Front. For. China (2006) 4: 394–399
DOI 10.1007/s11461-006-0043-3

RESEARCH ARTICLE

AN Shaoshan, HUANG Yimei

Rapid changes of soil properties following *Caragana korshinski* plantations in the hilly-gully Loess Plateau

Abstract In the semi-arid area of the Loess Plateau, *Caragana korshinski*, a leguminous shrub, is the dominant plant species widely used in vegetation rehabilitation programs. We collected soil samples in 8- and 18-year-old *C. korshinski* plantations to assess the effects of the shrub on the physical and chemical properties of the soil as well as enzyme activities. Soil samples were taken from two depths (0–20 and 20–40 cm) under the shrub canopy between shrubs. Results showed that shrub rehabilitation and development enhanced accumulation of organic C and total N. Carbon and nitrogen concentrations increased significantly with plantation age and had increased by 15.3–20.5-fold and 11.1–13.6-fold at 0–20 cm depth at the 18-year-old plantation compared with farmland soil. It was found that *C. korshinski* contributed significant enrichment of C and N contents under their canopies compared with farmland. The content of water stable aggregates in 18-year-old shrub land soil is higher than the 8-year-old shrub land, and the big aggregates (>5 mm) increased for the most part, by 67.4% and 59.0% in different layers, respectively. The contents of aggregates of over 0.25 mm in two shrub land soils in the upper layer (0–20 cm) increased by 4.6% and 14.1% compared with farmland. It indicates that *C. korshinski* afforestation can increase the content of aggregates. *C. korshinski* plantation can accelerate the increase of soil urea activity and invertase activity, respectively, especially in the upper layer.

Keywords *Caragana korshinski*, soil properties, plantation chronosequence, rehabilitation

1 Introduction

Loess plateau ecosystems have been affected by various forms of human activities for millennia. During the last century, fragmentation and degradation of the ecological environment have accelerated due to the increasing population pressure (Fu et al., 2000). In order to withstand the further deterioration of the natural ecosystems, the Chinese government has launched a series of nation-wide conservation projects focusing on the construction and recovery of these damaged ecosystems. As for the Loess Plateau, one of the most emergent tasks may be the recovery of the vegetation due to its crucial and sustainable agricultural development. The impacts of human activity on the Loess plateau were basically characterized by continuous and widespread stress like over-grazing and large-scale monocultures (wheat and maize).

To rehabilitate eroded lands and improve regional eco-environments, some successful measures are suggested, such as fish scale and inter-planting of shrub and grass, planting indigenous trees, shrubs and grasses adaptive to the eroded land. Large areas of artificial shrub forest on degraded land were established as soil and water conservation binders, which should give rise to significant changes in the local ecosystem. Information on these changes is required for a better understanding of the restoration mechanisms, the interactions between soil and plant communities, and for appropriate management and conservation of the environment in the Loess Plateau. The objective of the present study was to identify changes in soil properties following the establishment of artificial *Caragana korshinski* plantations on eroded land.

Translated from *Scientia Silvae Sinicae*, 2006, 42(1): 70–74 [译自: 林业科学, 2006, 42(1): 70–74]

AN Shaoshan (✉)
Institute of Soil and Water Conservation,
Chinese Academy of Sciences and Ministry of Water Resources,
Yangling 712100, China
E-mail: shan@ms.iswc.ac.cn

AN Shaoshan, HUANG Yimei
College of Resources and Environment,
Northwest Agricultural and Forestry University,
Yangling 712100, China

2 Materials and methods

2.1 The study area

This study area lies within 35°59′–36°02′N and 106°26′–106°30′E. Of the region, 90% is hilly, 4% is villages, rivers and lakes, and only 6% is considered suitable for intensive agriculture. The study area has a sub-arid climate characterized by heavy seasonal rainfall with periodic local flooding and drought. The average annual rainfall at the experimental site is 400 mm (1941–2000; C.V. 18%) with distinct wet and dry seasons. The rainy season starts in July and continues up to October, with a sharp increase in the rainfall from July to October and the July rainfall accounting for 24% of the annual rainfall. The reported annual evapotranspiration is approximately 1,000 mm leaving a potential rainfall excess of 1,000 mm per year. Most of the lands are located within a 1,600 m elevation and are closely dissected and sharp-edged with steep and very steep slopes. The mean annual temperature is 7°C and the slopes are deep (>20%), and the soil is slightly alkaline (pH 7.8–8.2). Soil profiles were described along transects at three locations of the hill slopes (upper, middle and lower); and soil samples were collected for physical, chemical, and mineralogical characterization. Morphologically, little differentiation within the horizons, texture and color in the regolith material was observed.

2.2 *Caragana korshinski* plantations and management

C. korshinski, a leguminous shrub, is widely distributed in the Loess Plateau and is a favored plant for restoring vegetation on eroded land (Cao et al., 2000). *C. korshinski* was widely planted on steep slope land around the experimental area. Planting was arranged in belts (row spacing 3 m, neighboring plant seedling spacing 1.5 m) and the orientation of the belts was parallel to the contour to prevailing soil erosion. Before planting, the dominant plant species on the eroded land were *Stipa bungeana*, *Heteropappus attaicus*, *Artemisia giraldii*, *Thymus mongolicus*, and so on. The vegetative cover was generally less than 10%; and water erosion often occurred during the summer and autumn rainy season. The soils had low organic matter content (0.8 g/kg organic C content) (An et al., 2006). *C. korshinski* grew into 1 m high shrubby belts 3–5 years after planting. With gradual stabilization of the eroded land, some short grasses, legumes and forbs invaded, and a stabilized shrubby-grass vegetation system was established. To date, an age series of 8-, 18-year-old *C. korshinski* plantations is distributed surrounding the village. After 10 years of *C. korshinski* growth, older shoots were pruned to facilitate regeneration. The 8- and 18-year-old plantations have undergone light livestock grazing in recent years.

Table 1 Morphological traits of *C. korshinski* by plantation age

Trait	Plantation age /year	
	8	18
Mean height /cm	98.8	108.3
Crown diameter	98.1 cm×86.3 cm	105.9 cm×89.2 cm
Number of shoots (N)	28	34
Ground diameter /cm	1.02	1.22

Values are means of 40 measurements

2.3 Study approach and sampling design

A common approach in studies of soil rehabilitation in relation to vegetative cover is to monitor plant and soil changes occurring along a vegetative chronosequence developed on similar soils under similar climatic conditions (Bhojvaid and Timmer, 1998). This chronological approach has been widely used in applied ecosystem research (Vernberg, 1988; Fang and Peng, 1997) and is considered ‘retrospective’ research because existing conditions are compared with known original conditions and treatments (Bhojvaid and Timmer, 1998).

The retrospective approach was adapted in this study because of the availability of closely located *C. korshinski* plantations established 8-, 18-years ago on eroded soils with similar properties. The plantations, therefore, provide a time gradient of shrub occupancy on similar sites. Changes in soil properties can be measured by comparing sites of different ages. Within each plantation (age of 8 and 18 years), three sites were selected as samples (three replicates). In addition, three non-vegetated land in the vicinity of the planted sites (farmland) were chosen as a control for the chronosequence. It was assumed that the soils of each site were similar prior to planting shrubs.

2.4 Soil sampling and analysis

Soil samples were collected in August 2003. In the two plantations (age 8 and 18), samples were taken from three *C. korshinski* belts. At each location, a composite soil sample from two depths (0–20 and 20–40 cm) was collected from five sampling points. Soil samples were taken from 0 to 20 cm depth using a shovel, and from 20 to 40 cm depth using a 5-cm diameter soil auger. Soil was collected under the shrub canopies as close to the center of the shrub as possible. The original samples for soil aggregates analysis were collected by plastic box without being disturbed.

Soil samples were air-dried and passed through a 2-mm sieve. Part of the air-dried and sieved samples was ground and passed through a 0.25-mm sieve for C and N analysis. Analytical methods for the determination of soil chemical properties: Soil pH was measured the day of collection in 0.01 mol/L $CaCl_2$, with a fresh weight/volume ratio of 1:2, the suspensions were swirled, and the pH electrode was placed in suspended supernatant (Multiline F/SET-3, Germany). Organic carbon content (ORGC) was determined by wet digestion with a mixture of potassium dichromate and concentrated sulfuric acid. Organic C was determined by dichromate oxidation of Walkley-Black, and total N was measured by the Kjeldahal procedure (ISSCAS, 1978).

Determination of soil aggregate stability and sand content: soil aggregate stability was determined by the revised Yoder method. Since the influence of the initial water content on aggregate breakdown had been noted, a wet sieving test with a single sieve was used for both air-dried and pre-wetted samples. For the determination of the air-dried aggregate stability, we dropped 10 g of the samples (1–2 mm) on a sieve with an opening of 0.25 mm placed in water. Then, we sieved them by raising and lowering with a distance of 5 cm at a strike of 30 times per minute for 5 min.

Invertase activity: For the determination of invertase activity, 15 mL of sucrose solution were used as the substrate. Soil portions were incubated at 37°C for 24 h with 5 mL of maleate buffer at pH 5.5. The samples were then filtrated quickly. Extract 1 mL to 50 mL flask and 3 mL dinitryl-salicylic was added, and then was extracted and determined at 508 nm. Assays without soil and without buffer were made at the same time as the control.

Urease activity was determined by Colorimetric technique. A phosphate buffer of 2 mL with pH 7 and 0.5 mL 1.066 mol/L urea were added to 0.25 g soil samples and then the samples were incubated at 30°C for 90 min and the volume was increased up to 10 mL with distilled water. The ammonium released was measured using an ammonium selective electrode. A control without urea was used with each sample.

Neutral phosphatase: soil samples were incubated for 1 h at 37°C, the p-nitrophenol released by phosphomonoesterase activity is extracted and colored with sodium hydroxide and determined photometrically at 400 nm.

3 Results

All results are the means of three replications. Data were subjected to analysis of variance using DPS software.

3.1 Soil chemical properties

The establishment and development of *C. korshinski* resulted in an enrichment of organic C and total N in the eroded soils (Table 2). Carbon build up at the 0–20 cm depth under the shrub canopy increased 2.10, 1.91-fold, respectively from the alley (8.53 g/kg, age 0) after 8, and 18-years of shrub occupancy. Total N accumulation followed the same pattern with respect to plantation age, but the values of increase were higher than those of C, with a 3.6-fold increase under the canopy and a 1.4-fold increase in the alley observed in the soil after 8 years of shrub growth (Table 2). With increasing plantation age, the C and N levels both generally increased under the shrub canopy. Soil organic C and total N levels declined sharply at the 20–40 cm depth in the plantations of all ages.

3.2 Soil physical fertility

Soil mechanics has a very important role in soil formation and agricultural land utilization. One remark of soil degradation is the sandification of soil texture. The data are shown in Table 3, where the content of clay in different shrub land shows that 18-year-old > 8-year-old shrub land>farmland. The content in the upper layer (0–20 cm) in 18-year-old shrub land soil increased to 69 g/kg than 8-year-old, the lower layer (20–40 cm) also increased (58 g/kg). The content of fine silt in 18-year-old shrub land is 50 g/kg and 44 g/kg in the two layers, respectively than 8-year-old shrub land in the two layers, but is higher than farmland. However, the content of sand is different, with 8-year-old shrub land having higher content than 18-year-old, which means that plant rehabilitation can increase the content of clay.

Soil aggregates structure is the main index of evaluating the soil quality and degradation degree, which shows the role of the composition of aggregates and micro-aggregates (Amezketa, 1999). The data are shown in Tables 3 and 4. The content of water stable aggregates in 8-year-old shrub land soil is higher than 18-year-old old shrub land, and the big aggregates (>5 mm) showed the most increase by 67.4%

Table 2 Soil properties of different ages of *Caragana korshinski*

Vegetation types and ages	Soil depth /cm	T.O.C /(g·kg^{-1})	Total N /(g·kg^{-1})	Available N /(mg·kg^{-1})	Available P /(mg·kg^{-1})	Available K /(mg·kg^{-1})	pH
18 years	0–20	10.42±1.88	0.29±0.01	35.55±1.33	1.84±0.15	109.04±1.22	7.97±0.01
	20–40	5.76±0.90	0.14±0.01	33.31±0.11	1.63±0.04	46.56±0.67	8.03±0.01
8 years	0–20	9.50±0.62	0.11±0.02	30.15±0.22	1.81±0.08	97.51±0.85	8.01±0.01
	20–40	5.70±0.85	0.09±0.01	27.26±0.13	1.64±0.09	55.73±0.23	8.07±0.02
Farmland	0–20	4.95±0.12	0.08±0.01	16.50±0.08	1.80±0.11	128.00±1.21	8.11±0.02
	20–40	4.35±0.08	0.06±0.01	15.40±0.06	1.65±0.21	47.00±0.35	8.16±0.03

Table 3 Soil mechanism of different ages of *Caragana korshinski* (g·kg^{-1})

Vegetation types and ages	Soil depth /mm	Sand/mm			Silt /mm			Clay /mm		
		>0.25	0.05–0.25	Sum	0.01–0.05	0.005–0.01	Sum	0.001–0.005	<0.001	Sum
18 years	0–20	1.00±0.00	58.00±2.16	59.00±2.16	501.33±4.99	83.00±4.90	584.33±0.94	105.00±5.10	251.67±3.68	356.67±2.05
	20–40	1.00±0.00	68.33±5.44	69.33±5.44	494.00±5.35	89.00±4.55	583.00±0.82	90.33±9.18	257.33±11.90	347.67±5.44
8 years	0–20	1.00±0.00	74.33±4.11	75.33±4.11	547.33±4.64	82.33±3.77	629.67±3.30	77.67±7.59	216.67±9.53	294.33±5.31
	20–40	1.00±0.00	58.00±2.16	59.00±2.16	501.33±4.99	83.00±4.90	584.33±0.94	105.00±5.10	251.67±3.68	356.67±2.05
Farmland	0–20	1.00±0.00	96.33±8.81	97.33±8.81	538.12±0.47	87.00±3.74	625.12±3.40	48.67±8.73	230.33±4.92	278.97±11.67
	20–40	1.00±0.00	79.67±781	80.67±781	539.28±0.51	84.67±2.25	623.93±1.25	55.00±2.17	242.67±0.94	297.67±0.57

Table 4 Soil aggregates of different ages of *Caragana korshinski* (g·kg^{-1})

Vegetation types and ages	Soil depth/cm	Soil aggregates					Total >0.25 mm
		>5 mm	2–5 mm	1–2 mm	0.5–1 mm	0.25–0.5 mm	
18 years	0–20	507.0±48.36	242.3±13.52	23.3±8.73	23.3±8.34	12.7±6.60	808.7±33.16
	20–40	398.0±15.94	233.7±2.49	25.0±2.94	25.0±5.35	14.3±3.30	696.0±4.08
8 years	0–20	434.0±78.65	269.0±16.51	28.0±7.79	31.0±12.19	15.3±5.44	777.3±59.79
	20–40	380.0±41.03	241.7±6.80	27.3±4.99	25.7±4.50	19.0±3.56	693.7±43.39
Farmland	0–20	373.0±39.34	239.4±15.92	26.2±9.74	22.4±1.05	21.7±5.31	681.2±41.80
	20–40	378.1±37.89	233.2±7.93	29.3±7.41	32.3±6.99	19.3±1.66	691.7±36.81

Table 5 Soil enzyme activities of different ages *Caragana korshinski*

Vegetation types and ages	Soil depth /cm	Urease/ (NH$_3$-N mg·kg^{-1})	Sucrase/ (Glucose mg·kg^{-1})	Neutral phosphatase/ (P$_2$O$_5$ mg·kg^{-1})
18 years	0–20	91.20±2.40	1434.63±91.95	5.40±0.65
	20–40	69.33±1.77	287.60±29.45	2.37±0.45
8 years	0–20	82.90±7.21	1351.30±425.80	6.73±1.17
	20–40	48.93±11.17	252.70±64.78	1.37±0.24
Farmland	0–20	46.63±0.85	814.33±32.31	3.67±0.09
	20–40	22.27±1.20	381.73±3.43	1.63±0.29

and 59.0% in the different layers, respectively. The contents of >0.25 mm in the two shrub land soil in the upper layer (0–20 cm) increased 4.6% and 14.1% compared to farmland. It showed that *C. korshinski* afforestation can increase the content of aggregates. The dispersed coefficient (<0.001 mm micro-aggregate/<0.001 mm clay) is low in the 18-year old shrub land soil, which also shows that the soil's susceptibility to erosion is low.

3.3 Soil enzyme activities

Soil enzyme activity plays an important role in the turnover of C, N, P and other nutrients. We analyzed urea activity, invertase activity and alkaline phosphatase in order to make senses of the role of *C. korshinski* in improving soil microbial quality. The results shown in Table 5 indicate that urea activity increased by 8.3 mg/kg in the 0–20 cm depth and 20.4 mg/kg in the 20–40 cm depth, respectively from the alley (8.53 g/kg, age 0) after 8, and 18 years of shrub occupancy under the shrub canopy. Compared to farmland, soil urea activity increased 1.95, 1.77-fold in 0–20 cm, and 3.11, 2.20-fold in the 20–40 cm. Invertase activity also increased 1.76, 1.66-fold in the 0–20 cm, but it decreased in the 20–40 cm compared to alley. Neutral phosphatase in the 8-year shrub land is biggest compared to alley and 18-years old. The dates showed that *C. korshinski* plantation can accelerate the increase of soil urea activity and invertase activity, especially in the upper layer.

4 Discussion

4.1 Change of soil characteristics after *C. korshinski* establishment

In the Loess Plateau, water erosion can be reversed through the implementation of conservation measures, including the establishment of artificial vegetation (Zhao et al., 2000). Despite the fact that shrubs are often regarded as indicators of desertification in disturbed landscapes (Schlesinger et al., 1990, 1996), they provide a crucially important protection against soil erosion by water in the Loess Plateau. Our present results indicate that the establishment and development of *C. korshinski* on eroded soil resulted in significant improvements of soil physiochemical properties. The positive effects increased with plantation age. These results are in agreement with a recent study conducted in the Horqin Sandy Land of northwestern China (Su et al., 2002). Soil particle size distribution reflected the extent of soil erosion by water erosion (Lobe et al., 2001). *C. korshinski* shrubs function as natural barriers for reducing water erosion. This accumulation contributes to increases in silt and clay to the topsoil and thus enhances the development of a stabilized surface layer. Furthermore, the increases in silt and clay and the accumulation of organic matter led to decreased bulk density and increased water permeation. All changes are conducive for plant growth. Carbon and N accumulations have been regarded as indicators of soil fertility and productivity (Jenny, 1958). The present results indicate that accumulations of C and N were very significant after C. *korshinski* establishment. The restoration of soil fertility induced by re-vegetation is a complicated ecological process that is simultaneously affected by many biotic and abiotic variables (Liu et al., 1998). First, shrub establishment and development not only offered an important safeguard against soil erosion, but the leaves of shrubs also trapped dust enriched with nutrients (Wezel et al., 2000). Second, C fixation through photosynthesis and its transfer via leaf litter and root turnover to the soil contributed to C accumulation. Third, N fixation by *C. korshinski* and N release by litter decomposition resulted in an increase in soil N content (Su et al., 2002b). The reduction in soil pH was probably related to vegetative cover because the extensive secretion of organic acids and the release of CO_2 from roots and/or microorganisms can lead to a decrease in pH (Tornquist et al., 1999).

4.2 Time effect for recovery of soil properties

Vegetation can influence soil by root extrusion, interlude and division. The decomposition of dead root and leaves can also form soil humus and other matters (Dan, 1999; Amiotti, 2000). The result of using *C. korshinski* plantation to meliorate soil is different from many authors in China. Niu et al. (2003) contend that after some years of *C. korshinski* plantation, parts of the soil nutrient will be deficient. Liu et al. (1997) figured out that soil nutrient condition had no relation to the growth years of *C. korshinski*. Wang et al. (1998) indicated that *C. korshinski* plantations deplete soil nutrients in the first four years. The recovery of a degraded habitat is influenced by climatic factors and the ecological conditions of the site (Thorhaug, 1980). In the present study, soil improvement occurred with plantation age. Two distinct phases were distinguished in the chronosequence, namely: a faster recovery rate during the early establishment stage (0–8 years) and a slower recovery rate during the late successional stage (8–18 years). Similar recovery patterns have been observed in other studies examining the restoration effects of tree plantations on degraded sub-humid sites (Bhojvaid and Timmer, 1998; Singh et al., 2001). During the early stage, C and N accumulation rates were higher under the shrub canopy than in the alley. However, at the later stage, similar accumulation rates were observed in the two locations. With increasing plantation age, expansion of *C. korshinski* roots and development of herbaceous species in the alleys tended to decrease the spatial heterogeneity in soil properties. It should be noted that C and N contents were still relatively low after 18 years of recovery.

5 Conclusions

In the semi-arid land of north China, shrub establishment plays an important role in the restoration of degradation ecosystems. The present study revealed some typical changes in soil properties in an age sequence of *C. korshinski* established on loessic soil.

Shrub establishment and development resulted in significant changes in soil properties including increased silt and clay contents, organic C and total N and decreased pH, especially at canopy. It showed the *C. korshinski* afforestation can increased the content of aggregates and also can accelerate the increasing of soil urea activity and invertase activity respectively, especially in upper layer.

Carbon and nitrogen concentrations increased significantly with increasing plantation age. Faster recovery rates for C and N dynamics were suggested at early establishment stage (0–8 years) and slower recovery rates at late successional stage (8–18 years).

Acknowledgements This study was supported by the National Natural Sciences Foundation of China (Nos. 40461006 and 90302001) and the Science Foundation of State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau (10501-153).

References

Amezketa E., Soil aggregate stability: a review, J. Sustain. Agr., 1999, 14(2/3): 83–151

Amiotti N. M., Sanchez L. F., Peinemann N., The impact of single trees on properties of loess-derived grassland soils in Agentina, Ecology, 2000, 81(12): 3,283–3,290

An S. S., Huang Y. M., Liu M. Y., Li B. C., The responses of soil fertility quality to ecological rehabilitation in Ningxia Loess Plateau region, Res. Soil Water Conserv., 2005, 12(3): 22–26 [安韶山, 黄懿梅, 刘梦云, 李壁成, 宁南宽谷丘陵区土壤肥力质量对生态恢复的响应, 水土保持研究, 2005, 12(3): 22–26]

Bhojvaid P. P., Timmer, V. R., Soil dynamics in an age sequence of *Prosopis juliflora* planted for sodic soil restoration in India, For. Ecol. Manag., 1998, 106: 181–193

Binkley D., Resh S. C., Rapid changes in soils following eucalyptus afforestation in Hawaii, Soil Sci. Soc. Am. J., 1999, 63(1): 222–225

Cao C. Y., Jiang D. M., Alamsa, Luo Y. M., Kou Z. W., Liu S. Y., Ecological process of vegetation restoration in *Caragana microphylla* sand-fixing area, Chin. J. Appl. Ecol., 2000, 11: 349–354 [曹成有, 蒋德明, 阿拉木萨, 骆永明, 寇振武, 刘世岩, 小叶锦鸡儿人工固沙区植被恢复生态过程的研究, 应用生态学报, 2000, 11: 349–354]

Chizicke E. O., Impact of fast growing species in lowland humid tropics, FAO For. Paper, 1980, No. 21, Rome

Fang W., Peng S. L., 1997, Development of species diversity in the restoration process of establishing a tropical man-made forest ecosystem in China, For. Ecol. Manag., 99: 185–196

Fu B. J, Chen L. D., Ma K. M., The relationship between land use and soil conditions in the hilly area of Loess Plateau in Northern Shanxi, China, Catena, 2000, 39: 69–78

Institute of Soil Sciences, Chinese Academy of Sciences (ISSCAS), Physical and Chemical Analysis Methods of Soils, Shanghai: Shanghai Science Technology Press, 1978: 7–59 [中国科学院南京土壤研究所, 土壤理化分析, 上海: 上海科学技术出版社, 1978: 7–59]

Jenny H., Role of the plant factor in the pedogenic functions, Ecology, 1958, 39: 5–16

Liu S. R., Li X. M., Niu L. M., The degradation of soil fertility in pure larch plantations in the northeastern part of China, Ecol. Eng., 1998, 10: 75–86

Liu Z. W., Li Y. S., Fertility and elements bio-cyclings of the *Caragana microphylla* L. forestland in the rolling Loess region, Chin. J. Ecol., 1997, 16(6): 27–29 [刘增文, 李雅素, 黄土丘陵区柠条林地养分状况及其循环规律, 生态学杂志, 1997, 16(6): 27–29]

Lobe I., Amelung W., Du Preez C. C., Losses of carbon and nitrogen with prolonged arable cropping from sandy soils of the South African Highveld, Eur. J. Soil Sci., 2001, 52: 93–101

Niu X. W., Zhang Q., Yang Z. P., Cheng B., Shi Q. L., Liu P., Li L., Research on change of soil properties of *Caragana* plantation in North-west of Shanxi Province, Acta Bot. Borea1.-Occident. Sin., 2003, 23(4): 628–632 [牛西午, 张强, 杨治平, 程滨, 史清亮, 刘平, 李磊, 柠条人工林对晋西北土壤理化性质变化的影响研究, 西北植物学报, 2003, 23(4): 628–632]

Schlesinger W. H., Raikes J. A., Hartley A. E., Cross A. E., On the spatial pattern of soil nutrients in desert ecosystem, Ecology, 1996, 77(2): 364–374

Schlesinger W. H., Reynolds J. F., Cunningham G. L., Huenneke L. F., Jarrell W. M., Singh K. P., Mandal T. N., Tripathi S. K., Patterns of restoration of soil physicochemical properties and microbial biomass in different landslide sites in the sal forest ecosystem of Nepal Himalaya, Ecol. Eng., 2001, 17: 385–401

Su Y. Z., Zhao H. L., Weng H. Y., Cultivation and enclosure effects on soil physicochemical properties of degraded sandy grassland, Chin. J. Soil Water Conserv., 2002, 16(4): 5–8 [苏永中，赵哈林，文海燕退化沙质草地开垦和封育对土壤理化性状的影响水土保持学报, 2002, 16(4): 5–8]

Su Y. Z., Zhao H. L., Zhang T. H., Influencing mechanism of several shrubs and subshrubs on soil fertility in Horqin sandy land. Chin. J. Appl. Ecol., 2003, 13(7): 802–806 [苏永中, 赵哈林, 张铜会, 几种灌木、半灌木对沙地土壤肥力影响机制, 应用生态学报, 2003, 13(7): 802–806]

Thorhaug A., Recovery pattern of restored major plant communities in the United States: high to low altitude, desert to marine. In: Cairns J., Jr (ed.), The Recovery Process in Resource Development, Vol. 2, New York: Pergamon Press, 1980: 541–649

Tornquist C. G., Hons F. M., Feagley, S. E., Agroforestry system effects on soil characteristics of the Sarapiqi region of Costa Rica, Agric. Ecosyst. Environ., 1999, 73: 19–20

Vernberg F. J., The function of pristine estuarine ecosystem. In: Hook D. D. (ed.), The Ecology and Management of Wetlands, Timber Press, 1988: 15–25

Virginia R. A., Jarrel W. M., Soil properties in a mesquite-dominated Sonoran desert ecosystem, Soil Sci. Soc. Am. J., 1983, 53: 36–40

Wang S. F., He S. Y., The evaluation of soil fertility under *Caragana korshinski* forestland, J. Qinghai Agric. For. Sci. Technol., 1998, 3: 29–31 [王生芳, 何世玉, 柠条人工林地土壤肥力的评价, 青海农林科技, 1998, 3: 29–31]

Wang T., Land use and sandy desertification in north China, J. Desert Res., 2000, 20: 103–108 [王涛, 中国北方土地利用与沙质荒漠化，中国沙漠, 2000, 20: 103–108]

Wezel A., Rajot J. L., Herbrig C., Influence of shrubs on soil characteristics and their function in Sahelian agroecosystems in semi-arid Niger, J. Arid Environ., 2000, 44: 383–398

Zhao H. L., Zhao X. Y., Zhang T. H., Causes, processes and countermeasures of desertification in the interlocked agro-pastoral area of north China, J. Desert Res., 2000, 20(Suppl. 1): 22–28 [赵哈林, 赵学勇, 张铜会, 我国北方农牧交错带沙漠化的成因、过程和防治对策, 中国沙漠, 2000, 20(增刊 1): 22–28]