Jiji Grass

Achnatherum splendens

Its Effect on Soil Properties, and its Potential for Soil Erosion Control in Dry and Cold Areas

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Jiji Grass. Its Effect on Soil Properties, and its Potential for Soil Erosion Control in Dry and Cold Areas

Abstract. Studies showed that jiji grass (*Achnatherum splendens*) could improve multiple soil properties, including soil physical properties, nutrients, anti-scourability and anti-erodibility, shear strength, and permeability, with its massive root system. As a result, it can be used for soil erosion control, terrace and slope stabilization, and farm land protection in cold and dry area. However, its most valuable function is to stabilize the edges of eroded gullies and deep cuts and prevent further erosion. Before extension or application in large scale, more studies are needed especially on the propagation technology.

Key words: grass, soil/water conservation, slope stabilization, Loess Plateau.

Contents

Chapter 1.   Jiji Grass and its potential for soil erosion control

Introduction

Soil erosion is one of the main problems that influences the agricultural production and environment in China. To prevent it, people had adopted many engineering methods, such as constructing terraces, dams, etc. These methods are effective to prevent soil erosion, but much labor and investment are needed. Biological measures can and should provide an alternative. Generally, biological methods need less money, and are highly efficient in controlling soil erosion, improving and protecting the ecological environment. Vetiver grass (*Vetiveria zizanioides*) technology has been applied successfully in some areas of south China. Its function for soil and water conservation has been approved by many countries of the world (Liyu Xu, 1998). But many experiments and practices revealed that vetiver is difficult to adapt under the low temperature of north China. Experts of the World Bank and other specialists have noted that Jiji grass (*Achnatherum splendens*), a perennial grass in north China has some similar features of vetiver. Jiji grass can not only endure drought, salt and alkali, but also adapts to the low temperatures of north China. Experts found that the soil was completely conserved where the grass grew. These provided a good basis for the need to research the grass. Some experiments have been carried out. But more research and extension work remains to be done. The biological characteristics, applications, propagation technology of jiji grass and its application on the Loess Plateau are summarized in this paper.

1. Review on ecological characteristics and distribution of jiji grass

Jiji grass is a halophytic and xeric-mesic grass and has a dense clump. It is distributed widely since it can grow under various ecological conditions, including flood land, dry river valleys and other low lands. In these regions, the groundwater is usually between 1- 4 m. The grass' root could develop to a deeper soil layer even to the phreatic water. Hence, this might help it avoid the unfavorable condition of high salt in the topsoil (Pasturage and Veterrinary Department of Agricultural Ministry, China, 1996). Therefore some think the grass could be used as an indicator plant of high groundwater tables. But some do not think so. Narrow leaves and sunken stoma helps the grass reduce transpiration and endure drought (Baining Lang, et. al., 1983). It would be beneficial for it to grow on hilly slopes and other places where the groundwater levels are low. Jiji grass mainly grows on deep and thick salinized meadow soil or meadow salinized soil with light loam, medium loam or sandy loam textures, and some sand in the topsoil (Dong Wang, 1989). The phenological periods of Jiji grass are: germinating in May, flowering in July and seeding in August (Dong Wang, 1989).

Jiji grass can form a single community with closed clumps and covering large areas of continuous distribution. Sometimes its community forms a striped or inlayed distribution in other plant communities, or forms an alternate community with other plants, i.e. compound body. These variations are associated with soil salt, moisture and other factors (Pasturage and Veterrinary Department of Agricultural Ministry, China, 1996).

Jiji grass is mainly distributed in drought and semi-drought pastoral or semi agricultural and pastoral regions of Inner Mongolia, Gansu, Qinghai and Xinjiang. Besides, there are sporadic distributions in Heilongjiang, Ningxia, Jilin, Liaoning, Shaanxi and Shanxi. It grows on fallow lands, sides of farmland, ridges, steep slopes and sides of highway, etc. (Pasturage and Veterinary Department of Agricultural Ministry, China, 1996, Yongguang Lu, 1999, Guichen Chen, et. al., 1993).

2. Utilization

2.1 Soil and water conservation

Jiji grass has strong adaptability to diverse environments and a strong tolerance to salt, alkali, drought and cold. It has massive roots, huge bio-mass and a character of dead stems not easily to falingl off (Qingchun

Hou, 1999). All these characteristics are conducive for the reducion of runoff, conservation of topsoil and the reduction of wind erosion.

We often find natural tussocks of Jiji grass on the sides of highway, slopes, hills and other places in the Loess Plateau. The grass plays an important role in fixing sand, blocking mud, separating flow, preventing erosion of gully head, protecting embankments of highways and preventing slope slide, etc. Some sandy dune of 50-60 cm in height fixed by the grass clump at base can be found in the wind erosion regions. The clump of Jiji grass can also accumulate snow in winter. This is beneficial to increase soil moisture and for pasture development.

2.2 Forage

Jiji grass over winters well and germinats early in spring before other grasses start to grow. Thus, it provides good grazing for livestock from spring to autumn. Its tender leaves are palatable for animals especial for horses and camels. But when the grass is mature only the spikes are eaten. Jiji grass has high content of nutrition. According to the data of the Comprehensive Survey Team of Chinese Academy of Sciences, the nutrient content of Jiji grass in different growing periods is as follows (Comprehensive Survey Team of Inter Mongolia and Ningxia, 1985, Comprehensive Survey Team of Loess Plateau, 1991).

Table 1. Composition of jiji grass (mg/kg)

G.P.	M	C.P.	C.F.	C.F.A.	N.F.E.	C.A.	Ca	P	Carotin
tillering	6.57	26.62	3.91	22.85	33.55	6.50	0.23	0.35	92.85
jointing	10.74	18.53	4.25	28.86	29.67	7.95	0.36	0.57	44.65
flowering	12.55	14.28	1.92	46.82	18.37	6.06	0.29	0.29	41.42
fruiting	12.49	5.48	3.79	29.05	42.46	6.73	0.25	0.17	-----
withering	7.64	2.14	3.84	38.31	41.06	7.01	1.07	0.29	-----

G.P.= Growing periods, M= moisture, C.P.= crude protein, C.F.= crude fat, C.F.A= crude fabric, N.F.E.= nitrogen-free extract, C.A.= crude ash,

2.3 Other usage

Jiji grass can be used to make high quality paper paste, artificial silk, woven baskets, cages, curtains, brooms, etc. A company in Zhengzhou has a patent for the technique of making paper with Jiji grass. The grass stems can also be used for culturing edible fungus (Tingfu Guo, 1995, Comprehensive Survey Team of Loess Plateau, 1991).

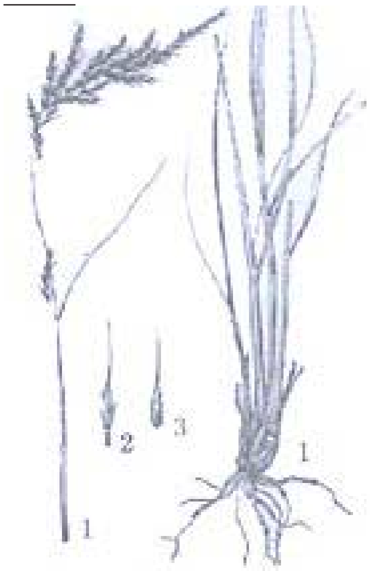
3. Propagation and cultivation techniques

3.1 Asexual reproduction

Jiji grass has strong tillering ability. Transplantation of the plant should be carried out in spring or autumn. In spring, the best time for transplanting is around the last ten-days of March and the first ten-days of April. At this time the plant does not start to sprout and the soil is just thawing. In autumn, it should be planted before the soil freezes. In order to improve seedling growth and survival rate, to decrease evaporation and nutrient consumption, the soil should be compacted and irrigated after transplanted (Jimin Cheng, 1998, Yongguang Lu, 1998).

3.2 Sexual reproduction

Seeds of Jiji grass should be harvested from August to September. They can be sowed while harvesting or sowed in the next Spring. Suitable sowing depth is about one finger thick (1-2cm). The best sowing time in summer is before or after rain, and completed by the first ten-days of July (Jimin Cheng,1998).



Achnatherum splendens.
Jiji Grass
1. plant 2. spike 3. seed

4. Current status of research and application

Due to the plant's unique characteristics including, height and toughness, massive root system and tolerance to salt, alkali, drought, cold, grazing and trampling, Jiji grass has been experimented for conserving soil and water. A project on the sowing and planting of Jiji grass hedgerows, financed by the World Bank, was conducted at Daqi, Inner Mongolia in 1992. Jiji grass was planted on the edges of terrace at Changtan town of Zhunqi in 1995 (Yongguang Lu, 1998). However, because of drought and lack of planting materials, these experiments were incomplete. Currently, research data realting to Jiji grass is still scarce.

With regard identifying varieties and the experiments on sowing and planting Jiji grass have been respectively carried out by Nanjing Institute of Botanical Science, Nanjing Institute of Soil science, and some units in Guangzhou. Because there was little knowledge about the transplanting and management technologies of Jiji grass, none of these experiments were successful.

Currently, there are some examples of applications of Jiji grass in north China. In wind erosion regions of Inner Mongolia, people purposefully planted Jiji grass along contours to stabilize dunes and reduce the damage caused by wind erosion. In mountainous areas Jiji grass has been planted to protect the embankment of roads. In some poor mountainous areas of Shanxi, farmers planted Jiji grass as protection for their "cave" dwellings.

General there has been little comprehensive research. Some articles indicated its function for erosion control, but most of them were based on field observations without detailed studies.

5. Need for research and application

Jiji grass is plentiful in China. Its total area reaches 220,000 ha. The distribution area in Inner Mongolia is the largest, with 180,000 ha accounting for 73 percent of the total (Yongguang Lu, 1998, Water Conservation Bureau of Shanxi, 1978). Jiji grass in north China is the equivalent to vetiver in south China for controlling erosion and other uses. Hence, research, use and protecting the grass resource are important tasks.

5.1 Detailed study on the mechanism of jiji grass for soil erosion control

Field surveys showed that jiji grass can prevent soil erosion, but how and why the grass plays this function is not clear. Therefore it is necessary to understand the effect of jiji grass in controlling soil erosion and its effect on other soil properties, including soil chemical, physical, and mechanical properties.

5.2 Ecological characteristics

Although there is information describing jiji grass' ecological characteristics, most of them are qualitative. More details are needed to determine the quantitative parameters, such as its tolerance to moisture, temperature, shade, salt, burning, etc.

5.3 Propagation

To use the grass for erosion control the most appropriate methods of propagation should be resolved. Although there was some description of the reproduction, there was no solid research back up. Field investigations showed that there was also very little knowledge available, if any, collected from farmers. There is a need to invetsigate how to multiply the plant and what factors influencing the multiplication, and how to plant and manage the grass in different ecological areas and under different usage.

5.4 Protecting the resources of wild Jiji grass

Jiji grass is a good herbage for large animals in spring and winter in north China. At present, most of the grassland is seriously degraded because of over grazing, some grasslands are close to extinction. Thus, there is a critical need to protect and use the grass resource properly.

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Chapter 2. Ecological Distribution and Utilization

The 'jiji' grass has a wide distribution in northern China with about 2.5 million hectares (Veterinarian Dept., 1996). It covers dry and semi-dry areas where it is used for grazing, semi-grazing, and semi-agricultural utilization. The grass is located in several provinces, mainly in northwest China, including Inner Mongolia, Gansu, Qinghai, Xinjiang, Shanxi, Shaanxi, Ninxia. The grass can be found in northeast China, such as Heilongjiang, Jilin, and Liaolin Provinces where precipitation is much higher than in the west.

Multiple investigations before and during the project showed that although Jiji grass has a wide distribution, it can generally be divided into three ecological zones, each of which has its own characteristic of utilization.

1 Meadow ecozone

In this ecozone the grass grows on the river plains, low flat land between hills, and low flat terrace. The land is characterized by a high ground water table (usually less than 2m) and high soil moisture. Sometimes the ground water appears at the soil surface and often contains salts due to the high evaporation. The roots of jiji can reach the ground water table where the soil has much less salts than surface soil. Most roots penetrate to about 40cm deep. The elevation is around 1000m above sea level. However it jiji can also be found on a large scale at much higher altitudes (over 3000m for example) in the far west region with less rainfall. The cation in the soil is dominated by Na+, followed by Mg2+.

An example site is Dongsheng City of Inner Mongolia. It has typical continental climate with 181 winter days from mid-October to next mid-April. It has mean January temperature from –10°C to –13°C, mean July temperature from 22°C to 23°C, and annual rainfall of 350-400mm. In this situation the grass covers 60-70% of the land surface with very few other associated species. Due to over grazing the pasture has been degraded with clumps of about 50cm high and flowering stems of 100-120cm high. However, in the past the grasses were very tall to the extent that it could hide cattle and horses as described in poetry and by early western explorers to Mongolia. The ground water in this ecozone is around 150cm below the soil surface, and occasionally at the ground surface. The saline meadow soil was derived from alluvial material that contains carbonate. However Cl accounts for over 70% of the total anions. On the soil surface there is usually a salt crust of about 0.5-2 cm thick which contains 58% salt (Table 2-1). The surface soil horizon of 10-25 cm thick under the crust usually has a salt content of from 0.08 to 53.00% depending on the micro-landform. Deeper soil contains little salts (the deeper, the less). From soil properties we can see that jiji grass is tolerant to salts and can grow well at pH 9 or even higher. In this ecozone the grass is self propagating and spreads by seeds because the surface soil is always wet and contains much moisture and results in large pastures which are very important for livestock grazing, especially in the early spring and winter when other grasses are not available (Photo 1, see Appendix 1). However due to over grazing the grass no longer covers the whole land surface as it did many years ago. Farmers use the stems of the grass to manufacture brooms (Photo 3, see Appendix 1) in large quantities for marketing. In another instance a company was established to plant jiji for pulp production.

Table 2-1. Soil properties in meadow ecozone

Depth(cm)	Texture	pH(water)	O.M.(g/kg)	T-N(g/kg)	T-P (g/kg)	S-P (mg/kg)	S-K(mg/kg)	T-salt (%)
S- crust	clay	9.1	15.6	0.34	1.46	31	1.55	58.00
0~5	loam	8.2	9.7	0.38	1.52	26	1.70	6.40
5~20	h-loam	8.4	16.0	0.39	1.44	2	0.186	3.48
20~50	h-loam	8.3	4.3	0.23	1.22	2	1.86	1.39
50~100	l-loam	8.4	5.0	0.27	1.16	2	1.90	0.74
100~150	h-loam	8.0	6.1	0.42	1.47	2	1.99	0.60

S- crust = salt crust, h-loam = heavy loam, l-loam = light loam, O.M. = organic matter,
T- = Total, S- = soluble, K= K2O, P= P2O5

2 Semi-desert ecozone

In this zone the grass grows on chestnut soil, light chestnut soil (the chestnut soil which contains even less moisture and organic matter), or brown soils (this soil is situated in areas that are drier than the chestnut soil areas) on the undulating landform. Under more arid conditions, or because the ground water table is too low (ens of meters or more below surface), the soil contains little moisture and usually contains some stone, possibly because fine particles were blown off by strong wind erosion. The parent materials can be loess or residual materials. The jiji grass is thinly distributed on the land in company with other drought and salt tolerance plants. The field investigation showed that jiji grass can grow on unproductive land where the grass is around 60 cm high, the flowering stems are hard and erect even in the winter, and thus can reduce wind speed and relieve wind erosion (Photo 2, Appendix 1).

At a typical site at Lanzhou of Gansu province. The mean annual temperature is 3-4°C. The lowest temperature in the winter was –7 – -12°C (the absolute minimum temperature reached –33.7°C). The highest temperature in the summer was 34°C. Annual rainfall was around 350mm of which about 50-70% was in the summer.
Due to little rainfall and high evaporation the leaching in the soil has been limited and the soil is base saturated with a pH 8 or higher, and contains little organic matter (Table 2-2). The soil also contains gypsum of about 10 - 20g/kg. The key problem in this ecozone is desertification. Therefore the limited cover of jiji grass is valuable for desertification control and for prevention of dune movement. Once the grass is removed it is very difficult to re-establish and desertification would be more serious which may change the semi-desert into desert. In addition to grazing, farmers in this zone also use the flowering stem to make broom and other small items for their own use. In this ecozone the grass also reproduces naturally from seeds. But because the soil has little moisture it is does not spread easily. Furthermore, due to human activities the grass has been degraded.

Table 2-2 . Soil properties in Semi-desert ecozone

Depth(cm)	O.M.(g /kg)	T- N(g/kg)	T- P(g/kg)	T- (g/kg)	S- K(mg/kg)	S- P(mg/kg)	pH(water)	CEC(mmol/100g soil)
0-20	17.6	0.94	0.60	17.1	100	9.6	7.7	17.15
20-40	8.1	0.49	0.57	16.3	95	5.2	8.5	18.46
40-80	4.0	0.28	0.64	17.4	107	1.3	8.6	15.15
80-120	3.1	0.24	0.68	17.4	130	0.3	8.9	10.6

O.M. = organic matter, T- = Total, S- = soluble, K= K2O, P= P2O5

3 Serious eroded gully zone

Loess plateau is a large plateau with 626,800 km^2 covered by loess up to 120 meter thick and is the most seriously eroded area in China, and possibly in the world. The soil contains carbonate (10%) and as much as 53-58% silty particles (0.02-0.002mm), as a result steep slopes are subject to collapse during the rainy season. Numerous gullies are formed over most of the plateau. Often villages are divided in two by a deep gully and it may take several hours walking from one part to the other. Although there are some species of plants which can grow in these areas, none of them can match jiji grass in stabilizing the gullies and preventing further erosion. Several field investigations in Shanxi, Shaanxi, Inner Mongolia and Ningxia provinces proved that jiji grass grows well on the edges of the these gullies, where the soil contains less moisture, higher porosity (capillary porosity in particular), and lower bulk density (Table 2-3). In this ecozone the grass has extremely long and strong root systems. Once the grass is established the soil can never be washed away by runoff. Photos showed that few tillers of the grass fixed a small loess mound, over 1 m high. This means that 1m depth of soil arond the clump had been eroded away (Photo 4, Appendix 1). It also grows on the top of earth and stone walls (Photo 8, Appendix 2; Photo 9, Appendix 3).

Table 2-3. Some soil characteristics on different micro-landform

Location	Soil moisture	Bulk density (g/cm3)	Total porosity (%)	Capillary porosity (%)	Non-capillary porosity (%)
Steep	6.52%	1.04	60.75%	40.58%	20.17%
slope		1.48	44.21%	32.56%	11.65%
		1.29	51.15%	35.13%	16.02%
Flat	15.69%	1.25	52.97%	30.58%	23.39%
		1.31	50.62%	26.49%	24.13%
Wall top	5.61%	1.36	48.51%	36.76%	11.75%

An example site is Yanbai of Shanxi Province that has an elevation of 1500-1800m above sea level with annual temperature for 6-10ºC and annual rainfall for 300-500mm. The soil is derived from loess which is many meters deep and subject to haevy erosion. The soil contains carbonate for around 180g/kg, and organic matter of over 6g/kg. It has a pH value of 8.6 or over (Table 2-4). Compared with flat land the jiji grass on the steep slopes of the eroded gully has much deeper root system, 2m for example (Photo 5, Appendix 2), in order to absorb moisture in deep soil horizons. As a result, jiji grass grows even better than on the flat land. This forms a peculiar function of jiji grass because most plants grow well on flat land where soil contains more nutrients and moisture. As a result of this characteristic, the steep slope was well stabilized and further erosion was prevented. Based on this feature the emphasis of present research was placed on the seriously eroded gully zone in order to seek a effective measure to stabilize the eroded gullies from further extension and to control soil erosion on the Loess Plateau.

Table 2-4. The soil properties on eroded gully area

Depth(cm)	O.M.(g /kg)	T- N(g/kg)	T- P(g/kg)	T- K(g/kg)	S- K(mg/kg)	S- P(mg/kg)	pH(water)	CEC(mmol/100g soil)
0-20	7.7	0.47	1.36	21.9	40	2.65	8.66	7.13
20-40	6.6	0.41	1.29	21.6	40	2.58	8.74	7.13
40-60	6.8	0.41	1.30	21.3	38	2.24	8.77	7.18
60-	6.9	0.42	1.30	21.2	36	2.28`	8.79	7.13

O.M. = organic matter, T- = Total, S- = soluble, K= K2O, P= P2O5

In this ecozone farmers use the grass to make brooms, curtains, sieves, baskets, and other small items. Besides, they use the grass to stabilize and dry their house (Photo 6, Appendix 2), and stabilize home gardens when situated on small pieces of higher land. Jiji grass was always found in the old villages where the houses were situated on the small high areas with steep slopes, possibly propagated by farmers when they used jiji brooms to clear their yards and the seeds from the broom heads germinated at the edges of yards (Photo 7, Appendix 2).

4 Ecological tolerance

Based on multiple field investigations in that region which covered several provinces and in combination with laboratory analysis, jiji grass can tolerate cold (<-33ºC) and hot (> 38ºC) climate. It is also drough-tolerant. For example it can even grow on earth walls in the dry area (Photo 8, Appendix 2). The annual rainfall changes from 500 mm to 200 mm, from east to west of the country. Additionally, it is tolerant to saline soil containing 50% or more salt. In such areas jiji is wet-tolerant and the salt containing water may appear on the ground surface. The grass is barren soil tolerant and can grow on stone walls with very little nutrients (Photo 9, Appendix 3). Although the grass is a light demander, it grew even better under tree shade possibly because the soil there had a little more moisture (Photo 10, Appendix 3). The most extraordinary property was that it was grew well on the edges of deeply eroded gullies or steep slopes where the soil had little moisture and higher capillary porosity (Photo 11, 12, Appendix 3). Like vetiver, jiji can withstand fire. It may grow better after burning (Photo 13, Appendix 3). Although part of the old grass, the central part in particular, may wilt, the clumps can stand several decades. Even if the clump looks almost dead, the soil mound remained stable (Photo

14, Appendix 3). However, several tests showed that the grass can hardly grow on acid (< pH 7.0) soil with a humid climate as in Nanjing (south China). When it was transplanted in Nanjing it died. However the young plants produced from seeds grew well in Nanjing during the first few weeks. Although it can stand animal grazing, long term over grazing may cause the grass to degenerate.

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Chapter 3. Effect of jiji grass on soil physical properties

As a measure to control soil erosion, plants when planted on the ground surface reduce the dynamic energy of rain drop impact, stop eroded sediments in situ, and improves soil properties that are beneficial to erosion control. For example plants can improve soil structure and porosity, and reduce soil dispersion, suspension, and displacement. Additionally, the induced improvement of soil physical properties by plant roots is advantageous to water permeating into the soil and the reduction of runoff. The roots of the plant, strong rooted grasses in particular, can combine soil material together as a whole against erosion.

Therefore soil physics is regarded as one of the important aspects for soil erosion control. Unfortunately there is little, if any, information available so far. This chapter studies the effect of jiji grass on the soil physical properties.

1 Materials and method

We studied the effect of jiji grass on soil physical properties, with with natural grasses and with Korshinsk Pea shrub (*Caragana korshinskii*) (the commonly grown and acceptable shrub for erosion control by local people), as controls. Both jiji grass and Korshinsk Pea shrub were around 10 years old. All the soils were derived from loess and at the same location.

Cutting rings were used to collect soil sample to determine bulk density, capillary porosity, non-capillary porosity, and the maximum water-holding capacity in capillary pores (Institute of Soil Science, Chinese Academy of Sciences, 1978).

2 Results and analysis

2.1 Effect of Jiji grass on soil porosity

Water-holding capacity of the soil directly influences food production and ground surface runoff. Soil water-holding capacity mainly depends on soil porosity condition. When rainfall penetrates into the soil through pores the soil moisture is improved and runoff which usually causes soil erosion is reduced. The roost of the plant can penetrate, devide, squeeze, and aggregate soil profiles and thereby improve soil structure and related porosity through its physical, chemical, and biological (including soil animals and micro-organ) functions.

The capillary pores, created by fine roots not only improve soil water retention, but also holds water within the soil profile for longer periods. However, the non-capillary pores only permit water to flow into the soil and then move downwards under gravity to ground water. These pores also reduce runoff, relieve or delay peak flooding during the heavy rains, and reduce flooding disaster. In addition they increase water flow in the rivers during dry season via enhanced groundwater and spring line discharge.

Different plants have different root systems and lead to certain porosity status. Because jiji grass has a strong and long root system consisting of numerous fine roots, the soil porosity is improved considerably.

Table 3-1. Effect of jiji roots on soil porosity

Treatment	Total porosity(%)			Capillary porosity(%)			Non-capillary porosity(%)		
	0-20cm	20-40cm	40-60cm	0-20cm	20-40cm	40-60cm	0-20cm	20-40cm	40-60cm
Jiji	53.04	58.01	57.10	45.35	44.50	45.10	7.69	13.51	12.00
K.P.	56.30	58.34	54.29	48.30	47.01	44.91	8.00	11.33	9.38
N.G.	52.91	51.00	44.85	44.32	42.80	42.30	5.59	6.20	5.55

K.P. = Korshinsk Peashrub, N.G. = land scattered with natural grasses

Table 3-1 indicates that the total porosity of the soil supporting jiji grass increased by 0.24%, 13.74%, and 27.31% at 0-20cm, 20-40cm, and 40-60cm depth respectively compared with the land scattered with natural grasses in the soil . The capillary porosity was increased by 2.32%, 3.98%, 6.62% compared with Korshinsk Pea shrub soil. Both total porosity and capillary porosity of jiji soil at the depth of 40-60cm are also higher, because jiji grass has much deeper root system and therefore improved deep soil properties. Regarding to non-capillary porosity, the jiji soil at almost all soil horizons is higher than both N.G. and K.P., except for the horizon of 0-20cm where the jiji soil has less porosity than the shrub. This is because jiji grass had much more deep roots, fine roots in particular.

2.2 Effect of jiji root on soil bulk density

Soil bulk density was effected by soil porosity. Strong root systems cause more porosity and therefore lower bulk density. Table 3-2 showed that the bulk density of jiji soil was mostly lower than other the other two treatments. Furthermore, there was little difference with soil depth because jiji grass has deeper fiber roots. For the soil with Korshinsk Pea shrub the bulk density was all lower than N.G. in 0-20 cm, 20-40 cm, and 40-60 cm. The lowest figure was at 0-20 cm. It indicates that Korshinsk Pea shrub roots effected the bulk density the most in the upper soil horizons.

Table 3-2. Effect of jiji root on soil bulk density (g/cm3)

Treatment	Soil depth (cm)		
	0-20	20-40	40-60
Jiji grass	1.16	1.12	1.14
Korshinsk Peashrub	1.15	1.13	1.21
N.G.	1.25	1.23	1.26

N.G. = land scattered with natural grasses

2.3 Effect of Jiji grass on soil water content

Table 3-3 recorded mean soil water content in May 2000 in the three treatments. There was only 7 mm rainfall in May and soil contained little water. Generally the lower soil horizon had greater water content. A tendency was that jiji soil had much more water than the shrub and N.G (natural grass soil). Compared with N.G., jiji soil had 75.86%, 50.66% and 27.80% more water in 0-20 cm, 20-40 cm, 40-60 cm respectively because of jiji grass a had strong root system and well developed capillary pores which enhanced water penatration into deeper soil in the rainy season and maintained moisture during the dry season. Even in dry season the soil still contained certain moisture which may support food crops if jiji was planted as hedges.

Table 3-3. Effect of jiji on soil water content (%)

Treatment	Soil depth (cm)		
	0-20	**20-40**	**40-60**
Jiji grass	6.63	7.88	7.63
Korshinsk Peashrub	4.47	5.84	5.62
N.G.	3.77	5.23	5.97

N.G. = land scattered with natural grasses

Micro-physiological feature observations showed many parallel micro grooves on the leaf surface of jiji grass. When temperature is high and evaporation is strong the leaves curled automatically to prevent further water loss (Photo 15, 16, Appendix 4). This feature indicated that jiji can adapt itself to both wet and dry environment. Thus we find jiji grass on wet land with ground water at the surface, and also on the top of earth or stone walls where soil moisture was extremely limited.

Table 3-4 indicated that both jiji soil and the shrub soil had greater maximum capillary water-holding capacity than N.G. At 40-60cm jiji soil had much higher maximum capillary water-holding capacity than the other two treatments, probably because jiji had strong deeper <1 mm roots which improved the soil property in the deeper horizons. Compared with N.G., maximum capillary water-holding capacity in jiji soil increased by 10.04%, 14.70%, 15.10% respectively in the 0-20 cm, 20-40 cm, and 40-60 cm horizons. It means that jiji grass can play an important role in soil water maintenance.

Table 3-4. Effect of jiji grass on maximum capillary water-holding capacity (%)

Treatment	Soil depth (cm)		
	0-20	**20-40**	**40-60**
Jjji grass	33.08	34.25	34.00
Korshinsk Peashrub	33.83	33.95	30.61
N.G.	30.06	29.86	29.54

N.G. = land scattered with natural grasses

3 Conclusion

Based on the data and discussion, it is concluded that since jiji grass had massive roots, <1 mm roots in particular, the soil pores, including capillary pores and non-capillary pores, were improved greatly which decreased soil bulk density that enabled the soil to have a higher capacity for water retention, reducing runoff, increasing water penetrationl. All of these indicated that jiji grass has great potential for soil and water conservation, soil physical property improvement, and crop production in Loess Plateau area.

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Chapter 4. Effect of jiji grass on soil nutrients

60% of the Loess Plateau area has hilly lands withy slopes over 15 º (Wenzhi Yang, 1992), and is characterized by serious soil erosion caused by over utilization, and high silt and carbonate content of the soil. The erosion has led to low agricultural productivity and a decline in soil fertility. Therefore, to control erosion, the maintainance and improvement of soil fertility becomes very important. It is expected that jiji grass when planted on the sloping farmland as hedges, or on the edges of terraces will stabilize the land and improve soil fertility, as it does vetiver in the tropics.

1 Methods

Asoil profile, 1m wide and 1.5m deep, was prepared on sloping land covered by jiji grass that was planted 10 years ago. The soil was divided into several horizons, each 20cm deep. Soil samples were collected for laboratory analysis. The items analyzed included organic matter (O.M.), total nitrogen, total phosphorous, total potassium, and available P, K, pH, and cation exchange capacity (CEC).

2 Results and discussion

Soil fertility decline is due mainly to the loss of silt (0.02-0.002 mm in diameter) and clay particles (less than 0.002 mm) (Yuancun Shen, 1998). If jiji grass can effectively control soil erosion and prevent these particles from washing away, soil fertility should be improved.

2.1 Effect of jiji grass on soil organic matter

Figure 4-1 showed that the jiji grass land had more organic matter than the land without jiji at all soil horizons from surface to 60cm and deeper. Also there is very little difference in organic matter throughout the whole soil profile treated with jiji grass. This is because the grass produced high leaf and stem biomass and large amounts of roots in the deeper soil, both of which effected organic matter content of surface soil and deep soil.

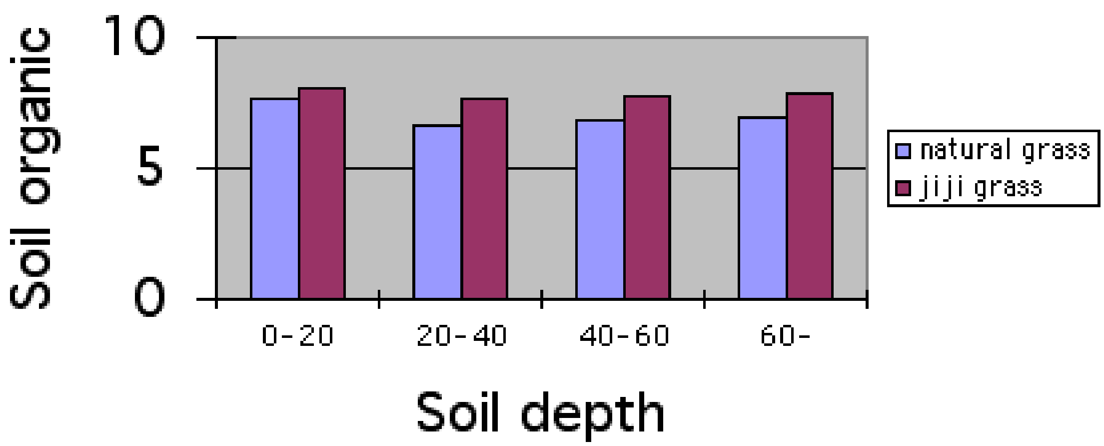

Figure 4-1 Effect of Jiji Grass on total soil Nitrogen

2.2 Effect of jiji grass on soil total nitrogen

It is clear that jiji grass increased soil total nitrogen through out the whole soil profile compared with the soil without jiji grass (Table 4-1). However, at 0-20cm it increased only a little, whilst the increment in deeper soils is more. This is possibly due to dead roots and soil animal activites. However, due to less moisture and strong aerobic decomposition, organic matter does not accumulate in large amounts.

Table 4-1. Effect of jiji grass on soil total nitrogen

Soil depth (cm)	Soil total nitrogen (g/kg)	
	Natural grass	Jiji grass
0-20	0.47	0.48
20-40	0.41	0.45
40-60	0.41	0.47
60-	0.42	0.46

2.3 Effect of jiji grass on soil phosphorous

Generally jiji grass increased both total phosphorous and available phosphoroius throughout the soil profile. However it significantly increased available phosphorous more (Table 4-2), i.e. increased by 0.53mg/kg (a 20.0% increase), 0.96mg/kg (37,2%), 0.94mg/kg (42%), 1.02mg/kg (44.7%) in the soil at 0-20 cm, 20-40 cm, 40-60 cm, and below 60 cm respectively. The same trend happened with nitrogen, i.e. higher levels at deeper depths.

Table 4-2. Effect of jiji grass on soil phosphorous

Soil depth (cm)	soil phosphorous (P2O5) (g/kg)		available phosphorous (P2O5) (mg/kg)	
	Natural grass	Jiji grass	Natural grass	Jiji grass
0-20cm	1.36	1.36	2.65	3.18
20-40cn	1.29	1.34	2.58	3.54
40-60cm	1.30	1.33	2.24	3.18
60-	1.30	1.38	2.28	3.30

2.4 Effect of jiji grass on soil potassium

The total potassium is higher than the control at the deeper soil horizons, 40-60 cm and below 60 cm (Table 4-3). It is even higher for available potassium. From top horizon to the bottom it is increase by 33 mg/kg (82.0% increase), 11 mg/kg (27.5%), 10 mg/kg (26.3%), and 7 mg/kg (19.4%) respectively. On the contrary, not like N or P, the potassium in the top horizon increased the most, probably due to biological accumulation of jiji grass leaves and stems.

Table 4-3. Effect of jiji grass on soil potassium

Soil depth (cm)	Soil total potassium (K2O) (g/kg)		Available potassium (K2O) (mg/kg)	
	Natural grass	Jiji grass	Natural grass	Jiji grass
0-20cm	2.19	2.19	40	73
20-40cn	2.16	2.15	40	51
40-60cm	2.13	2.17	38	48
60-	2.12	2.19	36	43

2.5 Effect of jiji grass on soil pH and cation exchange capacity (CEC)

Table 4-4 showed that pH value (determined by water) is increased from the top to bottom in the control soil, while it decreased in the jiji soil. All pH values in jiji soil are lower than the control. This indicates that jiji grass decreased soil pH in general. The deeper the soil, the lower the pH values.

Regarding CEC, all the values of jiji soil are higher than the control notably, i.e. the increase of 0.60, 0.63, 0.68, and 0.21 mmol/100g soil were found respectively in the soil of 0-20, 20-40, 40-60, and below 60 cm. It means that jiji grass can increase soil CEC. CEC relates normally to clay content and humic acid and is considered one of the factors that determines soil fertility.

Table 4-4. Effect of jiji grass on soil pH and cation exchange capacity (CEC)

Soil depth (cm)	pH		CEC(mmol/100g soil)	
	Natural grass	Jiji grass	Natural grass	Jiji grass
0-20	8.66	8.62	7.13	7.73
20-40	8.74	8.60	7.13	7.76
40-60	8.77	8.54	7.18	7.86
60-	8.79	8.50	7.13	7.34

3 Conclusion

From the data and analysis above we find that because jiji grass has strong fibrous roots the soil nutrient properties and soil fertility were improved including organic matter, nitrogen, phosphors, potassium, pH value, and cation exchange capacity. Meanwhile, the change should be useful for the improvement of other soil properties (soil physical and mechanical properties for example) related to soil erosion control, slope stabilization, and food production.

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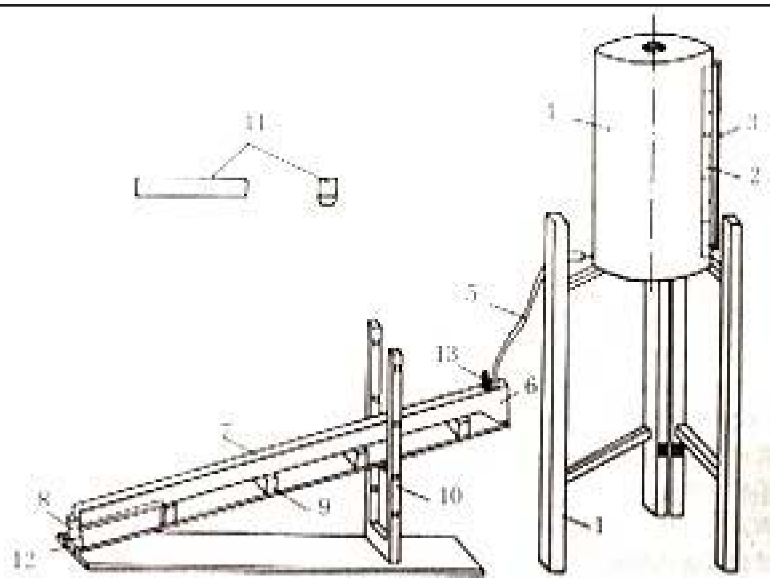
Chapter 5. Effect of jiji grass on soil anti-erodibility

As early as in 1960s Xianmo Zhu divided anti-erobility into anti-scourability and anti-erodibility, and defined them as: anti-erodibilty being the capacity that prevents soil from dispersing and suspending in situ; anti-scourability being the capacity that prevents mechanical destruction and soil movement downwards under runoff (Peihua Zhou and Chunlong Wu, 1993). The former depends on the affinity between the soil particle and water, and relates to soil physical and chemical properties. The latter depends on the cementation of soil particles including mini-particles. Indeed, the two characteristics mainly differed from laboratory determination: the former was determined under static water, while the latter used running water. They all reflect the ability of soil to counter erosion. Grass roots can fix and bind soil particles against erosion, which depended on different kinds of plants and their rooting pattern. The Dutch grassed clay dikes to prevent erosion by breaking waves (Krystian w.pilarczyk, 1998).

1 Materials and method

This chapter studies (1) the rooting feature of jiji grass and Korshinsk Pea shrub using the profile wall method (Yong Li and Xiaoqing Xu, 1992): A soil profile of 1.5 m long and 1 m deep was prepared on both jiji grass land and the land with Korshinsk Pea shrub. Each 20 cm of depth was deemed a horizon. The root density was observed and recorded. (2) Undisturbed soil in different horizons (0-20 cm, 20-40 cm, 40-60 cm) was collected respectively with a special sample collector and put into a trough measuring 4 cm wide, 3cm deep, and 60cm long to study anti-scourability (Figure 5-1) based on Dingsheng Jiang (1997). The soil from the land of Korshinsk Pea shrub was used as a control.

Fig.5-1, Device designed for anti-scourability determination



1. Support; 2. Scale; 3. Glass tube; 4. Water tank; 5. Soft tube; 6. Static water container; 7. Washing trough; 8. Soil sample container; 9. Wood blocks; 10. Slope adjuster; 11. Sample collector, 12.Hinge; 13. Water flow adjuster.

Slopes of 15 and 25 degrees that are common to the Loess Plateau, were designed and a rainfall rate of 20 mm/min was referenced to determine water flow speed and amount. A total amount of water of 1000 mm was used to flow over the soil sample within an 8 and 10 minute period respectively, depending on the degree of slope. The anti-scourability was measure as eroded soil (oven soil, g) under 1000 ml water. (3) To study anti-erodibilty, 30 smooth air-dried soil blocks with diameter of 0.5 - 0.7 cm were placed on a metal sieve with an aperture of 5mm, and then put under static water and the dispersed blocks were observed every 10 minutes in 1 hour. The anti-erodibilty index was obtained from: total non-dispersed block numbers/total block numbers.

2 Results and discussion

2.1 Root density of jiji grass

The white root of jiji grass is covered by brown chesive skin. The whole soil profile was dominated by numerous fiberous roots of less than 1 mm in diameter. Most of the roots (70%) were distributed in the soil between 0-40 cm, but there was also considerable numbers of roots below 40 cm. (Table 5-1). In some places the roots extended to 2 m or more.

All the roots were divided into two groups: roots of less than 1 mm in diameter and those over 1 mm, <1 mm roots accounted for over 90% of the total. In the soil horizons of 0-20 cm, 20-40 cm, and 40-60 cm the average jiji roots of less than 1 mm accounted for 4173.5, 2588.6, and 1890.2 roots/m2 respectively (Table 5-1), while the roots of less than 1 mm of Korshinsk Pea shrub soil were only 1798.8, 2005.8, and 594.7 roots/m2 in the 3 soil horizons from top to the bottom respectively (Table 5-2). It was obvious that jiji grass soil had denser root distribution than Korshinsk Pea shrub in almost all soil horizons, especially <1 mm roots, and therefore the jiji soil was better stabilized by the root system and might be subject to minimium erosion, as Yong Li (1993) indicated that there is a close relationship between root density and soil penetrability, anti-erodibilty, etc.

In the field we can easily find limited Korshinsk Pea shrub coarse roots (>2 mm) in the soil profile, instead of fine roots.

Table 5-1. Distribution of jiji grass in the soil profile (roots/m2)

Profile No.	0-20 cm		20-40 cm		40-60 cm	
	>1 mm	<1 mm	>1 mm	<1 mm	>1 mm	<1 mm
1	295.2	3541.9	147.6	2597.4	147.6	2125.1
2	383.7	2804.0	118.1	2420.3	29.5	2156.9
3	147.6	6139.3	147.6	3378.0	78.6	2305.8
4	324.7	6139.3	88.5	3307.8	59.0	1889.0
5	118.1	2243.2	132.5	1239.7	64.4	974.1
Average	218.4	4173.5	126.9	2588.6	75.8	1890.2

Table 5-2. Distribution of Roots of Korshinsk Peashrub (roots/m2)

Profile No.	0-20 cm		20-40 cm		40-60 cm	
	>1 mm	<1 mm	>1 mm	<1 mm	>1 mm	<1 mm
1	118.1	1305.8	206.6	1161.3	188.5	295.2
2	103.6	1541.9	108.5	1997.4	110.7	538.3
3	121.4	2136.5	136.2	2210.4	89.2	210.3
4	89.1	1325.6	91.2	1414.5	69.8	986.5
5	145.3	2684.3	132.5	3245.5	98.4	943.1
Average	115.5	1798.8	135.0	2005.8	113.3	594.7

2.2 Effect of jiji grass on soil Anti-scourability

Table 5-3 shows the effect of jiji grass on soil anti-scourability on 15 degree and 25 degree slopes respectively, compared with the natural grass and Korshinsk Pea shrub soils. It shows that the soil in the deeper horizons lost more during washing because there were less roots in the deeper horizon in general. For example the jiji soil of 40-60 cm horizon lost 95.10g/L, whereas the soil of 0-20 cm horizon was lost only 9.88 g/L. Also, the natural grass land soil lost the most among the three treatments in 20-60 cm, while the top soil was washed less than Korshinsk Pea shrub. It means that both jiji grass and Korshinsk Pea shrub had the capacity to prevent soil washing especially in 20-60 cm.

For the treatment on the slope of 25 degree, the soil loss in all the horizons of jiji land was less than Korshinsk Pea shrub land and the natural grass land. One thing that was not expected was that the top horizon of Korshinsk Pea shrub lost more soil during the washing than both jiji soil and natural grassland, possibly because Korshinsk Pea shrub had a lower root density, both coarse roots and fine roots. It contains some coarse lignification roots in the top horizon. All the data indicated that jiji grass has great potential in anti-scourability of the soil.

Table 5-3. Anti-scourability of soils with and without jiji grass (g/L)

Plant type	15° slope			25° slope		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
Jiji grass	9.88	93.24	95.10	18.18	71.69	115.23
Natural grass	11.70	103.30	156.43	19.38	211.12	220.60
Korshinsk Peashrub	13.57	91.49	77.22	37.41	104.24	116.47

2.3 Effect of jiji grass on anti-erodibility

Anti-erodibility is used to indicate the capacity of soil against dispersing and suspending in static water. If soil aggregates had high affinity for water, it would be easily dispersed and suspended in water, and therefore have a low anti-erodibility. The grass root can increase soil organic matter and promote related chemical and biological activities, and hence increase soil aggregation. In addition, the numerous fine roots combine soil particles together and produced obstruction against water dispersal. Table 5-4 showed anti-erodibility of three treatments. It indicates that the anti-erodibility of all treatments decreased from top to bottom significantly. Anti-erodibility of jiji grass was similar to that of Korshinsk Pea shrub, except for the top horizon where anti-erodibility of jiji grass was much higher than Korshinsk Pea shrub possibly because jiji grass had more fine roots than Korshinsk Peashrub. However, it is clear that anti-erodibility in both jiji grass land and Korshinsk Pea shrub land were much higher than natural grass. For example, the anti-erodibility of jiji grass at 0-20 cm and 20-40 cm was 2.78 and 2.66 times of the natural grass. If we compare table 5-4 with table 5-1 and table 5-2, and also Fig. 4-1, we can find the anti-erodibility is not a simply match with root investigation or soil organic matter content. It is possibly caused by not only grass-related chemical and physical properties, but also biological processes including soil animals, soil biota, and micro-organism.

Table 5-4. Anti-erodibilty of soils with and without Jiji grass (ratio)

Plant type	Soil depth		
	0-20 cm	20-40 cm	40-60 cm
Jiji grass	0.901	0.745	0.325
Korshinsk Peashrub	0.833	0.748	0.344
Natural grass	0.324	0.280	0.224

3 Conclusion

Jiji grass had higher root density and higher anti-scourability and anti-erodibility. All of these results are related to plant physical features, root system in particular, and related chemical, physical, and biological properties. The results indicated that jiji grass has high potential in soil erosion control and slope stabilization.

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Chapter 6. Effect of jiji grass on soil shear strength

Soil shear strength is one of the parameters reflecting soil mechanics. It shows the level that soil is subject to outside mechanical forces including soil erosion and land slippage. Therefore it is considered an important maesurement for civil constructions and water conservation.

In the recent years scientists studied soil erodibility with soil strength and studied the relation between soil shear strength and rainfall drops. The relation was described as following formula:

$$S = a + b (E / t)$$

Where:
S = Splashing loss, expressed as soil loss (g) per unit rain drop
E = dynamic energy, expressed as J (joule)
t = shear strength (kPa)
a, b = experienced parameters

Hansbo Poesen determined soil shear strength with PILCON (cross plate shearing device), and found that there was a close relation between splashing loss and soil strength (Luk, S.H., Et al, 1990). Ekanayake, Phillips, and Marden (1999) studied the ideal shear stress: displacement curves for soils with and without roots and expressed a high difference between two treatments. Hengchaovanich studied root-permeated and root-free soil shear strength and found that vetiver grass offered better shear strength increase per unit fiber concentration compared to soil for tree roots. (Hengchaovanich, 1998).

This paper studies the effect of jiji grass on loess soil shear strength and its relation with root density and soil moisture in order to discover why jiji grass has an effective function for erosion control and slope stabilization as found in the comprehensive field observations.

1 Natural condition of test area

The test area was located at Lishi City of Shanxi Province (37ºN, 110ºE). It has a continental climate with cold and dry winters and hot summers. The spring is dry and windy. It has a mean annual temperature of 8.8ºC, and sun shine for 2592 h. The mean annual rain fall was 492.5 mm (1953-1994), with frost-free for 160-180 days. Most of rainfall was concentrated in few months, or even few days.

2 Materials and method

Based on the field investigation on soil and root of jiji grass and Korshinsk Pea shrub, shear strength of soils with and without jiji grass was determined in situ with cross plate shearing device PILCON (made in England). The root density at the specific profile horizons, where shear strength was determined, was recorded. Relationship between shear strength and soil water content was illustrated.

3 Results and discussion

Figure 6-1 showed that there was a high shear strength for jiji grass in the top 2 horizons from 0-20 cm and 20-40cm. It means that jiji grass increased shear strength dramatically in the upper soil. But at depths below 40cm (or 50cm) for example, the shear strength for natural grass increased dramatically, possibly caused by soil water moisture, i.e. the deeper soil of natural grass had less moisture, while the jiji soil permitted water penetration into deeper soil through its long roots. Figure 6-2 Showed that there was a inverse correlation between shear strength and soil moisture. The less water, the higher shear strength.

Figure 6.1 Effect of jiji grass on soil shear strength

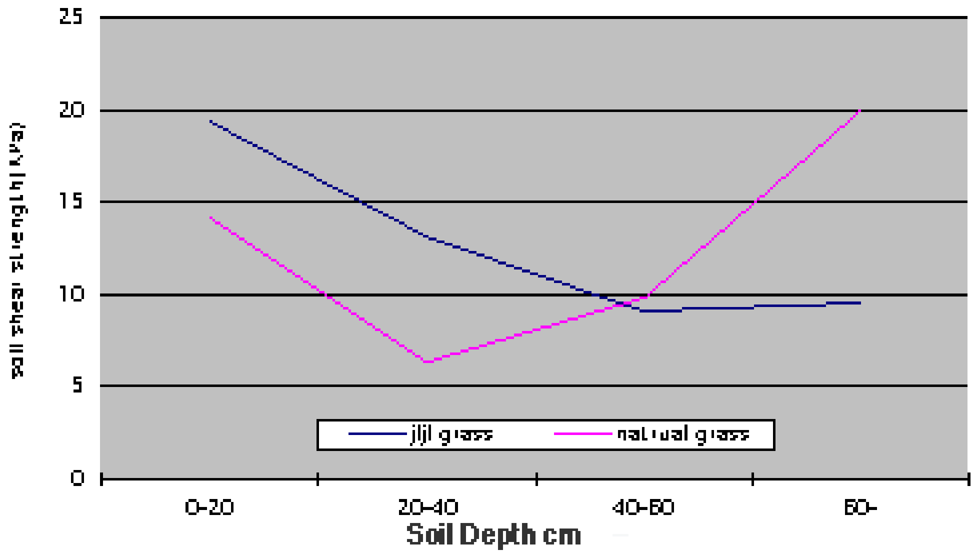
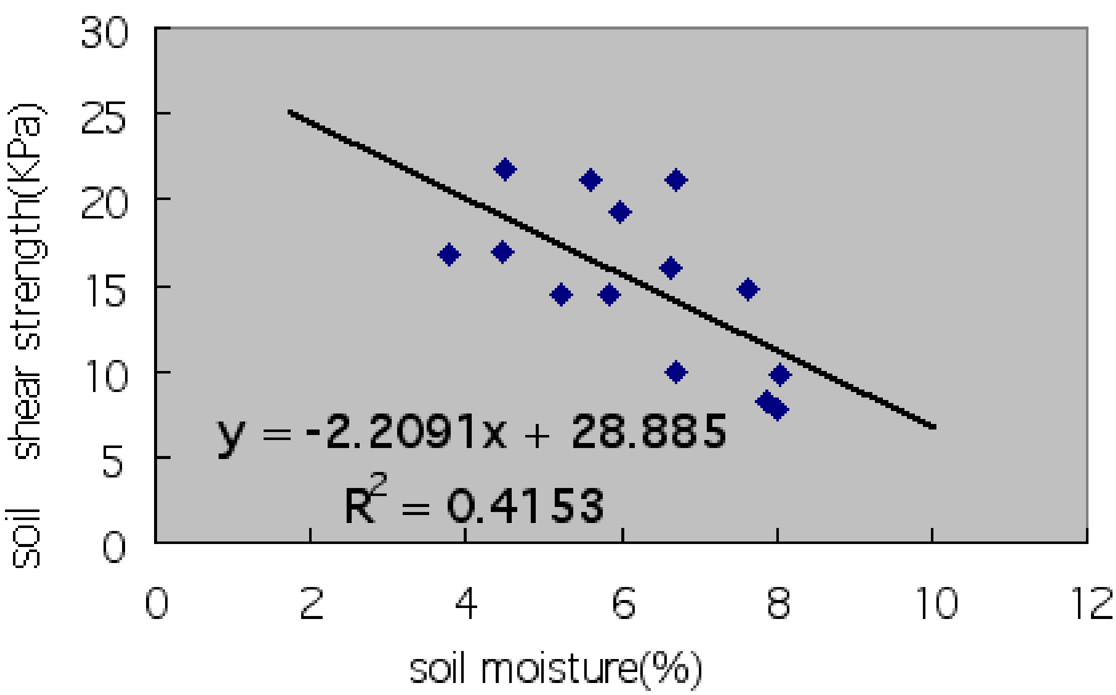


Figure 6.2 Relationship between soil shear strenth and soil water



Soil stability reflects the capacity of soil against displacement of soil particles or soil profile under outside factors such as water, wind, gravity, etc. It is influenced by soil adhesive and fractional force, while the sum of both is shear strength which varied with soil types and roots in the soil, and also soil water content. Under the same soil moisture regime jiji grass provided higher shear strength. The surface soil shear strength should be more important to prevent soil from erosion.

Table 6-1 shows more clearly that the jiji roots increased shear strength, i.e. the higher root density in a certain position of soil profile, the higher the soil shear strength. A former study also indicated that there was a positive correlation between root quantity (x) and shear strength (Y) with correlation coefficient for 0.9814 (Quanhou Dai et al, 1998):

$$Y = 0.0088 + 0.264x \quad n=16,\ r=0.981$$

Table 6-1. Effect of root density on soil shear strength

NO.	Root density (roots/cm2)	Shear strength(KPa)
1	7	30.0
2	10	45.0
3	12	44.0
4	16	62.0
5	18	72.0
6	21	94.0
7	26	110.0

4 Conclusion

Jiji grass can increase soil shear strength, the upper soil shear strength in particular, with its strong and dense roots. Additionally shear strength is related to the density of roots and soil moisture as well. Because the upper soil had higher shear strength water erosion was controlled effectively. From earlier research we found that jiji grass grew even better on the edges of eroded gullies with one or two meter deep root where the soil contained less water (see Chapter 2). As a result the shear strength there should be much higher, and erosion should be better controlled.

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Chapter 7. Effect of jiji grass on soil permeability

The soil permeability refers to the process of water moving downwards into soil profile under gravity. This parameter relates to soil erosion and soil fertility, i.e. if most rainfall can penetrate into the soil (the deeper soil horizons in particular), the runoff should be limited and therefore water erosion could be controlled considerably. If the soil had more porosity and good aggregation water may penetrate into deep soil profile more smoothly and soil may maintain more moisture for crop use during dry season.

There are many factors influencing soil permeability, such as soil structure, texture, mechanical composition, land surface condition (smooth or rough), soil porosity (size and patterns), and soil moisture. Under vegetative cover the soil contains more organic matter as well as soil animal and micro-organism activities. Also plant roots can penetrate and squeeze soil. All of these are beneficial to the improvement of soil structure and porosity and therefore beneficial to soil permeability. The strong deeply-penetrating jiji roots can lower soil bulk density and increase soil porosity and benefit soil permeability, and enable the soil profile to maintain more water that has penetrated from the soil surface. Also a grass fence across the slope can block water and sediment in situ allowing water more time to penetrate into soil.

This chapter studies the effect of jiji grass on the soil permeability and therefore on the farm production and erosion control.

1 Materials and method

Soil permeability was determined by double-ring method (Zhengshan, 1958). The two rings had same height of 25 cm. The inside ring had a diameter of 35 cm, and the outside ring 50 cm. The two rings were plugged into the soil to a depth of 15cm. Water was poured into both rings at a rate to keep a constant water level difference of 5cm between rings. The duration was recorded when the rate of permeability was steady. Water temperature which is related to permeability was also recorded.

2 Results and discussion

2.1 Effect of jiji roots on soil permeability

The initiative permeability rate (Ki) was obtained by:

$Ki = Q/td$

In which:

Q = water amount penetrated into soil during certain time,

td = time (30 minutes as usual),

To compare permeability the permeability coefficient at 10°Ê (K10) were calculated by:

K10£ΩKt/(0.7+0.03t),

Where:

Kt = the penetration speed (mm/min) at water temperature of t°Ê,

t = water temperature (°Ê),

` Under different vegetation the process of water penetrating into the soil differed significantly. Table 8-1 showed the three items, the permeability during the first 30 minutes, initiative permeability, and the permeability coefficient:

1) For the three items measured there were higher permeability figures under jiji grass and Korshinsk Pea shrub

than the control (natural grass).

2) The surface soil horizons for all the three treatments had the highest permeabilities, much higher than the bottom horizons. This property was more obvious under jiji grass and Korshinsk Pea shrub because the plant roots exerted more influence there.

3) The soil with jiji grass had the highest K10 (0.81 mm/min) compared with Korshinsk Pea shrub (0.47 mm/min) and natural grass (0.20 mm/min) for the soil of 40 – 60 cm, because jiji grass had a longer root system than the other treatments and therefore had greater effect on the permeability of deep soil.

Table 8-1. Water permeability into the soil under different vegetation

Treatment	Depth (cm)	Permeability Ist 30 min (Q) (mm)	Init. Perm. (Ki)(mm/min)	Perm. coeff. (K10) (mm/min)
Jiji grass	0-20	253.46	8.45	3.42
	20-40	197.59	6.59	0.90
	40-60	55.21	1.84	0.81
Korshinsk Peashrub	0-20	255.34	8.51	3.28
	20-40	186.62	6.22	0.66
	40-60	56.41	1.88	0.47
Natural grass	0-20	114.25	3.81	1.49
	20-40	46.38	1.55	0.22
	40-60	45.66	1.52	0.20

2.2 Correlation between root density and soil permeability

The correlation analysis between root (<1 mm in diameter) density and soil permeability during the first 30 minutes (mm) showed a positive relation (Table 8-2). It means that the roots, <1 mm in particular, played an important role on soil permeability.

Table 8-2. Correlation between soil permeability and root (<1 mm) density

Treatment	Regression equation	Correlation coefficient (r)	Distinction (P)	Number of samples (n)
Jiji grass	Y= 0.0532x+34.22	0.5962	<0.05	27
Korshinsk Peashrub	Y= 0.0041x-0.1953	0.6734	<0.05	9

Y = soil permeability during the first 30 minutes£®mm£©, X = root density (roots/m2).

3 Conclusion

The strong root system of jiji grass enabled the improvement of soil structure, porosity, and thus permeability, and therefore enabled more rainfall to penetrate into the soil and recharge the ground water, that not only reduced runoff and water erosion but also increased soil moisture for crop production.

References

Zhengshan, Fang, 1958, Investigation and study on the terrace of Loess Plateau in the middle and lower reaches of Yellow River, Science Press.

Chapter 8. Preliminary study on propagation properties

Although there was some description of jiji propagation (see chapter 1) there are no referenced practices supporting the jiji propagation process. this may be due to: 1) the large area of natural jiji steppe on the plateaus used as natural grazing place for many generations have been naturally self propagated; 2) local farmers did not realize the valuable function of jiji grass for erosion control and slope stabilization; 3) the grass could not generate direct benefit as compared to wheat or apples. This chapter describes the preliminary study on the propagation, both asexual and sexual.

1 Seed germination under salt-intimidated condition

Evaporation is high and the rainfall is limited in the Loess Plateau area of China. As a result the soil, the surface soil horizon in particular, contains salt content levels which may effect seed germination and plant growth. To recover vegetation and control soil erosion, one consideration should be the selection of salt-tolerant species of plants. The present study observes seed germination status under different salt levels.

1. 1 Materials and methods

The tested jiji seeds were collected from Shanxi Province in September 2000. Cultural dishes with a diameter of 9.5 cm were used, in which a filter paper was put on the bottom of each dish. A total of 100 seeds were put on the paper of each dish.

A mother solution of 1% salt concentration was prepared containing $Na2SO4$ and NaCl at a ratio of 6:4. and then a diluted solution of 1%, 2%, 3%, 4%, and 5% were prepared to moisten the paper and seeds, with distilled water as a control. Altogether six treatments including CK were implemented under room condition with temperature of 8-18°C. To avoid the changes of salt concentration transparency sheets were used to cover the dishes to prevent evaporation. The treatment was stared on 31 October 2000 and ended on 10 November.

1.2 Results and discussion

Table 8-1 showed that there was a tendency of germination decline with increasing salt concentration, i.e. the seed germination was restrained by salty solution. The seed germination rate was low, 60% for the control, which was the highest germination rate compared with salty solution treatments. It means that during field production the higher quantity of seeds should be used. At the concentration of 3% the germination rate was about 50% of the control. At the concentration of 5% the germination was 10%. These figures indicated that salt limited the germination, although jiji grass can tolerate certain salt concentration, 6% or higher for example (see chapter 2).

Table 8-1. Seeds germination under different salt intimidation during 10 days cultivation

Solution	CK	1%	2%	3%	4%	5%
Germination (%)	60	47	37	32	18	10

The effect of salt on seed germination resulted in a delayed germination (Xiaofang Sun, et al 2000). Table 8-2 indicated that germination was postponed for about one day under 2% salt concentration, while 4 % and 5% delayed the germination for around two days. The germination was seriously limited by high salt concentration under 5%. There was no new germinated seed on 7th, 8th, and 9th days under this concentration, which indicated that the maximum germination rate may remain 10%.

Table 8-2. Accumulated germination rates under salt treatment - %

Date (2000)	Salt concentration					
	CK	1%	2%	3%	4%	5%
4 Nov.	5	3	0	2	0	0
5 Nov.	28	14	8	9	0	0
6 Nov.	40	29	23	20	8	3
7 Nov.	49	41	29	30	12	10
8 Nov.	56	45	36	30	17	10
9 Nov.	60	47	37	32	18	10

Treatment was stared on 31 October 2000.

1.3 Conclusion

The germination of jiji seeds was constrained by salt treatment. Although germination was postponed by around 2 days, it may not influence reproduction much under 4% of salt concentration. The germination rate under control was also not high (60%). Practical experience showed that seed selection by water or wind(winnowing) was necessary before broadcasting to select ripened and plump-eared seeds.

2 Effect of salt on the growth of young seedlings

It is observed on large meadow areas that have soils with a high salt content and where there is a high ground water table, that jiji grass forms a plant community with jiji as its main component (Liao Guofan, 1996). It was found that the grass liked to grow on the edges of deep cuts and serious eroded broken landscape where soil contained little moisture due to high evaporation, possibly because these places have some special soil feature including higher salt content. The present study is to understand the effect of salt on the growth of young jiji plants in order to provide more information on the plant distribution, utilization, and propagation.

2.1 Materials and methods

2.1.1 Materials

The jiji seeds were collected from Lidayao village of Youyu county, Shanxi Province in September 2000.

2.1.2 Methods

The well developed seeds were selected and broadcasted on the 200 ml volume pots. Each pot was filled with 250g quartz sands. There were 50 seeds for each pot. The cultivation solution with different concentrations of salts were applied when the seedlings reached 3 cm high in average.

The salt-containing mother solution (%) was prepared with Na2SO4 and NaCl at a ratio of 6:4, which contained nutrient elements NH4NO3 48g/l; CaCl2 31mg/l; KH2PO4 10mg/l; MgSO4o7 H2O 123mg/l; and KCl 26mg/l. Micro-nutrients were also incorporated including EDTA-Fe (Liu Zhiyu, et al, 1980). Then the solution was diluted into 1%, 2%, 3%, 4%, and 5%. The solution without salt was used as control. The treatments were presented as y1, y2, y3, y4, y5, and CK respectively.

The seeds were broadcasted on 9 November 2000 and investigated and recorded. The whole test ended on 16 January 2001.

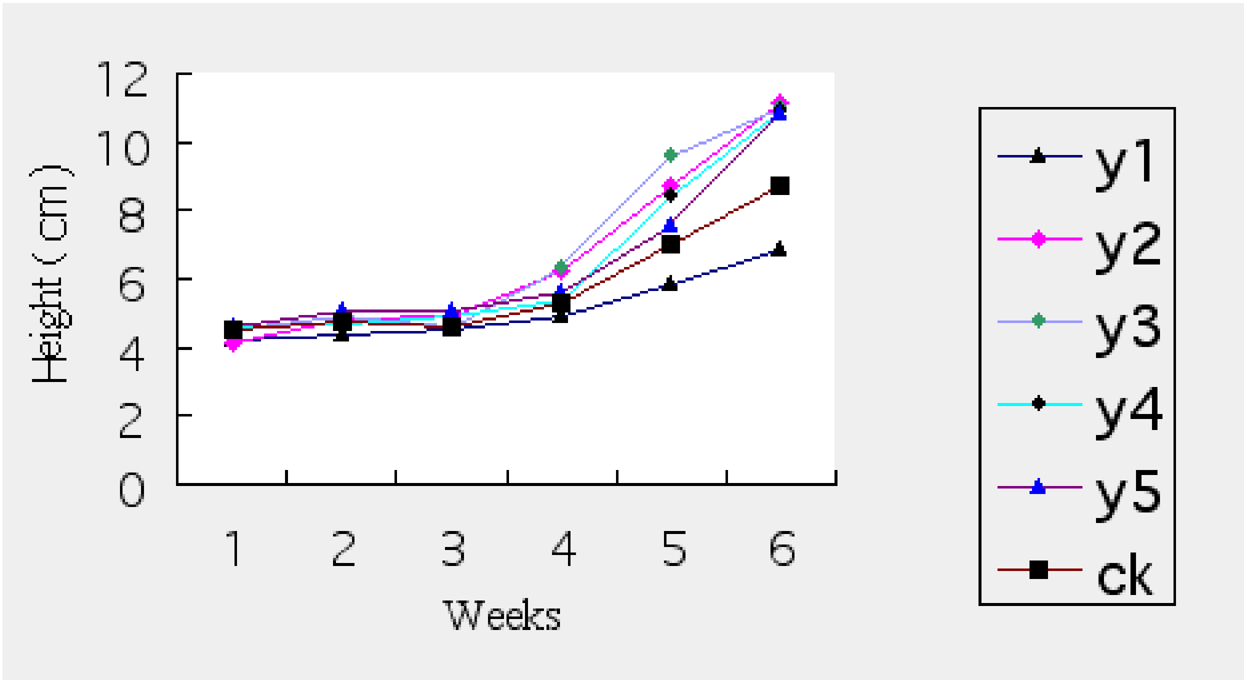
2.2 Results and discussion

The height and bio-mass of the seedlings were used to express the effect of salt on the growth of young jiji grass.

2.2.1 Effect of salt on height

The result showed that during the first 3 weeks since salt solutions were applied the effect of salt on height was not great (Fig. 8-1). However, the situation changed after the 3rd week. The plant treated with 2%; 3%; 4%; 5% liquids were all higher than the control, except that the plants treated with 1% was lower than control. It indicated that certain content of salt promoted the growth.

Fig. 8-1. Effect of salt on height



2.2.2 Effect of salt on bio-mass

Table 8-3 showed that there was no significant effect of salt on the bio-mass except that 3% and 4% solution increased the bio-mass, indicating that salt did not limit the growth. On the contrary certain salt concentrations promoted the growth.

Table 8-3. Effect of salt on bio-mass

Treatment	Mean weight (mg/plan)	Roots/above ground
y1	38.8	0.53
y2	39.0	0.53
y3	43.6	0.52
y4	41.8	0.55
y5	35.7	0.51
CK	39.6	0.52

2.3 Conclusion

Jiji grass was tolerant to salt, and furthermore certain salt content could even promote the growth. The result explained why the grass grew well on the edges of deep cuts and high salt content meadows. The study showed there was no negative impact of 5% concentration on plant height. It remains to be known the effect of much higher salt concentration on the grass.

3 Seeds germination on different zonal soils

To study the germination and suitability of Jiji grass on different soils, the soils from Shanxi (the original place of the grass), Jiangsu, and Jiangxi Provinces in southern China were collected and put into the pots. The three soils were loess soil, yellow-brown soil, and red soil respectively. They had quite different properties, such as pH, clay content, etc. (Table 8-4). The seeds were broadcasted on August 24 and recorded on September 9, 1999. The results showed that there was remarkable difference of germination rates among the three soils, i.e. 65%, 25%, and 5% for loess soil, yellow-brown soil, and red soil respectively (Photo 17, Appendix 4). It indicated that jiji grass can not grow well in southern part of the country possibly limited by pH and other related soil characteristics.

Table 8-4. Comparison of three soil properties

Soils	Location	pH(water)	O.M.(g/kg)	CaCO3 (g/kg)	<0.001mm (%)
Loessal soil	Shanxi	7.0	6.7	80	6
Yellow-brown soil	Jiangsu	5.2	12.5	0	30
Red soil	Jiangxi	4.5	11.2	0	40

Similar experience also showed that jiji can not grow well in Jiangsu province. The grass tillers were collected from Shanxi Province and transplanted in garden and pot in Nanjing, the capital of Jiangsu Province, in May 1998 and May 1999 respectively. But none of them survived.

4. Farmer's test on sexual propagation

Invited by China Vetiver Network, farmers in Zuoyun tested jiji sexual propagation. The test was arranged in Zhaohuose vellage. Three sunken beds were prepared with total area for 600 m^2 in order to collect rainfall. The general slope of eroded loess valley was Northeast. Seeds were collected in situ and broadcasted in June and July 2000 without irrigation, and covered with soil 1cm thick. The seedlings reached 5-10cm high in August 2000. The survival rate ranged from 10% to 40% influenced possibly by soil moisture and weather. When observed on 10 May 2001, the seedlings reached 10cm high.

5. Possibility of becoming a weed

Although there was no design specifically to confirm if the grass could become a weed, it was observed by field practice: 1) During several field investigations in several provinces we did not find the grass on farm land. 2) The grass seeds were extremely small (smaller than most grains) and had a weight for 0.88g/1000 seeds. Therefore they strict prerequisites of soil moisture and sowing. If the climate was too dry without irrigation or if the covering soil was too thick the seeds could not germinate.

6 Field experiments on asexual propagation

6.1 Field experiment at Shanxi Provincial Institute

There are some problems in asexual propagation for jiji grass:

1) Un-like vetiver, the center of jiji clumps are in poorer condition;
2) The roots of the grass are coated with rusty or wrotted-like skin. Therefore it is difficult to distinguish between the healthy roots and dead roots unless carefully identified during planting;
3) The stems are much thinner than vetiver and therefore it is difficult to plant jiji strictly with two or three tillers as done with vetiver.

In spring of 1999 about 500 kg of jiji grass was taken to Lishi from northern Shanxi Province and planted at experimental plots of the Soil and Water Conservation Institute of Shanxi province. Each plot had an area of 13 x 5 m^2. The grass was planted as hedges spaced 2m apart on a 23° slope. Each clump had around 10 - 20 tillers. Water was provided every few days to keep the soil to be moist. Investigation in July 1999 indicated that the survived rate was only 10%. However, the survived grass grew well reaching 70 cm high on average. Once survived, it can grow well without any management.

6.2 Field experiment by the World Bank Project

On 20 April 2000, about 1000 kg of jiji grass was transported to Lishi from Youyu County, 400 km away, and planted on a flat land. Watering was provided immediately after planting. Each clump was around 10 cm of diameter in average containing about 30 tillers. Investigations on 20 May showed that the survival rate, based on the clumps, was 65%. But later the number of survival plants decreased gradually caused by extreme dry weather and lack of irrigation facilities.

6.3 Field experiment in Ningxia Province

Altogether 6 plots of 20 x 5 M^2 were prepared on a 25° slope at Guyun Ecological Research Station of Chinese Academy of Sciences. Local tillers were collected from Liupanshan mountain and planted spacing 2m in April 1999, without irrigation. Each clump was around 5 cm in diameter. Investigated at the end of June showed that the survival rate was only 5%.

Similar tillers were planted on the irrigated flat land with an area of 1 Mu, spacing 50cm and 5cm for each clump in diameter, inter-cropped with vegetables. Observation showed that the survival rate was 95%, with 75 cm high at the end of first year.

6.4 Field experiment at Soil and Water Conservation Station of Shuozhou Prefecture

Jiji grass was collected from the nearby villages and re-planted at Soil and Water Conservation Station of Shuozhou Prefecture, Shanxi Province in different months of 2000 (Table 8-5). The results indicated that the survival rate can reach 100% if watering after planting, otherwise the rate would be decreased dramatically. Compared with the result from World Bank Project (refer 4.2), it was found that in such dry area moisture was the key factor influencing propagation. To guarantee the survival moisture should be maintained during the transportation and after planting. The grass started to grow on 5 April 2001 and reached around 20 cm high when investigated on 9 May 2001.

Table 8-5. Growth behavior of asexual propagation

Planting time	Watering after planting	Survival rate (%)	Bio-mass *(g/plant)	Height *(cm)	Height**(cm)	Roots **(cm)
15 July 2000	Yes	100	1.8	41 (9-91)	18 (5.9-27)	25 (23-27)
30 Aug 2000	No	20	2.3	37 (15-60)	17 (10-25)	21 (19-24)
27 Sep 2000	No	5	2.0	24 (10-45)	18 (10-24)	19 (14-22)

* Investigated on 2rd November 2000

** Investigated on 9 May 2001.

7 Conclusion

1) Jiji grass can be reproduced through either tiller planting or seeds. The main factor effecting the survival was moisture.
2) Salt could delay and decrease the germination but could promote the growth of young seedlings.
3) As usual, the quality of seeds is not satisfactory. It contained certain impurity matters. Additionally, the germination rate was not high (60%). Therefore, the seed quantity should be increased each unit area.
4) Further systematic study should be arranged that may include: 1) Best time for both sexual and asexual propagation; 2) Standard management on both sexual and asexual propagation; 3) Best number of tillers for each clomp; 4) Old plant as tillers may impact propagation. It is worth to be confirmed through experiments and therefore to establish reproduction base with newer tillers; 5) Transplanting

technology on the farm land and for embankment stabilization.

5) The grass could not grow well on the developed soils (Ultisol or Oxisol for example) or under tropical or subtropical climate.

8 References

Liao Guofan (Editor-in-Chief), 1996, Grass land resources of China, China Science and Technology Press, Beijing. 287-288.

Liu Zhiyu, Tang Yongliang, and Lou Zhicao, 1980, Nutrient disorder of main agricultural crops, Agriculture Press of Beijing, 24-85.

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Chapter 9. Summary and further needs of research

1 Distribution and major function

Jiji grass has a wide distribution in China, it can be divided into three ecological zones based on the different living conditions, each of which has its own characteristic of utilization, i.e. Meadow Eocene where the grass was the main pasture component for livestock; Semi-desert Eocene for anti-desertification and wind erosion control; seriously eroded gully zone for water erosion protection which was our main research topic.

2 Effect of Jiji grass on soil properties

Studies showed that since jiji grass had massive roots, <1 mm roots in particular, the soil physical properties such as pores, including capillary pores and non-capillary pores, was improved greatly that decreases soil bulk density, and enables the to soil have a higher capacity for water adjusting, reducing runoff, and increasing water penetration into soil.

Because jiji grass has strong fibrous roots soil nutrient properties were improved including organic matter, nitrogen, phosphors, potassium, pH value, and cation exchange capacity. This change should be useful for the improvement of other soil properties (soil physical and mechanical properties for example) related to soil erosion control, slope stabilization, and food production.

Jiji grass had higher root density than other local plants. The grass stabilized soil and had higher anti-scourability and anti-erodibility and therefore has high potential in soil erosion control and slope stabilization.

Jiji grass can increase soil shear strength, the upper soil shear strength in particular, with its strong and dense roots. Shear strength was related to the density of roots and soil moisture as well. Because the upper soil had higher shear strength water erosion was controlled effectively. The grass grew even much better on the edges of eroded gullies, it had a one to two meter deep root where the soil contained less water (see Chapter 2). As a result the shear strength there should be much higher, and erosion was controlled more significantly.

Strong root system of jiji grass promoted the improvement of soil structure, porosity, and thus permeability, and therefore enabled more rainfall penetrating into soil and recharge into ground water during raining season, which not only reduced runoff and water erosion but also increased soil moisture for crop production.

3 Ecological tolerances

Based on multiple field investigations in several provinces in combination with laboratory analysis, green house cultivation, and literature records it was confirmed that:

1) Jiji grass is tolerant cold temperature (<-33C) and hot (> 38C) climate.

2) It is also dry-tolerant. For example it can even grow on the earth wall in dry area. The annual rainfall changes from 500 mm to 200 mm or less, from east to west of the country.

3) It can be tolerant saline soil containing salt for 50% or more. In such areas jiji is wet-tolerant and the salt-containing water may appear on the ground surface. According to young seedling tests, certain content of salt may promote its growth.

4) The grass was barren soil tolerant and can grow even on stone walls with very little nutrients.
5) Although the grass is a light-demander, it grew even better under tree shadow possibly because the

soil there had a little more moisture.

6) The most extraordinary property was that it grew very well on the edges of deeply eroded gullies, cuts, or steep slopes where the soil had little moisture and higher capillary porosity.

7) Like vetiver, jiji can withstand fire. It grew better after burning. Although part of the old grass, the central part in particular, may wilt, the clumps can stand for several decades. Even if the clump looks almost dead the soil mound was still well stable.

8) The grass can hardly grow on acid (< pH 7.0) soil with humid climate as in Nanjing (south China). The young seedlings can germinate and grow for several months in Nanjing before dying.

9) Although it can withstand animal grazing, long term over-grazing caused grass degradation.

4 Main application potential

The first choice is to plant the grass at edges of the eroded gullies and deep cuts or slopes to prevent further erosion in the Loess Plateau area, and thus has a huge potential in the Loess Plateau area.

Additionally jiji grass can be used to stabilize new terraces and improve soil properties and therefore benefit food production. For the slope land, jiji grass should be planted along contours possibly spacing 1-2 m vertically based on the area of patches of farm land.

The grass can be planted for stabilizing amongst others: new construction sites, highways, railways, and dams.

5 Further study

Although preliminary test showed that the grass can be reproduced by both seeds and tillers, the survival rate was not as high as vetiver grass. Methods need to be found to improve both germination and survival rates. The following studies will be needed before extension or application on a large scale can take place:

1) The tillers we studied had come from old plants, possibly a few decades old, the survival rate was low, There is a need to study the growth and survival rates of nursery propagated planting material.
2) Propagation with seeds and transplanting technology.
3) The use of growth regulator on the vegetative propagation.
4) Establishment of jiji hedges (spacing, number of tillers/clump, management, etc.) and their effect on erosion and sediments control.

Appendix 1: Plate 1

Photo 1. Jiji pasture in Inner Mongolia

Photo 2. Jiji grass preventing wind erosion

Photo 3. Broom made of jiji stems.

Photo 4. Except for where this jiji grass clump is growing the surrounding soil has been eroded away.

Appendix 2: Plate 2

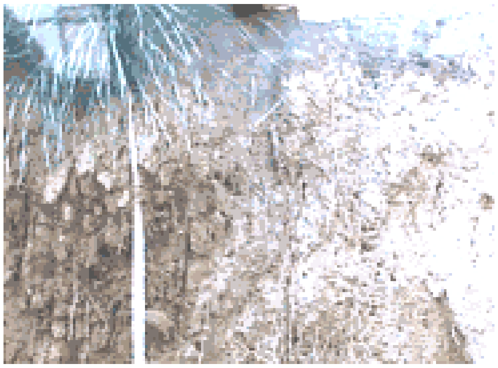

Photo 5. Jiji roots over 2 meters deep

Photo 6. Jiji grass grown on the top of earth house

Photo 7. Jiji on steep slopes near farmer's house wall under dry climate

Photo 8. Jiji can even grow on the top of the the typical Chinese earth wall under very dry conditions

Appendix 3: Plate 3

Photo 9. Jiji can grow on stone wall with very

Photo 11. Jiji grows well on edge of soil of steep slopes

Photo 13. Jiji grass tolerates burning

Photo 10. Jiji grew even better under trees

Photo 12. Jiji stabilized this cut slope. (natural profile)

Photo 14. Soil is nicely stabilized even though the grass was in poor condition.

Appendix 4: Plate 4

Photo 15. Cross section of jiji grass leaf under dry condition.

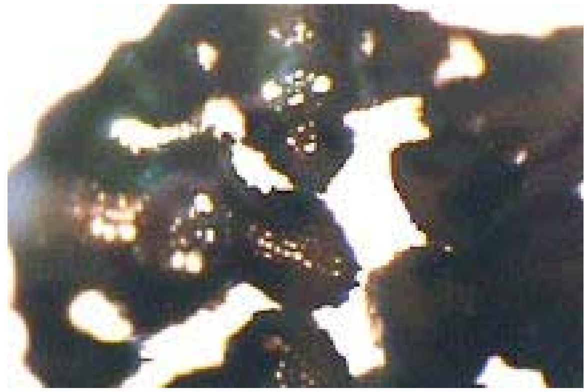

Photo 16. Cross section of jiji grass leaf under water saturated conditions

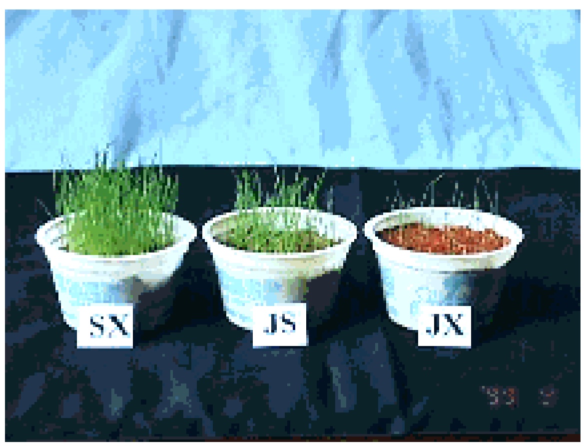

Photo 17. Seed germination

SX: Shanxi Province, Loessal soil
JS: Jiangsu Province, Yellow-brown soil
JX: Jiangxi Province, Red Soil

Appendix 5.

Project Personnel

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Yang Bulin, Technician, Director of High Quality Seed Reproduction Farm of Zuoyun County, Shanxi Province

Appendix 6.

Project Financial Statement

Chemicals for plants, soil, and water analysis	US$ 1300
Small laboratory instrument	US$ 600
Planting materials and transportation	US$ 710
Green house cultivation	US$ 350
Labor for field work	US$ 820
Literature and document	US$ 250
Small workshop	US$ 400
Domestic travels ($250/return x 2 pax x 5 times)	US$ 2500
Accommodations ($25 x 2 pax x 38 days)	US$ 1900
Accommodations for local partners($25 x 24 pax.day)	US$ 600
Field investigation trips and in-city travel	US$ 870
Supporting partner institutions (sub-total US$4700):	
Soil and Water Conservation Research Institute of Shanxi Province,	US$ 1700
World Bank Project Office of Luliang Prefecture, Shanxi Province	US$ 400
Soil and Water Conservation Station of Shuo Zhou Prefecture, Shanxi Province	US$ 600
Guyun Ecological Research Station of Chinese Academy of Sciences	US$ 1200
High Quality Seed Reproduction Farm of Zuoyun County, Shanxi Province	US$ 800
Total:	**US$15000**