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Relationship Between Soil and Water Conservation Practices and Soil Conditions in Low Mountain and Hilly Region of Northeast China

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Abstract: The soil and water conservation practices of ecological restoration (ER), fish scale pit (FP), furrow and ridge tillage across the slope (FR), shrub strips (SS), and vegetation-covered ridge (VR) are characteristic of the Jixing small watershed of the low mountain and hilly region of Jilin Province, Northeast China. This study aims to elucidate the effects of soil and water conservation practices on soil conditions after the short-term implementation of practices. Soil samples were collected from five soil and water conservation sites (ER, FP, FR, SS, and VR) and two controls (BL and CT) to investigate their properties. To evaluate the influence of soil and water conservation practices on soil quality, an integrated quantitative index, soil quality index (QI), was developed to compare the soil quality under the different soil and water conservation practices. The results show that not all soil and water conservation practices can improve the soil conditions and not all soil properties, especially soil organic carbon (SOC), can be recovered under soil and water conservation practice in short-term. Moreover, the QI in the five soil and water conservation practices and two controls was in the following order: ER > VR > BL > FR > CT > SS > FP. ER exhibited a higher soil quality value on a slope scale. In the low mountain and hilly region of Northeast China, ER is a better choice than the conversion of farmlands to planted grasslands and woodlands early in the soil and water conservation program.

Keywords: soil and water conservation practices; soil property; soil organic carbon; low mountain and hilly region; Northeast China

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1 Introduction

Wind and water erosion are considered the most destructive soil phenomena worldwide (Brady and Weil, 2008). Soil erosion is a modern global problem that induces severe economic consequences (Pimentel *et al.*, 1995; Montgomery, 2007), environmental effects (Lal, 1995), and accelerated degradation of soil quality (Young *et al.*, 1986; Davie and Lant, 1994; Zheng, 2005; An *et al.*, 2008). In the past 50 years, approximately 5×10^9 ha (~43%) of the earth's vegetated land has been degraded by human land use and associated activities, and approximately 15% of the earth's total land area has been eroded (Blanco-Canqui and Lal, 2008). Soil loss is the most damaging aspect of erosion. High quantities of lost essential nutrients due to erosion result in phospho-

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rus and potassium enrichment ratios of 2 and 3, respectively (Flanagan and Foster, 1989; Sharpley *et al*., 1991; Sharpley, 1999; Brady and Weil, 2008). Zheng (2005) reported that nutrient enrichment in the eroded sediment of different geographical locations is significantly affected by deforestation and that nutrient loss is accelerated in the early stages after deforestation.

The total area of soil and water losses in China is 3.56×10^6 km^2, accounting for 37% of the total national territory in 2010 (Zhao and Yao, 2010; Ministry of Water Resources of China, 2011). Soil and water losses are distributed primarily in the middle and upper reaches of the seven main river basins, including the Changjiang (Yangtze) River, the Huanghe (Yellow) River, the Zhujiang (Pearl) River, the Haihe River, the Huaihe River, the SongLiao River and Taihu Basin. The annual economic losses stemming from such problems amount to approximately 2.25% of the gross domestic product (GDP), whereas it is difficult to estimate the environment losses (Zhao and Yao, 2010; Ministry of Water Resources of China, 2011). The total area of soil and water losses in Northeast China is 2.816×10^5 km^2 in 2004, accounting for 36.5% of the black soil area (Tang, 2004). In the past 200 years, cultivation and accelerated erosion events have increased soil and water loss, destroyed soil structure, and increased the mineralization of soil organic matter (SOM), and the content of SOM decreased from 6.00–15.06 mg/kg to 1.98 mg/kg (Yan and Tang, 2005; Liu *et al*., 2008; Wang *et al*., 2009). Consequently, significant decreases in the physical properties, chemical properties and bioactivity of the soil were observed (Wang *et al*., 2002; Han *et al*., 2009).

The restoration of vegetation depends on the improvements not only in species diversity but also in soil conditions. Conservation management practices pertain to the methods that improve soil quality in more ways than merely preventing soil erosion (Brady and Weil, 2008). The implementation of conservation policies and programs has effectively stabilized or reduced soil erosion in developed countries, but a room for improvement remains (Blanco-Canqui and Lal, 2008). In the past 20 years, much effort has been devoted to studying the effects of converting vegetation land cover into cultivated land on soil quality. Such initiatives include the Conservation Reserve Program (CRP) in the USA (Davie and Lant, 1994; Gilley *et al*., 1997b; Gilley *et al*., 2001) and the studies on soil erosion and degradation in severely eroded regions, such as the Loess Plateau (Tang *et al*., 1987; Zheng, 2005; 2006) and the red earth area (Tian *et al*., 2003; Zhang *et al*., 2004) in China.

The control of soil and water loss has a long history in China and in the world. Some conservation theories, insights, and practices discussed in literatures are still adopted today in some areas, such as the Hani Terraces in Yuanyang County of Yunnan Province and the Longji Rice Terraces in Zhuang Autonomous Region of Guangxi (Gao, 1983; Tang, 2004). Experimental results confirm enhancement in soil productivity and conditions caused by soil and water conservation practices, such as engineering projects/practices, agricultural-technical measures, biological methods, and comprehensive measures, which benefit soil quality through long-term implementation (Tang, 2004). Han *et al*. (2009) found that compared with slope farmland terraces in Northeast China, the soil physical properties were improved after a rotation cycle of conventional tillage and flat plowing. Results of field experiments show that the best management practices implemented in a series not only significantly reduce sediment loss in farmlands but also improve soil characteristics, such as soil structure. A proportion of large and small macro-aggregates and mean weight diameter (MWD), as well as the physical properties of soil (e.g., moisture, evaporation, saturated hydraulic conductivity, and compaction), have not deteriorated in over 10 years of continuous no-till crop production (Blevins *et al*., 1983; Lichter *et al*., 2008). Soil aggregate stability and MWD significantly improved because of the implementation of conservation practices in oil palm plantations in sloping lands (Moradidalini *et al*., 2010). Fu *et al*. (2000; 2004) pointed out that land use/cover change (LUCC) can affect the physical properties of soil, such as bulk density, moisture variation, soil infiltration, and evaporation, given the significant differences among the various types of land use. This result indicates that reducing human disturbance is a more effective soil and water conservation practice compared with other strategies. The results of Zheng *et al*. (2005) showed that the type of soil management affects the protection of the physicochemical properties of soil during the early stages of reforestation. Meanwhile, during the application of soil and water conservation practices, some unsuitable practices were applied and had negative effects because of the differences of polices, investment, and improper configurations of the

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soil and water conservation measures around the China, for instance, single tree species in the red earth area of South China (Zheng *et al*., 2008), small but old trees (low productivity trees) caused by water and nutrient deficiency (Tang, 1998), soil dry layer happened with excessive consumption of underground water by unsuitable selection of artificial vegetation or climatic drought (Zhang and Liu, 2009). As a result, a special attention should be paid to the change of soil quality when the soil and water conservation practices were applied.

The concept of soil quality has received greater attention since the 1990s (Karlen *et al*., 1990; 1997; Andrews *et al*., 2004; Blanco-Canqui and Lal, 2008). The conceptual definitions, assessment approaches and indicators of soil quality are still evolving (Wienhold *et al*., 2004; Blanco-Canqui and Lal, 2008; Yue *et al*., 2010). For the soil quality of soil and water conservation practices, the researches were focused on the effects of the CRP in the USA (Davie and Lant, 1994; Gilley *et al*., 1997b; Gilley *et al*., 2001; Blanco-Canqui and Lal, 2008) and the changes of soil condition in China (Zheng *et al*., 2005; Han *et al*., 2009). Soil property change or quality restoration is a complex and variable process affected by many factors, including LUCC, land preparation methods, vegetation types, management methods, treatment periods, conservation practices, and the history of agrotechnology. These factors considerably influence soil properties (e.g., SOC content, nutrients, soil bulk density (BD), compaction, texture, and moisture) and may exert a positive or negative effect on soil properties and productivity (Gebhardt *et al*., 1985; Staley and Boyer, 1997; Fu *et al*., 2004; Tang, 2004; Gianfreda *et al*., 2005; Blanco-Canqui and Lal, 2008; Yildiz *et al*., 2010; Ciais *et al*., 2011; Yüksek and Yüksek, 2011).

Little attention has been paid to the quantification of the effects of soil and water conservation practices on soil quality by using assessment tools in China, especially in Northeast China, wherein soil quality deterioration caused by accelerated erosion after deforestation has become a core environmental issue. In 1999, the Chinese government launched a large-scale project called Grain for Green, the duration, direction, and function of which are continuously debated by scientists (Xu *et al*., 2010; Gao *et al*., 2011; Xu, 2011). The resolution of such issues carries considerable implications for policy decisions and for the improvement of environmental quality in China.

The Jixing small watershed (~12.68 km^2) in the low mountain and hilly region of Northeast China serves as a study area for the researches of the effects of soil and water conservation practices on soil and water losses. The variations in soil properties should be investigated and assessed quantitatively after the implementation of soil and water conservation practices. Given the low mountain and hill features of the study area, five typical soil and water conservation practices were selected and compared with bare land (BL) and conventional tillage (CT). The findings of this study are expected to help determine the relationship between soil and water conservation practices and soil conditions and therefore enable the selection of more environmentally sustainable conservation practices that can guarantee the viability of ecological systems in Northeast China.

2 Materials and Methods

2.1 Study area

The Jixing small watershed is located in Jile town, Meihekou City, Jilin Province, Northeast China (42°10′–42°14′N, 125°29′–125°32′E), which belongs to the Huifa River system. The study area has an average annual temperature of 4.02℃, and annual precipitation is 708.80 mm, of which 70% falls from June to August. The altitude ranges from 392.80 m to 969.10 m, and the area is approximately 12.68 km^2. The region is characterized by low mountains and hills, where the gradient considerably changes in most sections of the slope. The length and width of the small watershed is 6.50 km and 1.95 km, respectively. The secondary forest vegetation consists of temperate deciduous forest, which covers over 81.40% of the total area. According to Keys to Chinese Soil Taxonomy, the main soil types of the study area include gray-brown earth, albic bleached soil, meadow soil, and Fluvisol (ISSCAS, 2001). Water erosion is the main erosion type in the watershed, where sheet erosion occurs at the cultivated slope. The area affected by soil loss amounts to approximately 5.98 km^2 in 2007, occupying 47.2% of the Jixing small watershed region. The slight, moderate, strong, and severe erosion areas encompass 5.40 km^2, 0.16 km^2, 0.28 km^2, and 0.14 km^2 in 2007, respectively. The annual soil erosion modulus is 1906.20 t/km^2 (Chen *et al*., 2006; Han *et al*., 2007). A gully density of 0.18 km/km^2 characterizes the

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landforms, and nine gullies have a total length of 2.30 km and an area of 0.92 ha. The area affected by soil and water losses in the cultivated land is 76.20 ha, accounting for 77% of the total cultivated land of the watershed (Han *et al*., 2007).

A field experiment on soil erosion was conducted at Jixing observation station, established in 2004, on the southern slope of the Jixing small watershed. Previous study results showed that the effects of soil and water conservation practices on saving water and reducing soil loss were significant (Chen *et al*., 2006; Han *et al*., 2007; Zhang *et al*., 2009), and the results indicated that the soil and water conservation practices were found to be significantly effective in conserving water and reducing soil loss, and the runoff was saved 86.41%, 66.06%, 82.36%, 98.68%, and 92.00%, and the soil loss was reduced 96.9%, 98.61%, 78.82%, 83.32%, and 99.96% in average by the soil and water conservation practices of ecological restoration (ER), vegetation-covered ridge (VR), shrub strips (SS), fish scale pit (FP) and furrow and ridge tillage across the slope (FR) compared with that of BL, respectively.

2.2 Sample plot

In this study, seven run-off plots were selected (Table 1), all of which were bare slopes initially. These plots were located in the same slope and had similar soil characteristics. Two plots, namely, bare land (BL) and a conventional tillage (CT), were selected as controls. The other five plots, including ER, FP, FR, SS, and VR were used for the tests on soil and water conservation practices. The land surface of BL is flat, smooth, and bare, whereas CT and FR are characterized by furrows and ridges. The plot of ER indicated fallow or natural restoration, and the other four practices were artificial restoration. The selection criteria for each run-off plot included slope length of 30 m, width of 5 m, and gradient of 7°. According to Chen *et al*. (2006), the two control plots (BL and CT) and the five plots of soil and water conservation practices (ER, FP, FR, SS and VR) were widespread and representative in Northeast China.

2.3 Soil sampling and analyses

Soil samples were collected in August 2008, four years after the start of the experiment. For each plot, soil samples at the depths of 0–20 cm and 20–40 cm were stratified and collected from the entire slope with an S-shaped distribution. The distance between the sample points was 3 m, and 18 soil samples were collected at per sample plot. The samples from each point were homogenized via hand mixing, and the major live plant material, debris, and pebbles were discarded. The samples were sealed in plastic bags, transported to the laboratory, and then air-dried.

Soil pH was determined by using a pH electrode in a suspended supernatant of 2.5 parts distilled water (CO_2 removed) to 1 part sieved soil (2 mm) on a V/W basis. The mechanical composition of the soil was measured in split samples (passed through a 2 mm sieve) by using the density method (Pansu and Gautheyrou, 2006) after mechanical dispersion of the soil with sodium hexametaphosphate ($(NaPO_3)_6$). Soil textures were determined by using the soil texture triangle map of the International Union of Soil Sciences (IUSS) (Huang, 2000).

Table 1 Sample plots of different soil and water conservation practices in study area

Plot	Practice	Condition	Main vegetation types
ER	Ecological restoration	Fallow without any human activity; rely on self-restoring capacity of nature	*Kobresia bellardatus*, *Leonurus heterophyllus*
BL	Bare land	Bare and smooth surface without any vegetation; weeds cut when coverage rate reaches more than 5%	Few weeds
VR	Vegetation-covered ridge	Ridge formed on sloping land such as strip tillage or contour with herbaceous plant; one ridge every 5 m	*Hemerocallis citrina*, weeds
SS	Shrub strips	Shrub planted methods on sloping land such as strip or contour; distance of 5 m between ridges	*Amorpha fruticosa*, weeds
FP	Fish scale pit	One group fish scale pit every 5 m in horizontal direction or by contours; every pit is planted with some vegetation	*Prunus* spp., *Eragrostis pilosa*, *Kobresia willd*, weeds
FR	Furrow and ridge tillage across slope	Cultivation methods on sloping land such as strip tillage or contour; distance of 0.65 m between ridges; ridge height of 0.20 m	*Zea mays*
CT	Conventional tillage (furrow and ridge tillage with downslope)	Cultivation methods on sloping land along slope; distance of 0.65 m between ridges; ridge height of 0.20 m	*Zea mays*

Notes: Selection criteria for each plot: length, 30 m; width, 5 m; gradient, 7°. ER, ecological restoration; BL, bare land; VR, vegetation covered ridge; SS, shrub strips; FP, Fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage

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Soil bulk density (BD) was determined by using a circle-knife, and field water-holding capacity (FC) was determined by saturating a subsample from each replicate, allowing drainage for 48 h under covered conditions to approximate field capacity and then drying the samples at 105℃ overnight to determine final water content (ISSCAS, 1981).

Following Bao (2000), we analyzed the chemical properties of the soil samples which were passed through a 1 mm sieve to remove rocks, large roots, and macrofauna. Soil organic carbon (SOC) was determined by using wet digestion with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4). Available nitrogen (N_{avi}, alkali-hydrolyzed nitrogen, without NO_3-N) was analyzed by using alkaline diffusion with 1 M NaOH and 20 g/L H_3BO_3; available phosphorus (P_{avi}, 0.5 M $NaHCO_3$ extractant, Olsen-P) was analyzed by using colorimetry; and available potassium (K_{avi}, 1 M NH_4OAC extractant) was determined by using a flame photometer.

Soil urease and alkaline phosphatase activity were determined by using a colorimetry, and invertase activity was measured via titration, as described by Guan and Zhang (1986), Guan *et al.* (1991), and An *et al.* (2008).

2.4 Calculation of soil quality index

Soil quality index (QI) is a useful way of determining soil degradation or improvement. Different properties have different roles in maintaining soil quality. In previous study, the QI was developed and calculated by using selected soil factor membership values and their weights as follows (Zhang *et al.*, 1999; Fu *et al.*, 2004):

$$QI = \sum_{i=1}^{n} W_i \times Q(x_i)\ , \tag{1}$$

where W_i is the weight vector of soil quality factor i, $Q(x_i)$ is the membership value of each soil quality factor, and x_i represents the physical, chemical, and geological properties selected for the soil quality.

$Q(x_i)$ was calculated by using the ascending and descending functions as follows (equations (2) and (3)). A descending function was used for BD as its high value often indicates soil degradation, while an ascending function was used for soil moisture, clay percentage, and chemical and biological properties (Li and Zhang, 1991; Fu *et al.*, 2004).

$$Q(x_i) = \left(x_i - x_{i\min}\right) / \left(x_{i\max} - x_{i\min}\right) \tag{2}$$

$$Q(x_i) = \left(x_{i\max} - x_i\right) / \left(x_{i\max} - x_{i\min}\right) \tag{3}$$

where $x_{i\ \max}$ and $x_{i\ \min}$ are the maximum and minimum values of the soil quality factor i, respectively.

Experience and mathematical statistics or models were used to assign the weights to the indicators (Wang, 1994). In previous study, principal component analysis (PCA) was used to determine the weight of each factor. The cumulative percentage of the principal soil quality components and the values of the component capacity score coefficients were calculated through SPSS using the membership values $Q(x_i)$, and then the weights of the soil quality factors (W_i) were calculated by using the component capacity score coefficient (Equation (4)) (Fu *et al.*, 2004).

$$W_i = C_i / \sum_{i=1}^{n} \left(C_i\right)\ , \tag{4}$$

where C_i is the component capacity score coefficient of the soil quality factor i.

2.5 Statistical analysis

The same samples were analyzed thrice and their average value was calculated. Analysis of variance was used to compare the effects of the different types of land use on soil properties. Triplicate soil samples and extracts enabled the estimation of the standard errors in each analysis. All the analyses were conducted by using the statistics analysis system (SAS) program (SAS Institute, Cary, North Carolina).

3 Results

3.1 Changes in soil physical properties

Compared to BL and CT, all of the soil and water conservation practices did not improve the physical properties of the soil, and not all physical properties were restored (Table 2). Soil moisture is a variable factor dependent on site conditions. The soil moisture of ER was significantly greater compared with those of the other land covers, of which SS exhibited the lowest value. The difference between the soil moisture of SS and of BL was not statistically significant (Fig. 1).

Only the field water-holding capacity (FC) in the ER plot improved, approximately 13.4% and 12.1% higher compared with those of BL and CT, respectively (Table

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2). The FC of the other four practices decreased compared with that of the controls. The soil bulk density (BD) of FP exhibited a statistically significant increase compared with those of the controls, and the BD of FP was the highest probably because of the cut-off drain formed by human compaction. The BD of the five practices were not improved compared with CT. In the short-term period, the soil and water conservation practices increased BD of the FP practice and the BD were 10.85% and 15.32% higher than those of BL and CT, respectively. However, compared with BL and CT, the FC decreased 1.16% and 2.23%, 9.28% and 10.27%, 4.52% and 5.56%, and 2.99% and 4.05% for the VR, SS, FP, and FR, respectively, while the FC of ER increased 13.37% and 12.14%, respectively.

Soil texture improved after the implementation of the five practices. The proportion of 0.02 mm to 0.002 mm particles increased at the depths of 0–20 cm and 20–40 cm in the five practices compared with those in BL and CT, indicating an increase of the soils particles only at the 20–40 cm depth except the 0.02–0.002 mm soil particles significantly decreased at the top 20 cm in VR. With regard to soil particle composition, the proportion of 2–0.02 mm particles was larger compared with those of the 0.02–0.002 mm and < 0.002 mm particles. Compared with BL and CT, all of the soil and water conservation practices did not improve soil texture. Particles of 2–0.02 mm were more abundant at the depth of 0–20 cm than 20–40 cm, while particles of 0.02–0.002mm and < 0.002 mm were fewer at 0–20 cm except of the SS practice. At the depth of 0–20 cm, the proportion of 2–0.02 mm particles in VR increased, but decreased in the other four plots. The proportion of 0.02–0.002 mm particles increased in all the plots to a higher level than that in BL. The proportion of < 0.002 mm particles in BL was the highest in both soil layers among all the plots. At the depth of 20–40 cm, the proportion of 2–0.02 mm particles in CT was the highest. Moreover, the VR had a greater number of particles compared with the other four plots, which exhibited the values lower than that of BL. The proportion of 0.02–0.002 mm particles in the ER, VR, SS, FP, and FR were higher compared with those in BL and CT. The proportion of < 0.002 mm particles in BL was the highest among all the plots. All the soil and water conservation practices only enhanced the proportion of 0.02–0.002 mm particles than that of BL and CT. The ER improved the physical properties of the soil at a statistically significant level compared with BL and CT did.

3.2 Changes in soil chemical properties

As shown in Fig. 2, the SOC content of BL was the

Table 2 Soil properties of the different soil and water conservation practices

Plot	Soil depth (cm)	pH	FC (%)	BD (g/cm^3)	Soil particle composition (%)			Soil texture
					2 mm to 0.02 mm	0.02 mm to 0.002 mm	< 0.002 mm	
BL	0–20	5.44±0.24c	32.76±0.36bc	1.29±0.00b	56±1.41ba	29±1.41i	17±2.83b	Sand clay loam
	20–40	5.48±0.06c	–	–	47±0.00fe	33±1.41fe	20±1.42a	Clay loam
CT	0–20	5.35±0.01c	33.12±0.02b	1.24±0.02c	55±0.00ba	31±1.41hg	13±0.00d	Loam
	20–40	5.73±0.09b	–	–	55±0.00ba	32±0.00fg	13±0.00d	Loam
ER	0–20	6.15±0.04a	37.14±0.20a	1.22±0.01c	53±0.00bc	34±0.00e	13±0.00d	Loam
	20–40	5.86±0.05b	–	–	45±0.00fg	38±0.00c	17±0.00b	Clay loam
VR	0–20	5.72±0.40b	32.38±3.20bc	1.23±0.01c	57±0.00a	30±0.00hi	13±0.00d	Sand clay loam
	20–40	5.88±0.02b	–	–	49±0.00de	36±0.00d	17±0.00b	Clay loam
SS	0–20	5.80±0.01b	29.72±2.52c	1.28±0.03b	53±0.00bc	34±2.00e	13±2.00d	Loam
	20–40	5.73±0.03b	–	–	41±0.00h	48±0.00a	11±0.00e	Silty loam
FP	0–20	5.41±0.16c	31.28±0.66bc	1.43±0.03a	43±6.00hg	42±0.00b	15±0.00c	Clay loam
	20–40	4.95±0.01d	–	–	35±0.00i	48±0.00a	17±0.00b	Silty clay loam
FR	0–20	4.12±0.00e	31.78±3.24bc	1.23±0.03c	51±0.00dc	33±1.41fe	15±0.00c	Clay loam
	20–40	5.09±0.08d	–	–	47±0.00fe	36±0.00d	17±0.00b	Clay loam

Notes: Mean values and standard errors are shown. Means with the same letter in the different rows are not significantly different at the 0.05 level, and the (–) symbol indicates no analysis. ER, ecological restoration; BL, bare land; VR, vegetation covered ridge; SS, shrub strips; FP, Fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage; FC, field water-holding capacity; BD, soil bulk density; pH was measured in 1∶2.5 soil-water suspensions. Soil texture was classified based on the Soil Texture Triangle Map of the IUSS (Huang, 2000)

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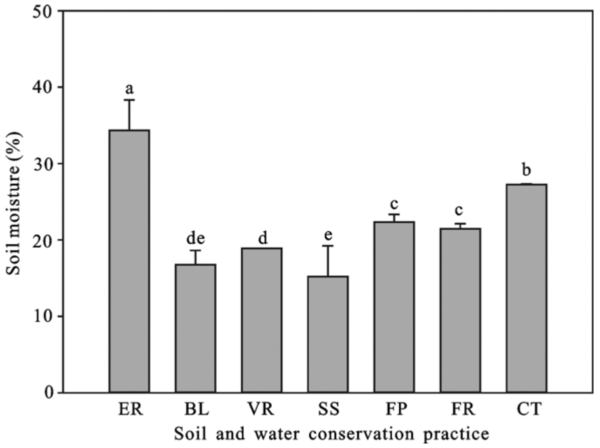

Fig. 1 Variations in soil moisture in different soil and water conservation practices (0–20 cm). BL, bare land; ER, ecological restoration; VR, vegetation covered ridge; SS, shrub strips; FP, fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage. Means with the same letter in different rows are not significantly different at the 0.05 level

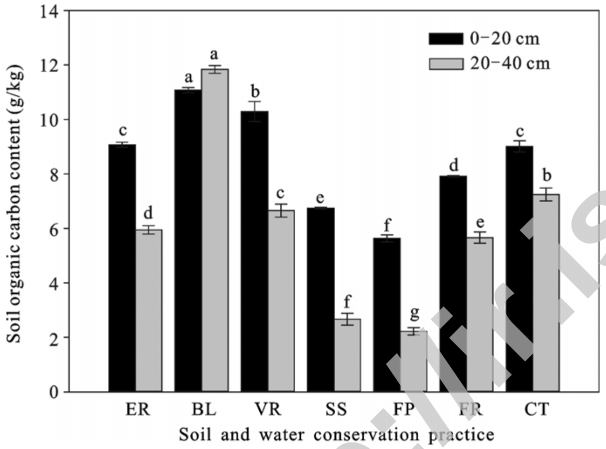

Fig. 2 Changes in soil organic carbon content in different soil and water conservation practices. BL, bare land; ER, ecological restoration; VR, vegetation covered ridge; SS, shrub strips; FP, fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage. Means with the same letter in different rows are not significantly different at the 0.05 level

highest not only at the 0–20 cm depth (11.1 g/kg), but also at the 20–40 cm depth (11.8 g/kg). The SOC content at the 0–20 depth was significantly lower than that at the 20–40 cm depth, except in BL.

Compared with the BL, in the 0–20 cm layer, the SOC contents of ER, VR, SS, FP, and FR decreased 7.3%, 39.2%, 49.3%, and 28.7%, respectively, and at the 20–40 cm depth, the SOC contents of ER, VR, SS, FP, and FR decreased 49.6%, 43.6%, 77.4%, 81.2%, and 52.0%, respectively.

Compared with CT, in the 0–20 cm depth, the SOC content of ER and VR increased 0.7% and 14.2%, respectively, and in the 20–40 cm depth, the SOC contents of the ER, VR, SS, FP, and FR significantly decreased 17.9%, 8.2%, 63.2%, 69.3%, and 21.9%, respectively. It indicated that not all soil and water conservation practices increased the SOC content.

From Table 2, it could be found that soil pH between 0–20 cm and 20–40 cm depths in ER, FP, FR, and CT exhibited statistically significant changes, while those in the other plots did not. In the 0–20 cm layer, pH of ER, VR, and SS were significantly higher than those of BL and CT. The pH of the FP and FR at the 20–40 cm depth were significantly lower than those of BL and CT.

The impact on the contents of alkali-hydrolyzed nitrogen (N_{avi}), available phosphorous (P_{avi}), and available potassium (K_{avi}) was different by the ER, VR, SS, FP, and FR, and the contents of N_{avi}, P_{avi}, and K_{avi} at both 0–20 cm and 20–40 cm depths were significantly higher in the ER than those of BL and CT (Fig. 3). The upper 20 cm of the ER had the highest available nutrient at 129.5 mg/kg, 30.6 mg/kg, and 306.1 mg/kg for N_{avi}, P_{avi}, and K_{avi}, respectively. As can be seen from Fig. 3a, VR enhanced N_{avi} content in both depths than that of BL, while the SS, FP, and FR did not. The P_{avi} contents for VR and FR increased 24.4% and 14.2% in the 0–20 cm depth and 29.6% and 26.4% in the 20–40 cm depth compared with those of BL, which were statistically significant (Fig. 3b). Moreover, the P_{avi} contents for SS and FP were significantly lower in the 0–20 cm depth while significantly higher in the 20–40 cm than those of BL. The K_{avi} contents in both depths of the SS, FP, and FR were significantly lower than those of BL, and only the ER and VR could enhance the K_{avi} content compared with the CT (Fig. 3c). Consequently, it was difficulty to improve the condition of N_{avi}, P_{avi}, and K_{avi} in short-term period through the application of soil and water conservation practices.

3.3 Changes in soil enzyme activities

The invertase, urease, and alkaline phosphatase activities in the upper 20 cm were significantly higher than those in the 20–40 cm layer, except for the urease activity in BL. The FP exhibited the lowest values in both depths (Fig. 4), e.g., in the 0–20 cm depth, invertase activity of 5.40 glucose mg/g/24h; urease activity of 472.00 NH_3-N mg/kg/24h; and alkaline phosphatase

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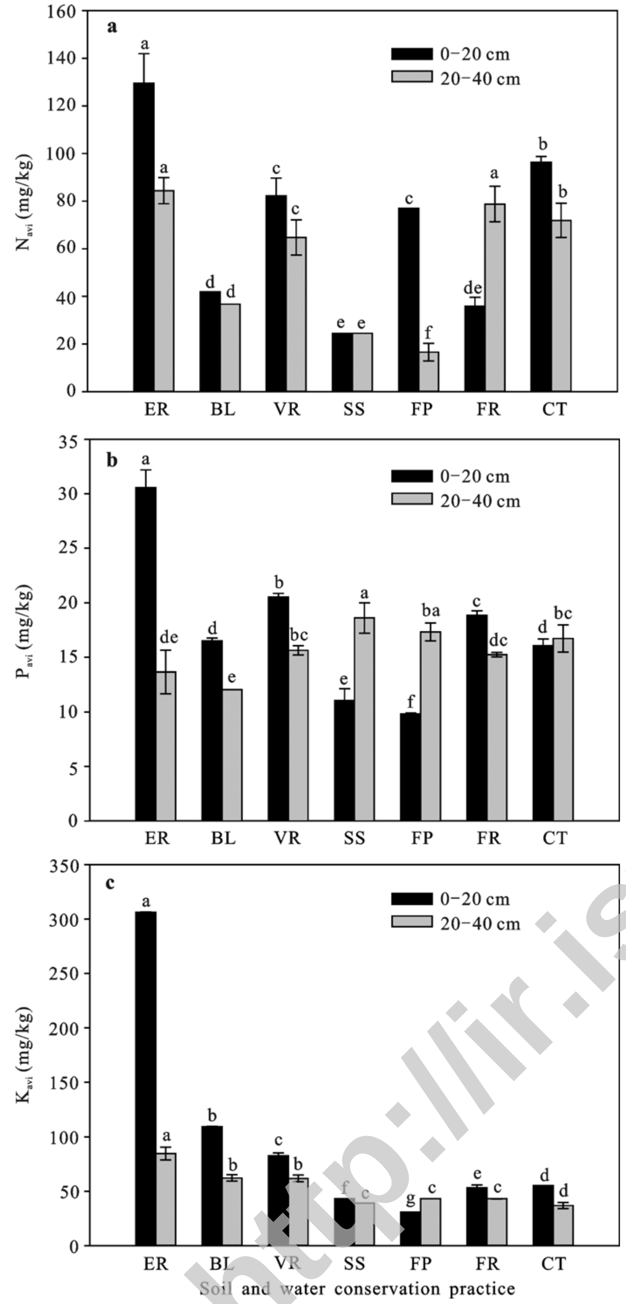

Fig. 3 Changes in alkali-hydrolyzed nitrogen (N_{avi}) (a), available phosphorous (P_{avi}) (b), and available potassium (K_{avi}) (c) contents in different soil and water conservation practices. BL, bare land; ER, ecological restoration; VR, vegetation covered ridge; SS, shrub strips; FP, fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage. Means with the same letter in different rows are not significantly different at the 0.05 level

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activity of 1021.20 phenol mg/kg/24h; in the 20–40 cm depth, the invertase activity of 0.90 glucose mg/g/24h; urease activity of 214.00 NH_3-N mg/kg/24h; alkaline phosphatase activity of 139.20 phenol mg/kg/24h. It showed that not all human activities enhanced soil enzyme activities.

Compared with BL, only ER improved the invertase activity in the 0–20 cm depth (Fig. 4a). The ER, VR, and FR significantly increased urease activity at the 0–

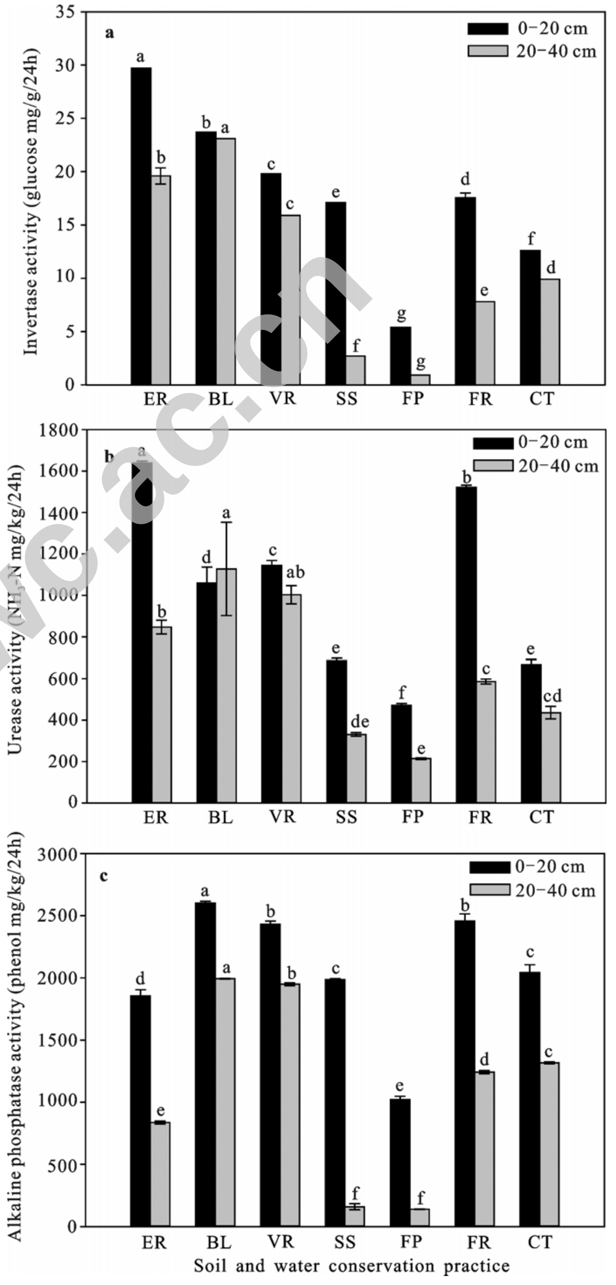

Fig. 4 Change of soil enzyme activities under different soil and water conservation practices. a, invertase activity; b, urease activity; c, alkaline phosphatase activity. BL, bare land; ER, ecological restoration; VR, vegetation covered ridge; SS, shrub strips; FP, fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage. Means with the same letter in different rows are not significantly different at the 0.05 level

20 cm depth by 54.7%, 8.1%, and 43.7%, respectively. However, the urease activity decreased for all the practices at the 20–40 cm depth (Fig. 4b). No conservation practice improved alkaline phosphatase activity, which reduced to a lower content than that in BL (Fig. 4c).

The invertase activity at the 0–20 cm depth under all conservation practices, except that under FP, significantly increased statistically compared with that under CT (Fig. 4a). Invertase activities increased 135.7%, 57.1%, 35.7%, and 39.3% in the ER, VR, SS, and FR, respectively. At 20–40 cm depth, the invertase activities in ER and VR increased 97.9% and 60.6%, respectively. In the ER, VR, and FR, the urease activities significantly increased in both soil depths, and urease activities increased 145.7%, 71.7%, and 128.2% at the 0–20 cm depth and 94.3%, 130.1%, and 34.4% at the 20–40 cm depth, respectively (Fig. 4b). Only VR significantly enhanced the alkaline phosphatase activities in both layers with 19.1% and 48.1%, respectively, and FR exhibited an improvement in alkaline phosphatase activity in the 0–20 cm depth (Fig. 4c). The above results indicated that the FP was not applicable to ate soil enzyme activities in the present study.

3.4 Soil quality characteristics

Given the absence of several soil properties in the 20–40 cm depth, the soil quality index was calculated by the soil properties in the top soil layer of 0–20 cm. The calculated integrated soil quality index (QI) reflects the relative soil quality degree of the different soil and water conservation practices. The membership values ($Q(x_i)$) of each soil quality factor under different soil and water conservation practices were calculated by using equations 2 and 3, and the results are shown in Table 3.

As can be seen from Table 4, the cumulative percentage of the principal soil quality factors components was calculated by using the PCA program, and the top six principal factors that influenced soil property in this study included P_{avi}, alkaline phosphatase, FC, clay particle, SOC, and N_{avi}.

From Table 5, we could find the weights of the soil quality factors (W_i) calculated by Equation 4. In this study, W_i was calculated by using the four component capacity scores because their cumulative percentage reached 91.08%. The integrated quality index (QI) was further derived from Equation 1.

Figure 5 shows the QI values under different soil and water conservation practices. The QI values for ER, BL, VR, SS, FP, FR, and CT were 0.886, 0.523, 0.543, 0.248, 0.131, 0.477, and 0.449, respectively. The results indicated that the soil and water conservation practices resulted in significantly different soil quality levels. The QI values varied significantly from 0.131 to 0.886, in which the ER and FP exhibited the highest and lowest *QI* values, respectively.

4 Discussion

4.1 Effects of soil and water conservation practices on soil physical properties

Erosion significantly affected the native structure of soil (Poesen and Nearing, 1993; Nearing *et al.*, 1994). The

Table 3 Values of membership functions of soil quality factors under different soil and water conservation practices (0–20 cm)

Factor	ER	BL	VR	SS	FP	FR	CT
X_1 (BD)	1.000	0.667	0.952	0.714	0.000	0.952	0.905
X_2 (FC)	0.458	0.278	0.210	0.000	0.358	0.410	1.000
X_3 (soil moisture)	1.000	0.082	0.194	0.000	0.373	0.327	0.630
X_4 (clay particle)	0.000	1.000	0.000	0.000	0.500	0.500	0.000
X_5 (pH)	1.000	0.650	0.788	0.828	0.635	0.000	0.606
X_6 (SOC)	0.632	1.000	0.857	0.204	0.000	0.419	0.619
X_7 (N_{avi})	1.000	0.167	0.551	0.000	0.500	0.108	0.683
X_8 (P_{avi})	1.000	0.322	0.516	0.059	0.000	0.435	0.299
X_9 (K_{avi})	1.000	0.285	0.187	0.045	0.000	0.081	0.089
X_{10} (urease activity)	1.000	0.503	0.577	0.183	0.000	0.900	0.167
X_{11} (invertase activity)	1.000	0.753	0.593	0.481	0.000	0.500	0.296
X_{12} (alkaline phosphatase activity)	0.528	1.000	0.893	0.611	0.000	0.910	0.646

Notes: BD, soil bulk density; FC, field water-holding capacity; SOC, soil organic carbon; N_{avi}, alkali-hydrolyzed nitrogen, P_{avi}, available phosphorous, K_{avi}, available potassium

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Table 4 Cumulative percentage of principal soil quality factors components

Component number	Percentage of variance (%)	Cumulative percentage (%)
1	44.42	44.42
2	24.91	69.33
3	12.73	82.06
4	9.02	91.08
5	7.42	98.50
6	1.50	100.00
7	0.00	100.00
8	0.00	100.00
9	0.00	100.00
10	0.00	100.00
11	0.00	100.00
12	0.00	100.00

Table 5 Values of component capacity and weights of soil quality factors

Factor	Capacity	W_i
X_1	0.332	0.103
X_2	0.098	0.030
X_3	0.282	0.087
X_4	0.130	0.040
X_5	0.135	0.042
X_6	0.274	0.085
X_7	0.268	0.083
X_8	0.423	0.131
X_9	0.381	0.118
X_{10}	0.351	0.109
X_{11}	0.374	0.116
X_{12}	0.176	0.055

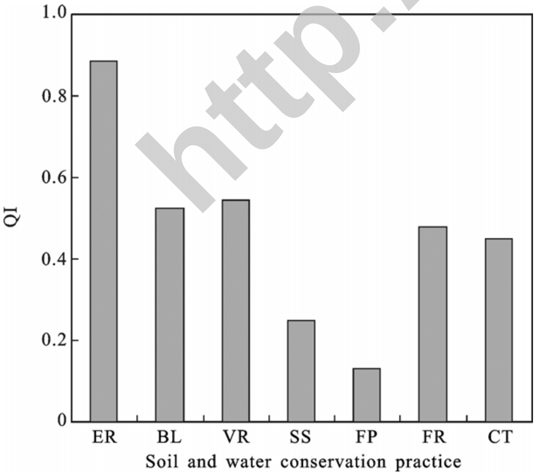

Fig. 5 Soil quality index (QI) under different soil and water conservation practices. BL, bare land; ER, ecological restoration; VR, vegetation covered ridge; SS, shrub strips; FP, fish scale pit; FR, furrow and ridge tillage across the slope; CT, conventional tillage

rehabilitation of eroded and degraded land necessitates appropriate management. Repairing or enhancing soil quality took a long time. Surface particles removed by accelerated erosion decreases infiltration, increased surface runoff, and further degrades the physical properties of soil (Zhang and Horn, 2001; Wei *et al.*, 2006; An *et al.*, 2008). Severely but not reversibly degraded soils might take as long as 100 years to return to a self-sustaining state suitable for agriculture (Blanco-Canqui and Lal, 2008). Canopy and surface litter could effectively control water- or wind-induced soil erosion, as well as water and water quality losses (Baker and Laflen, 1983; Gebhardt *et al.*, 1985; Zheng *et al.*, 2004; Hazel *et al.*, 2008). Degraded soil with topsoil might take 20 years to recover, but this duration could be reduced to three to five years with proper management. However, the recovery of self-sustaining, mature ecosystems in areas that were unsuitable for intensive agriculture may take 100 years or more (Daily, 1995). Seybold *et al.* (1999) reported that the recovery periods for soil with macroporous topsoil, 90% of BD, 71% of particle density, and 33% and 100% of aggregate stability were 24, 50, 79, 10, and 45 years, respectively. Han *et al.* (2009) also found that compared with slope farmland terraces in Northeast China, lands treated via conventional tillage and flat plowing after a rotation cycle exhibited decreased soil bulk density (0.12 g/cm^3), increased total porosity (1.97% to 2.93%) and infiltration rate (0.40 mm/min), and elevated water-stable aggregate content (> 0.25 mm) in the arable layer of minimum tillage. Conventional tillage and flat plowing increased water-stable aggregate content by approximately 14.4% and 19.7%, respectively. According to Yüksek and Yüksek (2011), soil field capacity, permanent wilting point, plant available water, and saturated hydraulic conductivity increased but BD decreased in the depth of 0–10 cm in Turkey′s semi-arid region after a nearly 10-year plantation period. In this study, not all of the soil and water conservation practices could improve soil properties, particularly the physical characteristics, at the top 20 cm, and not all soil physical properties could be improved by the soil and water conservation practices in the short-term.

4.2 Effects of soil and water conservation practices on soil chemical properties

The chemical properties of the soil were affected by an

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excessive number of complicated and diverse factors. Sparling *et al*. (2003) thought that resilient soils not only improved the physical properties rapidly (< 15 yr) but also enhanced chemical and biological properties, however, the soil chemical properties recovery could take long time (100–150 yr) to reach the pre-undisturbed or equilibrium levels, 59 yr following degradation, pH, mineral N, total C, N and P, CEC had recovered 71%–85% while soil respiration as compared with non-degraded soils. Our results showed that not all soil and water conservation practices could increase the values of the soil chemical properties, and not all of the soil chemical properties, especially SOC, in Jixing small watershed were rehabilitated by the conservation practices. Moreover, the original SOC might have been depleted or mineralized after the implementation of the practices, indicating that more time is needed for the SOC to be restored (Brady and Weil, 2008). Among the soil properties, SOC or soil organic matter (SOM) was a sensitive indicator of soil quality that served as a suitable indicator of soil quality within a narrow soil range (Murage *et al*., 2000, Sparling *et al*., 2003). The SOM fraction might offer further insights on soil structure, texture, water-holding capacity, fertility changes, and availability, as well as the sustainability of past management practices (Barrios *et al*., 1996; Kapkiyai *et al*., 1998; Wu *et al*., 2007). However, the effects of conservation practices on SOC dynamics were indeterminate because the SOC dynamics was often complex and variable (McCarty *et al*., 1998; Al-Kaisi *et al*., 2005; Liang *et al*., 2007). Conservation practices (e.g., no-till, crop rotation, cover crops, crop residues, and manure application) were key not only for controlling soil erosion (runoff and water loss), but also for improving productivity, C storage, and C emission reduction (Blanco-Canqui and Lal, 2008). This result might be attributed to the disturbances caused by human activities, such as the cutting and removal of weeds every fall, as well as the land preparation every spring. These activities reduced SOC accumulation, even with the growing consumption of the land′s crops, coupled with the decomposition of soil exposed to air. Organic matter in cultivated soil had less physical protection than organic matter in uncultivated soil because of the removal of large quantities of biomass during land clearing, a reduction in the quantity and quality of organic input to the soil, and the increase in SOM decomposition rates (Blair *et al*., 1995; West and Post, 2002). These results indicated that cultivation decreased soil nutrient contents. The higher decomposition rates could be attributed to the enhanced biological activity caused by soil mixing from tillage and higher temperatures from increased soil exposure (Barber, 1995). In addition, tillage or land preparation periodically broke up macro-aggregates and exposes previously protected organic matter in soil macro-aggregates. Yüksek and Yüksek (2011) evaluated the soil nutrient contents, soil nitrogen transformation rates, and annual litter-fall biomass and nitrogen concentrations in 20 yr to 35 yr old of invasion with paired pine-oak and adjacent black locust stands, the results showed that long-term proper restoration or plantation methods can improve the nutrition conditions of soil.

The humus and nutrition contents (e.g., N, P, and K) decreased because of the damages in natural flora (Niu and Wang, 1992; Gregorich *et al*., 1998; Navarrete and Tsutsuki, 2008). During the implementation of the conservation practices (e.g., in the terraces), the original tillage layer (from 0 cm to 20 cm) with abundant soil microbes was buried, the release and decomposition of organic nutrition were affected by the decrease in the amounts of fungi and bacteria in the 0–20 cm depth. This phenomenon, which was caused by poor physical conditions and nutrition (Tang, 2004), loss of TN, TK, and available P and SOM in terrace fields, was reduced to approximately 97.9%, 97.1%, 96.7%, and 97.3%, respectively (Han *et al*., 2009). In the US, minimum-till or no-till management systems reduce soil quality, particularly in terms of TN, as observed in the Conservation Reserve Program (CRP) lands converted to croplands (Davie and Lant, 1994; Gilley *et al*., 1997a; 1997b; 2001). In the present study, the application of soil and water conservation practices on eroded soil was shown to result in important short-term changes in soil nutrients. The negative or positive effects of different practices on soil chemical properties (e.g., N_{avi}, P_{avi}, and K_{avi}) in Jixing small watershed were also observed by Tian *et al*. (2010) and Yüksek and Yüksek (2011).

4.3 Effects of soil and water conservation practices on soil enzyme activities

The effect of disturbance on soil quality was difficult to determine because of the inherent variability of soil. Moreover, physical and chemical soil properties changed too slowly to reflect recent management history. Mi-

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crobial and biochemical soil properties have been suggested as early and more sensitive indicators of changes in soil quality than soil C because they manifested shorter timescales and were crucial to the ecological function of soil, thereby resulting in larger spatial and temporal variability (Karlen *et al*., 1994; Bandick and Dick, 1999). Soil enzyme activities were increasingly used as indicators of soil quality because of their relationships with decomposition and nutrient cycling, ease of measurement, and rapid response to changes in soil management (Dick, 1994; Dilly *et al*., 2003). Kandeler *et al*. (1999) found that enzyme activities at the top 10 cm of the soil profile were significantly increased after only two years of minimum and reduced tillage compared with conventional tillage. On the other hand, significant effects of tillage treatments on microbial biomass, N mineralization, and potential nitrification were observed only after four years (Geisseler and Horwath, 2009). The results of this study showed that soil and water conservation practices significantly affected soil enzyme activities, but these changes were indeterminate. In the studies on small practice plot-induced effects, enzyme activities from single-sampling data should be interpreted with caution. The observed changes of the soil enzyme activities might not be caused solely by the implemented practices. Our findings were similar with those of Yang *et al*. (2010), that is, soil enzyme activities were significantly affected by tillage, cropping systems, and land use (e.g., the CRP), all of which were correlated with other soil properties. Geisseler and Horwath (2009) also found similar results, which were, the significant effects of tillage treatments on microbial biomass, N mineralization, and potential nitrification were observed only after four years. Fifty nine years following degradation, invertase and sulphatase activities had recovered 94%–110% while soil respiration as compared with non-degraded soils (Sparling *et al*., 2003).

4.4 Effects of soil and water conservation practices on soil quality

Previous researches were not limited to single soil property (Wang and Gong, 1998), but was concentrated on the evaluation of multiple soil properties (An *et al*., 2008; Yüksek and Yüksek, 2011). Some studies were focused on the soil quality with LUCC by experience and by using mathematical statistics or models (Zhang *et al*., 1999; Fu *et al*., 2000; 2004; Cao *et al*., 2008; Levi *et al*., 2010; Xu *et al*., 2010). The FP exhibited the lowest QI value because of human disturbances in this study, and it agrees with the results of Fu *et al*. (2004), who stated that reforested land and cultivation decrease soil quality levels. However, in previous study, the SS did not have a high soil quality level (Fu *et al*., 2004) because the soil was disturbed when the shrub strips were shaped by humans. The results of the FP and SS indicated that human disturbances tended to trigger degradation succession (Fu *et al*., 2004). The QI of VR and FR indicated that vegetable cover and contour cultivation could be used to improve soil properties as they controlled soil loss better compared with BL and CT, respectively (Han *et al*., 2007; Zhang *et al*., 2009). Meanwhile, the ER with high quality level could be used to restore or maintain soil property as it could decrease soil erosion and improved soil conditions in an ecosystem (Wang *et al*., 2002; Chen *et al*., 2006; Han *et al*., 2007; Han *et al*., 2009; Zhang *et al*., 2009). Therefore, the ′close to nature′ or ′leave nature as it is′ approach might be better than the policy of ′changing farmland to forest land′ or ′afforestation and reforestation′ (Fu *et al*., 2004; Gao *et al*., 2011; Xu, 2011) in controlling soil loss and recovering the soil quality in the low mountain and hilly region of Northeast China during the early period.

5 Conclusions

In the low mountain and hilly region of Northeast China, the soil physical, chemical and biological properties exhibit significant differences among the different soil and water conservation practices. Compared with the BL and CT, not all soil and water conservation practices can improve soil properties and not all soil properties can be recovered in short-term. In the short-term, ER may be a better alternative for the rehabilitation of erosion-depleted soil condition.

An integrated quantitative method is developed to compare the soil qualities under different soil and water conservations practices. The results show that soil quality index (QI) under fiver soil and water conservations practices was in the order of ER > VR > FR > SS > FP. The ER can be used to restore the soil properties of areas where the conditions are suitable for the secondary succession of local vegetation. The ER may be a better approach for improving soil quality than the conversion

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of farmlands to planted grasslands and woodlands in soil reclamation projects for eroded sites in the low mountain and hilly regions of Northeast China.

Controlling soil and water losses is only the first task, the soil quality reclamation is the ultimate goal of the conservation practices. From the results of this study, the soil quality rehabilitation should be considered as a long-term goal of different soil and water conservation practices, rather than short-term goal. Further research is necessary to better understand the interactive relationships among landscape properties, ecosystem properties, soil erosion, soil nutrients, and LUCC, including its history and management. Long-term effects of different soil and water conservation practices on soil property should be investigated further.

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