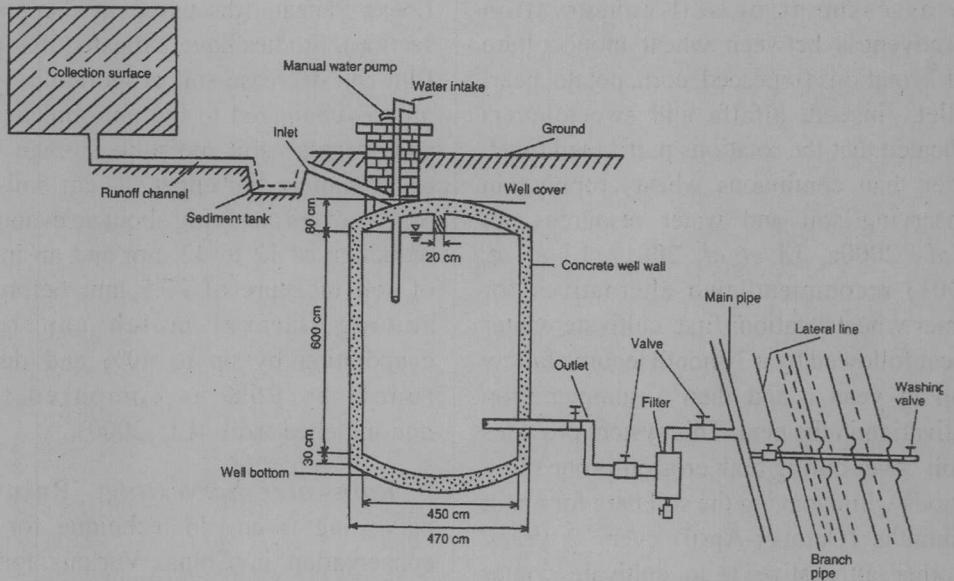


Fig. 7. A schematic diagram showing the small-scale rainwater harvesting system being widely used by household farmers in semi-arid areas of Gansu Province (Source: Li *et al.*, 2000b)

2000; Li *et al.*, 2000b). The RHA system consists of collection surface (catchment), runoff channel, sediment tank, storage container and supplemental irrigation system (Fig. 7). The popular catchments for runoff concentration are rooftops (Fig. 8), courtyards, asphalt-paved roads (Fig. 9), plastic film covers on greenhouses (Fig. 10) and cleared or smoothed hillsides.

Containers for the storage of rainwater include tanks and mini-reservoirs. There are two basic types of tanks in wide use in the Loess Plateau: traditional earthen tanks and modern concrete tanks. The capacity of these tanks is usually between 15 and 60 m<sup>3</sup> depending on locality and purpose. At present, harvested rainwater is mainly used for household domestic purposes and limited supplemental

irrigation. After the implementation of the rainwater-harvesting program, RHA has yielded obvious benefits and shown great promise in alleviating water and food problems in the Loess Plateau. A key case is the 1-2-1 rainwater harvesting program launched by the Gansu provincial government to assist each rural household to build about 100 m<sup>2</sup> of concrete catchment, two concrete storage tanks and irrigate one mu (1/15 ha) of cropland for production of high market value cash crops. Up to 1999, this program has helped farmers construct approximately 22 million m<sup>2</sup> of concrete catchments and 9.1 million storage tanks, supplying 1.31 million rural residents and 1.2 million livestock with adequate drinking water. At the same time, about 14 million ha of farmland has been irrigated

using harvested rainwater (Li, 2000; Li *et al.*, 2000b).

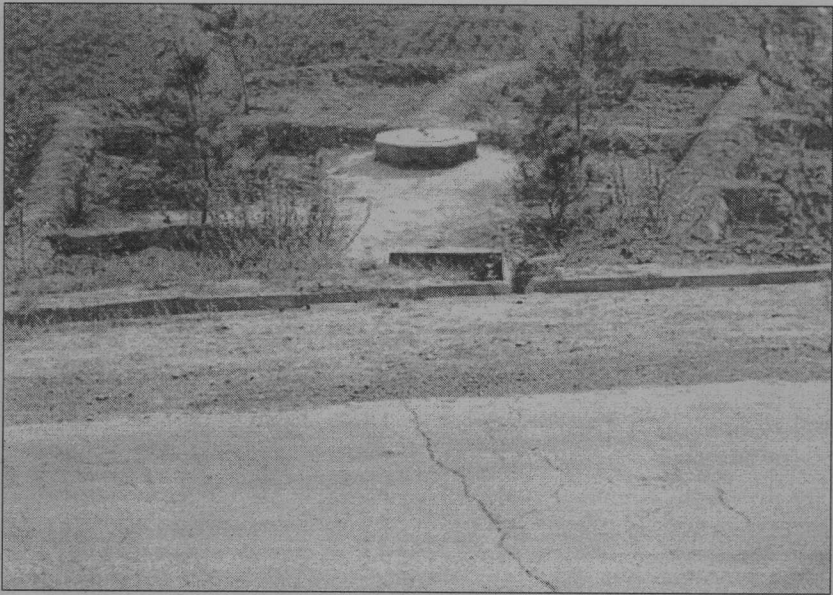
Rainwater harvesting offers a method of effectively developing water resources of arid and semi-arid regions. It shows great promise in helping to alleviate water and food shortages, as well as prevent soil erosion to some extent. However, the current rainfall-harvesting practices in China are still confined to rural family units to supply household water needs and for limited irrigation purpose. Properly designed rainwater-harvesting systems for afforestation in mountainous areas, and rainwater harvesting systems for urban areas are still in the experimental stages. More research is needed to assess the hydrological, ecological, social and economic aspects of rainwater harvesting from a plurality of perspectives in a wide range of different localities (Li, 2000). Moreover, successful

rainwater harvesting systems need to be combined with other agricultural technologies such as water-saving techniques, crop management and soil fertility management.

*Comprehensive management for soil and water conservation:* Implementing soil and water conservation measures is limited by many factors such as low farmer incomes, low productivity and the low standard of living in areas prone to soil erosion. In view of land resources, environment, and social characteristics, sustainable agriculture in the Plateau should be based on: rational land use, with self-sufficient grain production; building protective woodlands; increasing commercial fruit tree planting; and animal husbandry (Liu, 1999). Consequently, to be successful, soil and water conservation needs to be integrated within a comprehensive agricultural management system. Watershed-



Fig. 8. Rooftops for rainwater harvesting in the Loess Plateau.



*Fig. 9. Asphalt paved road for rainwater harvesting in the Loess Plateau.*

scale comprehensive management systems in the Loess Plateau are an example of integrated system of soil erosion control and sustainable agriculture development. The principle is to take the watershed as the basic unit to control soil erosion and develop agriculture. It consists of adjusting land use pattern, returning the steep sloping croplands to pasture and woodland for vegetation restoration, building terrace and dam lands as essential grain cropland for high and stable crop yields, and planting cash trees or developing animal husbandry for high economic benefits. Liu (1999) reported that farmers' incomes in the Ansai watershed increased 8-fold and thus soil erosion was reduced by over 70% after 20 years of watershed-scale comprehensive management.

### **Conclusions**

Though great achievements have been made in soil and water conservation in arid and semi-arid areas of China, many problems

still await effective solutions. Because of the complexities and component interactions in soil and water conservation systems, technical support is critical for efficient management. Most research so far has been highly descriptive or empirical. There is still insufficient experimental field evidence to answer many important questions related to soil and water conservation, such as overall planning of rational water use in the oases of arid zones; water balance in the vegetative sand stabilization areas; sand accumulation around the outer-edge palisades; silt origin in watersheds; water cycle characteristics in soil and water conservation systems, and the effects of soil and water conservation practices on regional water resources and land productivity. Moreover, soil and water conservation is also significantly affected by economic, political and social or cultural factors (Beatty, 1982), therefore, further research is needed to assess the ecological, social and economic impacts of soil and

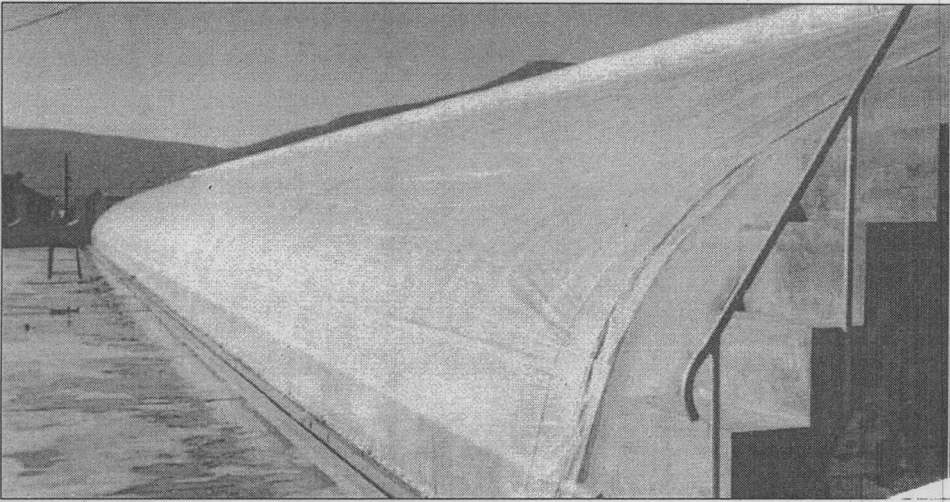


Fig.10. Plastic film covers on greenhouse for rainwater harvesting.

water conservation system from a plurality of perspectives in a wide range of different localities. Such studies may provide us a better understanding of the ecological adaptability, economic viability and social acceptability of the soil and water conservation systems.

Success in soil and water conservation often requires a combination of various measures, and it needs to be integrated within a comprehensive agricultural management system. In order to gain the potential ecological and economic benefits from soil and water conservation, policy and funding support are also necessary.

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