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Relationships between Soil, Topography and Tree Growth in a Water Harvesting System in the Loess Plateau, China

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Abstract: The Loess Plateau in northwestern China is one of the most seriously affected regions by soil erosion in the world. We conducted investigations in a field afforestation site in the north of Loess Plateau to clarify the relationships between soil, topography and tree growth in a small scale water harvesting system, called "fish-scale-pit (FSP)". The site (200 × 50 m) was located on a northern slope (0 – 25°) of a hill. There were 314 FSPs in the site. The survival rates of the planted trees at near hilltop and near gullies were lower than the other area. The tree height showed weak and positive correlations with slope angle (R = 0.43). Bottom of hills were better areas to make FSPs than hilltops, considering their water balances. Although the difference in the average tree heights between large-leaf and small-leaf trees was small, the bearing rate of the large-leaf trees was much higher than small-leaf trees.

Keywords: Fish-scale-pit, Loess Plateau, Topography, Tree growth, Water harvesting

1. Introduction

The Loess Plateau in northwestern China is a plateau that covers an area of some 640,000 km² in the upper and middle of the Yellow River. Loess is the name for the silty sediment that has been deposited by wind storms onto the plateau over the ages. The Loess Plateau is one of the most seriously affected regions by soil erosion in the world. Soil erosion has drastically deteriorated land resources, environments and ecosystems in this region. Furthermore, the enormous amount of the eroded soil is aggrading the river bed of the Yellow River. Therefore, the Yellow River is an "above ground river" that is seriously threatening the security of its lower reach. Chinese government has been promoting a large national greening project since 1999, called "Grain for Green Project", as a countermeasure against this problem. The main objective of this project is to reduce soil erosion by converting croplands on steep slopes and degraded lands to grasslands and tree-cover. For afforestation on steep slopes in the Loess Plateau, a small scale water harvesting system, called "fish-scale-pit (FSP)", is commonly used to reduce erosion and increase soil water storage. The FSP is a pit dug in an ellipsoidal-semicircular shape (**Fig. 1a**); the typical depth of a pit is 0.2 – 0.4 m, and the lengths of major and minor axes of the lip are 0.5 – 1.5 and 0.5 – 1.0 m, respectively (Tang, 2004). FSPs were named after pits deployed on a large scale looked like fish scales (**Fig. 1b**). To evaluate the effectiveness of FSP systems, we have conducted two types of investigations in the north of Loess Plateau: i) water balance analysis and modeling of FSPs in an experimental site using various monitoring devices (Saito *et al*., 2008) and ii) investigations on soil, topography and tree growth in a field afforestation site. In this study, we mainly focused on the afforestation site. The objective of this study was to clarify the relationships between soil, topography and tree growth in the FSP systems and to obtain beneficial information for afforestation using FSPs.

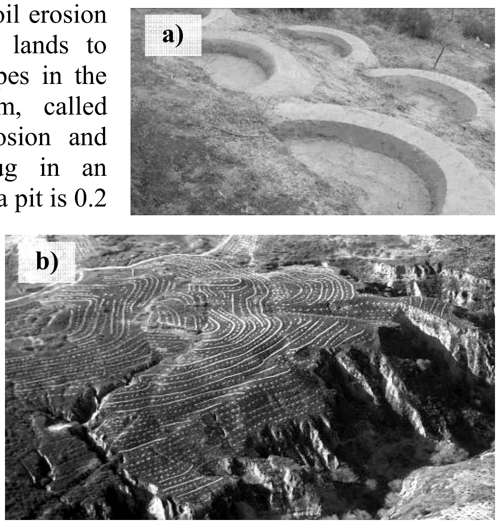

Fig. 1. Pictures of fish-scale-pits (FSPs): a) typical design of FSPs in Yanan and b) FSPs deployed on a large scale in Yuilin.

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2. Materials and Methods

The investigations on FSPs have been conducted in Liudaogou Basin (lat 38˚47′N, long 110˚21′E) located in Shenmu District, Shaanxi Province, China (**Fig. 2**). The average annual temperature of this region is 8.4 ˚C. The average annual precipitation for this region is about 440 mm and hence categorized as semi-arid. More than 70% of the annual precipitation falls from Jun to September.

Figure 3 shows the sketch of the field afforestation site. The site (200 × 50 m) was located on a northern slope (0 – 25˚) of a hill. On both sides of the site, along the slope, were deep eroded gullies. There were 314 FSPs on the site. Each pit had a 2-3 m long runoff area. The site was divided into three zones (Fig. 3): Zone A (top area of the hill: 119 pits), Zone B (middle area of the hill: 69 pits) and Zone C (bottom area of the hill: 126 pits). There were steps between the zones.

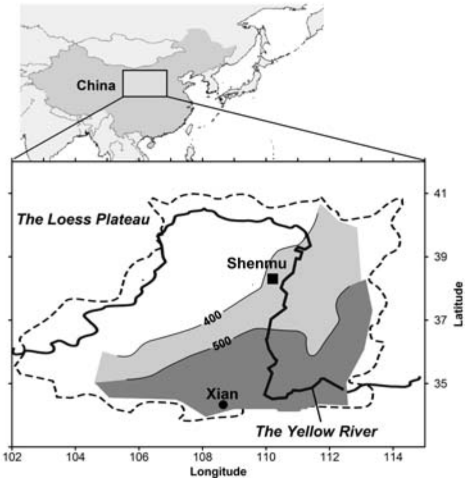

Fig. 2. Location of the investigation site. Curves are mean annual precipitation in mm.

A plum tree (*Prunus armeniaca* var. *ansu* Maxim) had been planted in each FSP in 2000, by farmers. The farmers replaced dead trees with new seedlings when they found dead trees. The seeds of the trees can be sold as materials for herbal medicines. Minimum threshold precipitation for forest establishment in the Loess Plateau is about 500 mm, hence it is difficult for the trees to survive on the hillslopes without the FSPs. The leaf types of the trees in this site were divided into two groups: large-leaf and small-leaf.

We investigated tree heights, leaf types, survival rate, bearing rate, slope angles of the runoff areas and positions of the pits in the site. Volumetric soil water content, θ (m^3 m^{-3}), and soil bulk electrical conductivity, σ_b (dS m^{-1}), from the soil surface to a depth of 10 cm, were also measured using WET sensor (Delta-T Devices Ltd., Burwell, UK) at every pit and runoff area. The σ_b values were converted to the electrical conductivity of the soil solution, σ_w (dS m^{-1}), using the θ values and a preliminarily determined calibration function. All investigations were conducted in May and October in 2008.

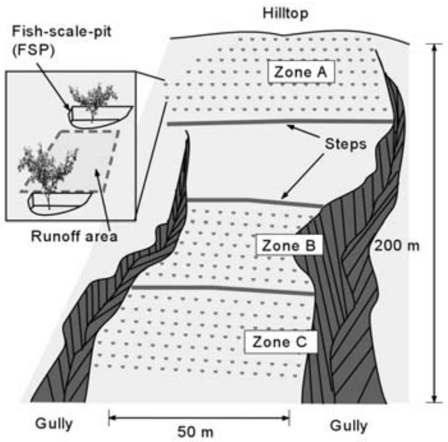

Fig. 3. Sketch of the field afforestation site.

3. Results and Discussion

Table 1 lists the results of tree growth investigations. In 252 of the 314 pits, trees are living and average tree height was 130.0 cm. Although the farmers have replanted new seedlings some times, 20 % of trees were dead in total. The trees in Zone C (bottom area of the hill) showed highest survival rate and average tree height.

Figure 4 shows differences in survival rates at different locations of the pits. We defined two rows of the pits across the slope nearest to the hilltop (21 pits) as “near hilltop” and two columns of the pits along the slope nearest to the gullies (70 pits) as “near gully”. The survival rates at near hilltop and near gully were lower than the other area. In particular, more than 60 % of trees were dead at near hilltop. These results suggest afforestation should not be performed near hilltops and gullies.

Relationship between slope angles of runoff areas and tree heights is presented in **Figure 5**. The tree height showed weak and positive correlations with slope angle (R = 0.43), meaning that increase in the slope angle might increase the tree height. This is probably because increase in slope angle increases runoff generation. However, even in low angle areas (angle < 10˚), where enough runoff generation can not be expected, many trees were living and grew to over average tree height (130 cm). These results

Table 1. Results of tree growth investigations.

	Number of pits	Living trees	Dead trees	Survival rate (%)	Average tree height & (Standard deviation) (cm)
Total	314	252	62	80	130.0 (45.2)
Zone A	119	91	28	76	126.2 (52.0)
Zone B	69	46	23	67	123.7 (34.0)
Zone C	126	115	11	91	135.5 (43.1)

Table 2. Comparison of average soil water content (θ) and electrical conductivity of the soil solution (σ_w).

Date	Average θ (m^3 m^{-3})		Average σ_w (dS m^{-1})	
	in FSPs	runoff areas	in FSPs	runoff areas
May 14th, 2008	0.13	0.10	1.82	1.85
Oct 13th, 2008	0.14	0.11	1.63	1.62

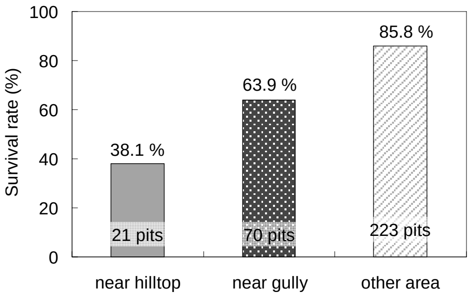

Fig. 4. Differences in survival rates at different locations of the pits.

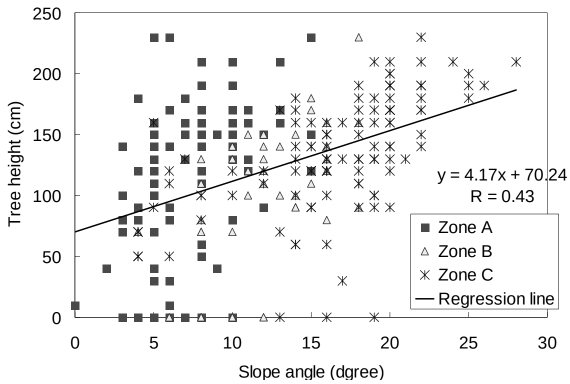

Fig. 5. Relationship between slope angles of the runoff areas and the tree heights. The tree heights of the dead trees were assigned a value of 0 cm. The data from "near hilltop" and "near gully" were excluded in this analysis.

suggest that the FSPs can function as "water basins" for collecting rain water falling directly into the pits, and runoff water from the slope may be used as supplementarily water to grow the trees.

Average θ in the FSPs was slightly higher than that in the runoff area (**Table 2**). One of the reasons for this tendency would be that rainfall and runoff water had been stored in the pits. In addition, shadows made by the walls of the pits and canopy cover of the tree might reduce evaporation from the soil surface in the pits; the same tendency have been observed in the experimental site (Saito *et al.*, 2007). The average σ_w values were low, and no significant difference in the σ_w was found between in the FSPs and runoff areas, meaning that the problem of salt accumulations has not occurred in the FSPs.

Jiang (1997) indicated that soils at bottom area of hills generally have higher water content than soils at hilltop areas in the Loess plateau. Our measurements also supported their results; e.g., average θ of runoff areas in Zone C (0.14 m^3 m^{-3}) was higher than that in Zone A (0.07 m^3 m^{-3}) on Oct. 13th, 2008. This is because evaporation is high at hilltop due to strong wind and insolation, in contrast, runoff water tends to gather at bottom areas of hills.

As can be seen in Figure 5, most of the steep slope areas (angle < 10°), where enough runoff generation can be expected, were observed in Zone B and C. The same tendency was observed in other hills in the investigation region. In conclusion, bottoms of hills are better areas to make FSPs than hilltops, considering their water balances.

Comparison of average tree height and bearing rate between leaf types are shown in **Figure 6**. There

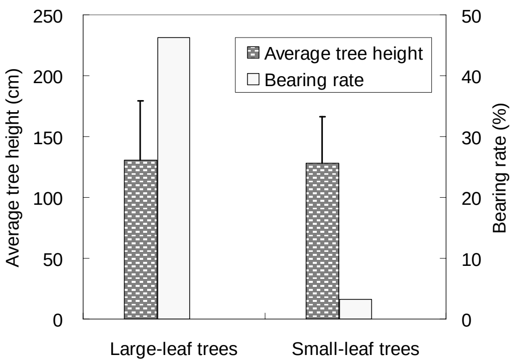

Fig. 6. Comparison of average tree height and bearing rate between leaf types. The error bars are standard deviation.

Fig. 7. Picture of bare runoff areas. Grass covers were completely cut by farmers.

were 156 large-leaf trees and 96 small-leaf trees in the investigation site. Although the difference in the average tree heights between large-leaf and small-leaf trees was small, the bearing rate of the large-leaf trees was much higher than small-leaf trees. This indicates that selecting large-leaf type seedlings may contribute to increase in bearing rate when farmers plant trees.

In several afforestation sites in the investigation region, grass covers of runoff area were completely cut by farmers (**Fig. 7**). This treatment may contribute to growth of trees in pits through increase in runoff generation and decrease in wasteful transpiration from grasses. However, bare runoff slopes are very weak against wind and water erosion. Therefore, this treatment by farmers, removing vegetation cover, is not suitable for the original objective of the Grain for Green Project. Further education on ecology for farmers may be needed for successful results of the project.

4. Recommendations

The location of the pit and the slope angle were major contributing factors to the tree growth in the FSPs on the hillslope. We list some recommendations for successful afforestation using FSPs;

- We should not make FSPs on gentle slopes and near hilltops and gullies, since the survival rate of the planted trees will be low in such areas.
- Bottoms of hills are better areas to make FSPs than hilltops.
- Selecting large-leaf type seedlings may contribute to increase in bearing rate and hence income of farmers.
- Further education on ecology for farmers will contribute to successful results of the Grain for Green Project.

Acknowledgements

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