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Full Length Research Paper

Soil mineralized nutrients changes and soil conservation benefit evaluation on 'green project grain' in ecologically fragile areas in the south of Yulin city, Loess Plateau

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The 'green project grain' was initiated to reduce water and wind erosion on marginal and highly erodible sloping croplands by removing them from permanent production planting and soil-conserving vegetation such as grassland/forest. We chose 53 plots of 265 sites in the ecologically fragile areas in the south of Yulin city in Loess Plateau, in order to assess the soil net mineralized nutrients changes and benefit evaluation. Field plots were established on a loamy site on some representative models of planting tree (grass) species for afforestation (such as *Orientalis*, *Jujube*, *Amorpha*, *Apricot* and *Alfalfa*) for over 5 years and on an adjacent site (<30 m) in the same elevation of sloping cropland (no-tillage). As a comparison, all soil samples were analyzed for total nitrogen, phosphorus, potassium (kalium) and soil organic matter. Results showed that after over 5 years of grassland/forest conversion of cropland to forest land, surface soils at the study area were significantly higher in the average total nutrients of nitrogen, phosphorus and organic matter by mass than sloping croplands, but the average total of kalium was in contrast. These results emphasize the need to evaluate benefits of soil conservation in fertilizer, so assessment on the ecological economic value of soil conservation in nitrogen, phosphorus and soil organic carbon in forest/grassland ecotone to steep cropland were 15.135, 0.142 and 2.412 billion yuan, respectively, but soil conservation benefit in kalium produced a negative value with 40.42 billion yuan. Benefits of soil conservation in fertilizer had a positive and negative relationship for exhibiting almost different values significantly. The soil mineralized nutrients changes and benefits of soil conservation with two-pronged relationships could be useful soil quality indicators in the ecologically fragile areas in soil management systems.

Key words: Green project grain, ecologically fragile areas, soil conservation benefit.

INTRODUCTION

The 'green project grain' was famous for serious soil erosion in the ecologically fragile areas in Loess Plateau, and an extensive cultivation on the steep croplands had led to soil mineralized nutrient loss owing to more grain harvest for farmers (Huang, 2000). Since 1999, the Chinese government has carried out the 'green project grain', which was one of ambitious ecological reconstruction with the world's largest land conversion programs of a budget of RMB 400 billion until 2010 to prevent soil erosion and alleviate poverty (WWF, 2003). During this period, 14.7 million ha steep cropland and 17.3 million ha degraded land were converted to forest and grass (Zhang, 2003). Therefore, in the hill of the Loess Plateau,

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converting cropland to forestland and grassland is good for improving the conditions of soil mineralized nutrient.

Ecological reconstruction features of water conservation improve soil fertility (Wu, 1998; Chang, 1999). At present, there are three research results on soil nutrient changes for the project, in which some studies suggested that one of the net mineralized nutrients (such as soil organic matter (SOM)) in surface soils for conversion from cropland to forest and grass-land significantly increased (Peng et al., 2005; Bronick, 2005; Yang et al., 2006; Zheng et al., 2007; Zhang et al., 2008; Wu et al., 2008); and some proved that one of the net mineralized nutrients in surface soils decreased (Puget et al., 1999; Li et al., 2000, 2006). Another study showed that one of the net mineralized nutrients in surface soils decreased in the previous years and resumed growth in the following years (Liu, 1996; Six et al., 2000; Jin et al., 2001; Zhu, 2005), and in this, like in so many of these issues of the 'green project grain', the government and scholars have been very zealous to face the problem head-on, answering calls in ecological conservation to evaluate the benefits of soil conservation in fertilizer.

The objective of this paper is to provide scientific and comprehensive approach for the benefit evaluation of soil conservation. Specifically, this research has two goals: (1) To explore the soil mineralized nutrient changes from the aspects of land use and tree (grass) species of afforestation in the course of implementing Grain for Green project. (2) To undertake an ecological economics approach to assess the effectiveness of soil conservation in fertilizer, considering soil mineralized nutrient benefits as well as the benefits offered by government for further promoting the sustainable development of 'green project grain'.

MATERIALS AND METHODS

Description of the study area

The study area is located in six southern counties of Yulin city (109 ° 29'-110 ° 47'E, 36 ° 04'-38 ° 23 'N) in Northeast China, with an area of 9434.5 km^2 and a population of 1.5 million. The climate has a typical medium temperature and warm temperate climate with long-term mean annual temperature and precipitation of 6 ~ 11.3℃ and 400 ~ 600 mm, respectively, and 70% of its precipitation falls during the summer and autumn (May to September). Dominant soils in the study area are cultivated in loessial soils with sparse vegetation cover.

The main tree/grass species are *Orientalis, Jujube, Amorph, Apricot* and *Alfalfa*. It is conventional in the region to plant these species during the reforestation and afforestation period, and 83,606.67 h m^2 of croplands have been converted to forest and grass land for the project. The south of Yulin city was selected as a study area for this research because the typed ecologically fragile areas found in the region are highly representative of the ecosystem's restoration and enhancement potential of northwestern China, as are the challenges faced in implementing the 'green project grain'.

Samples and data collection

The study was conducted during 2009, and a total 53 plots (samples) of 265 sites were chosen. The 53 plots with differing management ages (<ten years), but same soil classification and landscape position, were identified to represent diverse models of planting tree (grass) species (soil samples in *Orientalis*, *Jujube*, *Amorpha*, *Apricot* and *Alfalfa* were chosen with nine replicate plots, respectively) for afforestation in the ecologically fragile areas in the south of Yulin city in Loess Plateau, and on an adjacent (<30 m away) steep cropland (soil samples were chosen with eight replicate plots). Each plot with 20 × 20 m area has five replicate sites, which were randomly chosen by S-type route, and one soil sample consisted of five core sites (5 cm in diameter) for each location. In depth increments of 0 to 20, 20 to 40 and 40 to 60 cm, respectively, were collected using a 5 cm diameter hammer driven soil core sampler. Soil samples, with five sites from the same depth and at the same site, were mixed thoroughly to give the composite three samples, and soil samples were placed in sealed plastic bags and taken to the laboratory. Soil bulk density was determined at each site using a soil corer (stainless steel cylinder with a volume of 100 cm) at 0 to 20 cm depth, with five replicates. In the laboratory, each soil sample was thoroughly passed through a 2 mm sieve to remove roots and incorporated litter. Afterwards, it was air-dried and divided into two parts. One part was used first for determining the total nitrogen, phosphorus and potassium (kalium), while the second part was further sieved to 0.25 mm and used for determining the soil organic matter. Soil organic matter was measured by the Walkey-Black method, total N by the Kjeldahl procedure, total P by NaOH melt-Anti-molybdenum antimony colorimetry and total K by NaOH melt-flame photometric.

Methods and data treatment

To assess the benefits of soil nutrients and fertilizer conservation for 'green project grain', the benefits were divided into three parts:

(1) The water and soil erosion was taken by mass in the forest/grass land to cropland as contrast, while benefits of water and soil conservation were assessed by the method of universal soil loss equation (USLE).
(2) Changes of soil net mineralized nutrients (total N, P and K) were analyzed on sloping cropland to forest-grass land, and the ecological economic method was used to estimate the economic benefits. Specific formulas were given as follows (Jin, 2001; Lai, 2006):

$$q_i = p_i * \rho_i * h / 10 \quad (1)$$

Where, q_i is the soil net mineralized nutrients density (g/cm²), p_i is the soil net mineralized nutrient by mass (g/kg), ρ_i is the mean soil bulk density (g/cm^3), h is the soil depth (cm) and i is a certain kind of mineralized soil nutrient. The economic benefits of soil protection fertilizer are usually written in the following form:

$$S_2 = s_e \sum_i^n q_i * k_i * v_i * 10^{-2} \quad (2)$$

Where, S_2 is the value of benefits of soil fertilizer and soil protection (million yuan), s_e is the conversion area for converting cropland to forest/grass land (h m^2), k_i is the ratio of the net amount of soil mineralized nutrients to fertilizer, the ratio of soil N, P

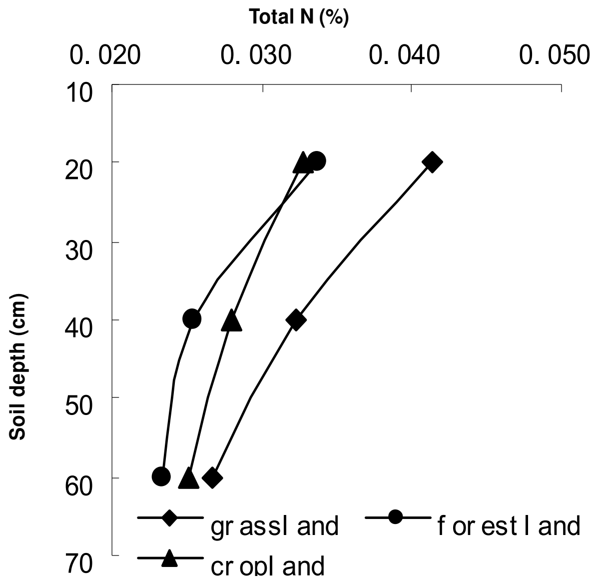

Figure 1. Change of total N in land use.

and K converted by phosphate and potassium chloride were 132/28, 132/31 and 75/39, respectively, v_i is market prices for all types of soil mineralized nutrients and i is a certain kind of soil mineralized nutrient.

Benefits of carbon stock in soil

Soil is likely to be a potential sink of carbon following afforestation in the long-term. However, stock changes of soil organic carbon following afforestation vary significantly with land use/cover types before planting and other bio-physical conditions (Paul et al., 2002). In general, soil organic matter (%) is related to soil organic carbon (%) according to the following equation:

Soil organic matter (%) = soil organic carbon (%) × 1.724

Benefits of soil carbon sequestration are usually written in this form:

$$q_i = p_i * \rho_i * h * (1-\delta)/10 \quad (3)$$

Where δ is the volume percentage of gravel in soil (%). The total soil fixed carbon in the 'green project grain' was calculated as follows:

$$Q = q_i \times 10^{-2} \times S \quad (4)$$

Where, Q is the total amount of soil fixed carbon (million t), and S is the area of returning cropland to forest-grass land (h m^2). The value of carbon sequestration in the 'green project grain' was calculated by the following formula:

$$S_3 = [Q \times (C_1 + C_2)]/2 \quad (5)$$

Where, S_3 is the value of the fixed CO_2 in the 'green project grain' (million yuan), C_1 is the cost fixed CO_2 of afforestation (million yuan/t), C_2 is the Sweden's carbon tax (dollar/t·c) and Q is the total amount of net soil fixed carbon (million t).

All data were analyzed using theStatistical Package for the Social Sciences (SPSS) software, with a multiplication of compa-risons, and as such, analysis of variance was used to determine the differences among the treatments.

RESULTS

Total mineralized nutrient changes in land-use

The average total nitrogen content by mass was not significant in forestland, grassland and cropland (P = 0.05). From 0 ~ 60 cm in the soil profile, the total nitrogen content in grassland improved two times than those of the sloping cropland and forest land, respectively, but the changes of total nitrogen content were not significant between forest land and cropland (Figure 1 and Table 1). In the study area, *Alfalfa* was planted on the lands that were converted from the cropland to grass land, and which caused the total nitrogen content levels to be significantly higher for its properties of nitrogen-fixing. As such, the total nitrogen content in grassland, cropland and forest-land decreased by 26.8, 23.7 and 30.4% in the 0 to 60 cm depth, respectively (Table 1).

The average total phosphorus content by mass was not significant in forest land, grassland and cropland (P = 0.05). From 0 ~ 20 cm soil profile, the total phosphorus content in forest land and grassland increased by 2% than that in cropland; while from 20 ~ 40 cm, the total phosphorus content in sloping cropland increased by 6.26 and 4.04% than those in forest land and grassland, respectively, but increased by 2.1% in grass/forest land. From 40 ~ 60 cm, the total phosphorus content in sloping cropland increased by 2.53 and 3.72% than those in forestland and grassland, respectively, but increased by 2.1% in forest/grass land (Figure 2).

The average total phosphorus content by mass in grassland decreased by 4.18% with an increasing depth of 0 to 60 cm, but the total phosphorus content by mass in forest land decreased by 6.91% in the 0 ~ 20 cm to 20 ~ 40 cm depth, and increased by 2.8% in the 40 ~ 60 cm to 20 ~ 40 cm depth.

The average total kalium content by mass was not significant in forestland, grassland and cropland (P = 0.05). For 0 ~ 20 cm soil profile, the total kalium content in forest land increased by 1.78 and 0.58% than those in grassland and cropland, respectively, and the total kalium content in cropland increased by 1.18% than that in grassland. For 20 ~ 40 cm soil profile, the total kalium content in forest land increased by 2.3 and 2.83% than those in grassland and cropland, respectively, while the total kalium content in grassland increased by 0.55% than that in cropland. For 40 ~ 60 cm soil profile, the total kalium content in cropland increased by 5.05 and 5.8%

Table 1. Soil mineralized nutrients of land use in different soil depths.

Land use type	Number of sample	TSN		TSP		TSK		SOM	
		Mean (g. kg^{-1})	CV (%)	Mean (g. kg^{-1})	CV (%)	Mean (g. kg^{-1})	CV (%)	Mean (g. kg^{-1})	CV (%)
Forest land	**36**								
0 ~ 20 cm	36	0.34	66.2	0.51	12	17.4	10.8	8.02	53.3
20 ~ 40 cm	36	0.25	35.2	0.48	8.9	17.3	5.1	5.91	39.8
40 ~ 60 cm	36	0.23	42.9	0.49	7.5	16.8	13.1	4.42	30.4
Grassland	**9**								
0 ~ 20 cm	9	0.41	31.9	0.51	7.2	17.1	6.1	9.67	32
20 ~ 40 cm	9	0.32	36.3	0.49	7.7	16.9	10.1	5.86	27.2
40 ~ 60 cm	9	0.27	24.4	0.48	7.7	16.9	9.4	4.89	24.6
Cropland	**8**								
0 ~ 20 cm	8	0.33	28.9	0.5	7.5	17.3	4.8	5.53	23.3
20 ~ 40 cm	8	0.28	36.3	0.51	7.2	16.8	12.8	4.48	24.4
40 ~ 60 cm	8	0.25	34.2	0.5	7.8	17.8	5.5	3.55	19.9

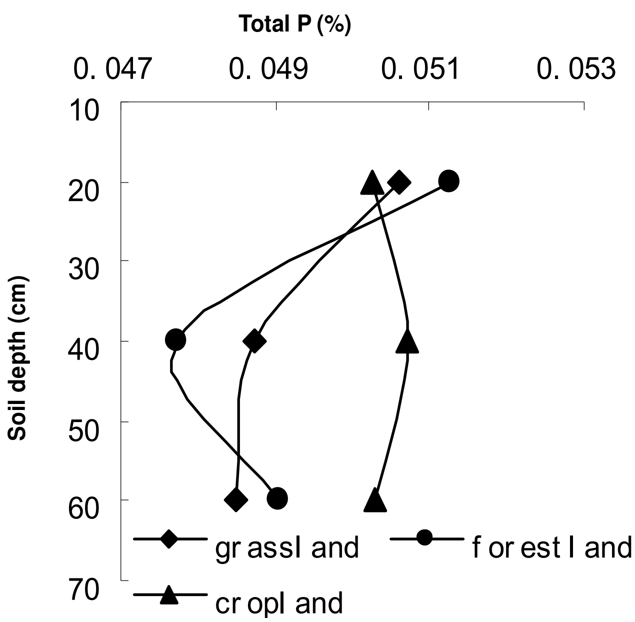

Figure 2. Change of total P in land use.

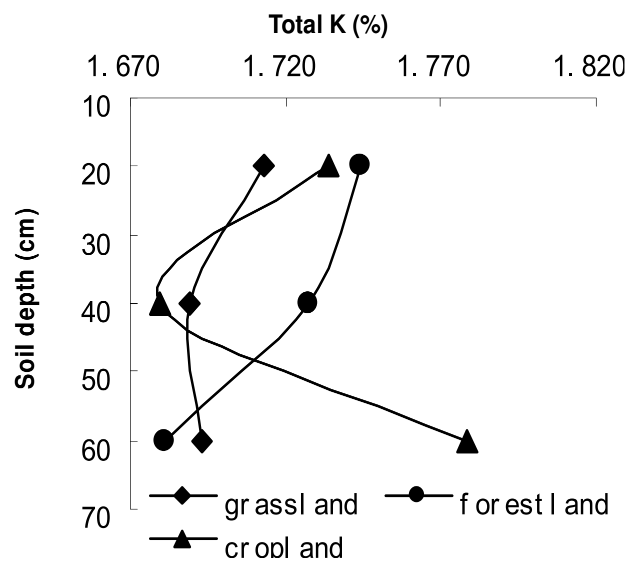

Figure 3. Change of total K in land use

than those in grassland and forest land, respectively, while the total kalium content in grassland increased by 0.7% than that in the forest land (Figure 3).

The total kalium content by mass in the forest land decreased by 3.6% with an increase in soil depth; however, for cropland and grassland, the total kalium content decreased by 3.1 and 1.4% in 20 ~ 40 cm to 0 ~ 20 cm depth and increased by 5.88 and 0.2% in 40 ~ 60 cm to 20 ~ 40 cm depth, respectively. The average soil organic matter (SOM) content by mass was significant in forest land, grassland and cropland ($P < 0.05$). Figure 4 indicates that SOM content in grassland, forest land and cropland decreased by 49.42, 44.92 and 35.3% in the 0 - 60 cm depth, respectively. For 0 ~ 20 cm soil profile, SOM content increased by 20.56 and 75.04% in grassland to forestland and cropland, respectively, and increased by 45.2% in forest land to cropland. For 20 ~ 40 cm soil profile, it increased by 0.87 and 32% in forestland to grassland and cropland, respectively, and increased by 30.83% in grassland to cropland. For 40 ~ 60 cm soil profile, it increased by 10.69 and 37.83% in grassland to forestland and cropland, respectively, and increased by 24.52% in forestland to cropland.

Generally, changes of the total nitrogen content and SOM content by mass were significant than the total kalium and total phosphorus. For 0 ~ 60 cm soil profile, only SOM content by mass boosted in forest/grass land to cropland. For 0 ~ 20 cm soil profile, the total nitrogen,

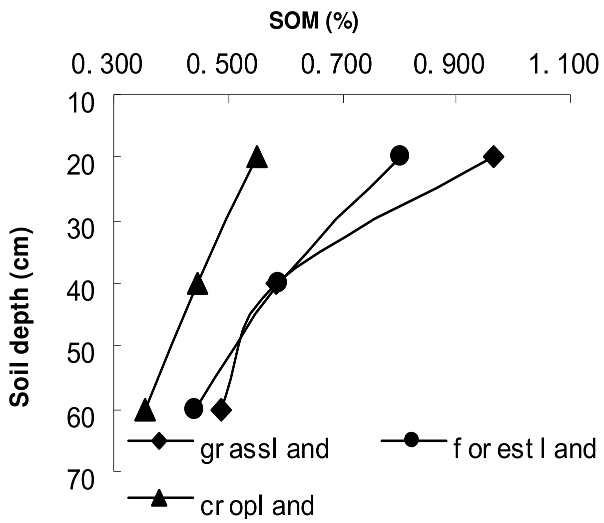

Figure 4. Change of total SOM in land use.

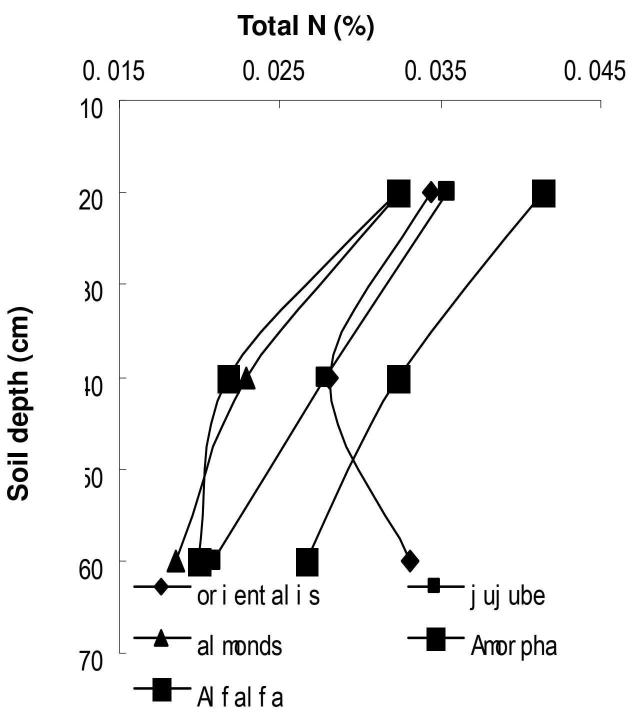

Figure 5. Change of N in different tree (grass) species.

phosphorus and SOM contents in forest/grass land, were larger than those in cropland. For 40 ~ 60 cm soil profile, the total phosphorus and kalium contents in cropland increased than those in the forest/grass lands, and the total nitrogen content in grassland was larger than that in cropland, and was higher in cropland to forest land. In other words, SOM content by mass was one of the main indexes for soil restoration in ‘green project grain’, but the total nitrogen, phosphorus and kalium also played an important role in soil restoration.

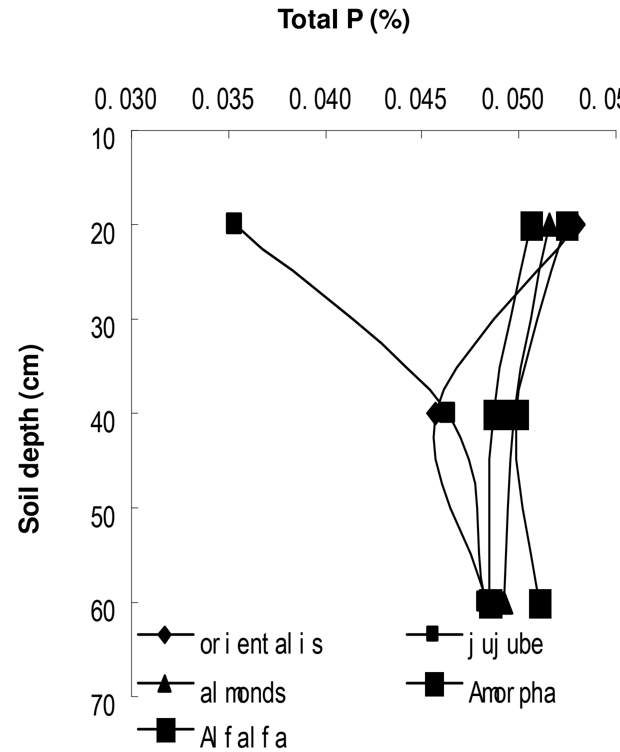

Figure 6. Change of P in different tree (grass) species.

Characteristics of soil nutrient models used for afforestation in planting tree (grass) species

After 5 to 10 years of vegetation recovery, the average total nitrogen content by mass in *Jujube, Almond, Amorpha fruticosa* and *Alfalfa* decreased by 41.11, 42.81, 38.55 and 35.4% in the 0 to 60 cm profile with an increasing soil depth (Figure 5), but *Orientalis*, increased by 18.53% in the 0 to 20 cm and 20 to 40 cm depth and decreased by 18.15% in the 20 to 40 cm and 40 to 60 cm depth. In the 0 to 20 , 20 to 40 and 40 to 60 cm depth, the average total nitrogen content by mass is followed, respectively as, *Alfalfa* > *Jujube* > O*rientalis* > *Almonds* > *Amorpha*; *Alfalfa* > *Orientalis* > *Jujube* > *Almonds* > *Amorpha*; *Orientalis* > *Alfalfa* > *Jujube* > *Amorpha* > *Almonds*.

The average total phosphorus content by mass in *Alfalfa, Almond* and *Amorpha* decreased by 4.18, 4.58 and 2.62%, respectively, with an increase in soil depth (Figure 6), but increased by 36.39% in *Jujube*, and in *Orientalis*, it increased by 13.72% and decreased 5.93% in the 0 - 20 to 20 - 40 cm and 20 - 40 to 40 - 60 cm depth, respectively. In the 0 – 20 and 20 - 40 and 40 - 60 cm depth, the average total phosphorus content by mass is followed, respectively as, *Orientalis* > *Amorpha* > *almonds* > *Alfalfa* > *Jujube*; *Amorpha* > *Almonds* > *Alfalfa* > *Jujube* > *Orientalis*; *Amorpha* > *Almonds* > *Alfalfa* > *Orientalis* > *Jujube*.

The average total kalium content by mass decreased

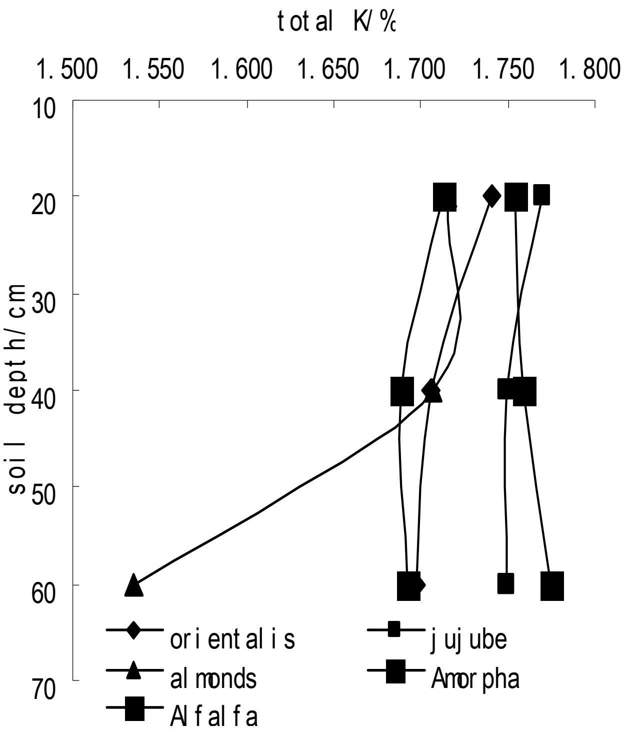

Figure 7. Change of K in different tree (grass) species.

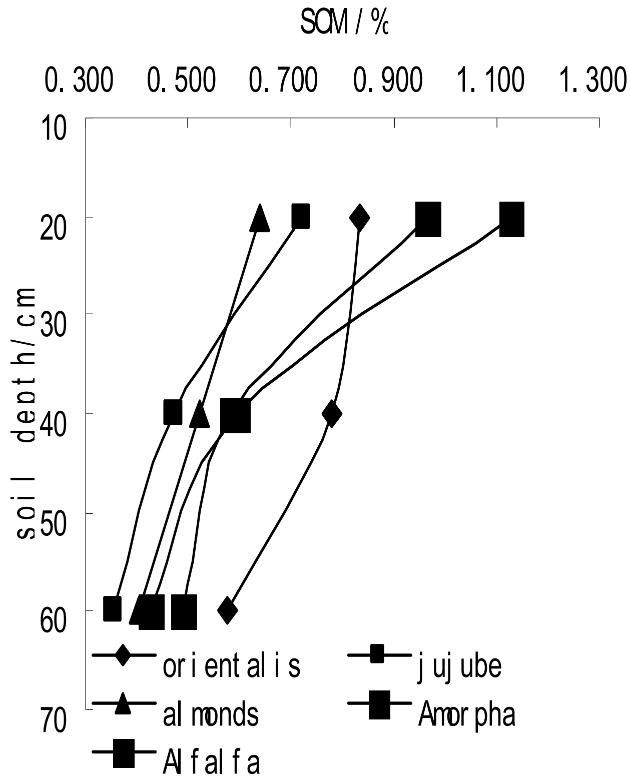

Figure 8. Change of SOM in different tree (grass) species.

by 1.15, 25.28, 11.97 and 10.48% in *Jujube, Orientalis, Alfalfa* and *Almond*, respectively with an increase in soil depth (Figure 7), but in *Amorpha,* it increased by 1.19%. In the 0 to 20, 20 to 40 and 40 to 60 cm depth, the average total kalium content by mass is as followed, *Jujube* > *Amorpha* > *Orientalis* > *Almonds* > *Alfalfa*, *Amorpha* > *Jujube* > *Almonds* > *Orientalis* > *Alfalfa*, *Amorpha* > *Jujube* > *Orientalis* > *Alfalfa* > *Almonds*, respectively.

The average SOM content by mass decreased by 50.46, 58.27, 30.8, 62.18 and 49.42%, respectively, in *Jujube, Almond, Orientalis, Amorpha and Alfalfa* with an increase in soil depth (Figure 8). In the 0 to 20, 20 to 40 and 40 to 60 cm depth, the average SOM content by mass is as followed, *Amorpha* > *Alfalfa* > *Orientalis* > *Jujube* > *Almonds*, *Orientalis* > *Amorpha* > *Alfalfa* > *Almonds* > *Jujube, orientalis* > *Alfalfa* > *Amorpha* > *almonds* > *Jujube*, respectively.

Soil conservation benefit

This study was carried out to assess soil conservation benefit only in two and three parts in the 0 to 20 cm depth.

S_2 of soil conservation benefit in fertility

The mean of total nitrogen, phosphorus and kalium content by mass was 0.38, 0.51 and 17.29 g/kg in forest/ grass land ecotone in the 0 to 20 cm depth, and were 0.33, 0.5 and 17.34 g/kg in cropland, respectively (Table 2). The economic values for forest/grass land ecotone to steep cropland were 1,513,520 and 14,240 yuan (RMB) in soil conservation benefit of nitrogen and phosphorus, respectively, but the soil conservation benefit in kalium produced a negative value with 4,042,061 yuan (RMB).

S_3 of soil conservation benefit in carbon sequestration

The mean SOM content by mass was 5.133 and 3.207 g/kg, respectively in grassland/ forest ecotone and steep cropland in the 0 to 20 cm depth (Table 3). As such, the soil conservation benefit in the carbon sequestration produced an economic value of 241,160 yuan (RMB).

DISCUSSION

Changes of soil net mineralized nutrients in land use

Primary factors affecting soil fertility were land utilization and vegetation type (Saggar et al., 2001). Average total nitrogen, phosphorus, kalium and SOM content by mass decreased with the increasing soil depth, but the rates

Table 2. Average nutrients of land use in the 0 to 20 cm soil layer.

Type	Mean of total N (g/kg)	Mean of total P (g/kg)	Mean of total K (g/kg)
Forest-grass land	0.38	0.51	17.29
Cropland	0.33	0.5	17.34
Net benefit/Yuan	1513520	14240	4042061

Table 3. Benefit of soil carbon sequestration in 0 ~ 20 cm soil layer.

Land use	Mean of SOM (g/kg)	Mean of SOM (g/kg)
Forest-grass land	8.85	5.133
Cropland	5.53	3.207
Net benefit/Yuan		241,159.9

varied across a wide spectrum. However, the mean of the total nitrogen and SOM content by mass were significantly higher than the total phosphorus and kalium in rate. Some researches showed that the total nitrogen and SOM content by mass decreased significantly higher than other soil net mineralized nutrients in the Loess Plateau (Wei and Shao, 2007). Accumulation effects improved better in total nitrogen and SOM to total phosphorus in forest/grassland ecotone, and in the SOM content that was highlighted (Wang et al., 2007). Nonetheless, SOM in grassland carbon was significantly higher than farmland in the conversion of farmland to grassland in 5+ years (Reeder, 1998). Some studies pointed out that the total kalium content by mass in grassland was significantly higher than that in cropland, but the paper's results are contradictory. The main reason was different from the soil parent material.

Changes of soil net mineralized nutrients models used for afforestation in planting tree (grass) species

Vegetation type determined the nature of soil organic matter, and then, was regarded as one of the major factors influencing the vertical distribution of soil organic carbon and nitrogen (Jobbagy and Jackson, 2002; Li et al., 2005). Generally, the total nitrogen content by mass in *Alfalfa* was higher than other tree (grass) species; however, total nitrogen content by mass in *Orientalis* was larger than *Alfalfa* in the 40 to 60 cm depth, which could be explained by SOM being higher. *Jujube* had stronger nitrogen-fixing function than *Almond*, and this had been verified by Hu et al. (2009) in the Loess Plateau. Total nitrogen content by mass in *Amorpha* was the lowest, because famers often chop its branches to make baskets. It was overly complex and confusing to the total phosphorus and kalium in different form of planting tree (grass) species for afforestation, and in different roots' systems that absorbed certain soil mineralized nutrients (Wu et al., 2004). Potential researches were proposed to strengthen the regional vegetation under different soil mineralized nutrient.

Soil conservation benefit

In soil conservation benefit, most of the discussions concentrated on the issue of benefits in parts one and three, few of which were on the application of benefit in part two. This is what the paper discusses as its values.

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