EFFECTS OF LAND USE ON SOIL QUALITY ON THE LOESS PLATEAU IN NORTH-WEST SHANXI PROVINCE

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Abstract: Northwest Shanxi is located at the eastern border of the Loess Plateau. In order to guard against wind, to conserve water and soil, to fix sand, a large area of Caragana microphylla was planted in the hilly loess plateau in the north-west Shanxi province during the 1960s. To investigate how these measures affected soil properties and ultimately soil quality, a case study was conducted in Wuzhai (North-west Shanxi Province). Soil samples were collected from adjacent Caragana microphylla land, farm land, poplar forests, fallow land and mixed plantations of Caragana microphylla and poplar. Initially, soil properties under the five land-uses were studied separately. Then an evaluation indicator system was developed according to the principle of evaluation indicator selection. Subsequently, the method of multivariate analysis was used to carry through a complete scientific evaluation. Results showed a significant influence of land-use on soil properties. The value of SQI was the highest under the mixed plantation and, compared with the mixed plantation,the SQI of farmland decreased greatly. The SQI of fallow land was the lowest, but considering the soil nutrient content, land fallowing improved soil fertility to some extent. It was further shown that growing Caragana microphylla and mixed polar and Caragana microphylla plantation was the most sustainable ways of developing the loess plateau.

Keywords: Loess Plateau, Land use, Soil quality, Caragana microphylla

1. INTRODUCTION

The loess plateau is the energy and heavy chemical industry base and ecological barrier of eastern region and the frontier of ecological barriers. At present, the loss plateau is one of the areas of China where ecological degradation is most serious and the sustainable development ability is the lowest. The grave loss of soil and water, not only threaten the sustainable development of the loess plateau, but also the surrounding area even the whole nation directly.

Northwest Shanxi is located on the eastern border of the loess plateau.In order to guard against wind, to conserve water and soil, to fix sand and to develop animal husbandry, a large area of Caragana microphylla was planted in the hilly loess plateau in the north-west Shanxi province during the 1960s. Caragana microphylla has a developed rootstructure, is very hardy, and has considerable ability to conserve water and soil. However, to date, it is unknown whether these measures have been effective.

The aim of this research is to choose a representative site in north-west Shanxi Province, study soil properties and soil quality under different land uses in this area, and evaluate the existing ecology renewal measures.

2. MATERIALS AND METHODS

2.1 Study sites

The experiment was conducted in Wuzhai County(38°44′～39°17′N and 111°28′～112°E), north-western Shanxi Province, in northern China. The county has a semi-arid climate. The average yearly temperature is 4.1℃－5.5℃, while the mean annual rainfall is 400mm. The altitude lies between 1200m and 1400m.the soil is loam and the soil fertility is regarded as poor (Liu and Zhang, 1992).

2.2 Soil sampling and analysis

From April to November 2006, soil samples were collected from five land use types every month. Five adjacent land-uses with the same slope, having similar terrain factors, and used continuously for 30 years were selected: (1) farmland (buck wheat), (2) *Caragana microphylla,* (3) poplar, (4) mixed plantation of *Caragana microphylla* and poplar, (5) fallow land (fallowed for 3 years). Three typical sites were selected in each land type. All of the sites were located by GPS and flagged separately. At each site, three soil samples at each depth, 0-20 ㎝ depth and 20-40 ㎝ depth, were collected within a 100 ㎝ radius.

Each sample weighed about 1 ㎏ and samples from the same depth and the same site were bulked for analysis. Soil samples were analyzed for organic matters (OM), total nitrogen (TN), available P (AP), available K (AK), total K (TK), and total P (TP), soil bulk density, pH and soil enzyme activity. Bulk density was determined by the core method. Soil pH was determined in 1:2.5 soil slurry, using a combination glass electrode. Soil OM was analyzed using the rapid dichromate oxidation techniques (Tiessen and Moir, 1993), TN was measured using the Kjeldahl technique (McGill and Figueiredo, 1993), and AP was extracted using the Olsen method (Olsen and Dean, 1965). AK was extracted with 1N ammonium acetate, adjusted to pH 7 (Simard, 1993), TP and TK were determined in a nitric-perchloric digestion extract, P by the method of Murphy and Riley (1962) and K by flame photometry.

2.3 Evaluation method

An evaluation indicator system, including physical indicators, chemical indicators and biological indicators was developed according to the principle of evaluation indicator selection. Following this, multivariate statistical analysis was used to carry through a complete scientific evaluation: according to membership function,realized the transaction of original data to the same dimension; as well as utilizing principle component analyzing solved how to determine the distribution of weightiness about every evaluated indicator.

We conducted one-way analyses of variance (ANOVAS) using SPSS software, with land use class as the main effect. The LSD procedure was used to separate the means of the soil properties at $p \leq 0.05$. Principal component analysis was used to determine the distribution of weightiness about every evaluated indicator.

3. RESULTS AND DISCUSSION

3.1 Effects of land use on soil physical, chemical and biological properties

Soil under Caragana microphylla had the lowest bulk density, liquid percent,solid percent and the highest gas percent, and compared with other land uses, the difference was significant (Table 1). Soil of fallow land had the highest bulk density, 1.51 g/cm^3 and the lowest gas percent.

Tab.1 Effects of land use types on soil bulk density (0～20cm)

Land use	*Sampling depth (cm)*	*Bulk density (g/cm3)*	*Liquid percent (%)*	*Gas percent (%)*	*Solid percent (%)*
Fallow land	0～20	1.51^a	16.2^a	22.37^d	61.43^a
Farm land	0～20	1.33^{bc}	13.5^b	35.82^b	50.73^c
Caragana microphylla	0～20	1.16^d	11.7^d	39.91^a	48.39^c
Mixed plantation of poplar and *Cragana mcrophylla*	0～20	1.29^c	12.4^c	37.76^b	49.89^c
poplar	0～20	1.37^b	13.1^b	31.95^c	54.95^b

Different letters above data represent statistically significant difference at p＜0. 05.

The root system of *Caragana microphylla* belongs to the axis-tiller type and has a strong penetration. During the root growth process, the soil is loosened leading to a decrease of bulk density and solid percent and an increase of gas percent (Niu *et al*., 2003). Consequently, soil density under *Caragana microphylla* was the lowest and, also because of the presence of roots of *Caragana microphylla*, the soil bulk density of the mixed plantation of *Caragana microphylla* and poplar was lower than that of poplar forest and this difference was significant. Due to human activity and animal tracking, fallow land had the highest soil bulk density.

Soil under the mixed plantation had the highest soil organic matters and total nitrogen (Table 2), most likely as a result of the abundant litter on the surface soil of the mixed plantation and the obvious humification of litter (Peng *et al*., 1996). Soil OM and TN under *Caragana microphylla* and poplar were lower than that under the mixed plantation, but higher than that under fallow land and farmland (Table 2). Soil under farmland had the lowest OM and TN (Table 2). This was because there were less residues accumulating on the surface of farmland, coupled with the impact of cultivation which enabled the rapid decomposition of the organic matter and the release of nitrogen. This nitrogen was available to, on one hand be absorbed and assimilated by the crops, but on the other hand be a major source of nitrate leaching (Peng *et al*., 1996). Higher soil OM content in shrub land compared with that in arbor land was also reported in a small catchment of the Loess Plateau (Gong *et al*., 2004).

The trend of AK content between the several land use types was similar to the trend of organic matter. The soil under poplar had the lowest AP content (Table 2). The AP under *Caragana microphylla* and the mixed plantation was higher than that under poplar, but lower than that under farmland (Table 2). The use of P fertilizer may account for the highest AP content of soil in farmland. Because of the huge plant biomass, high absorption of soil nutrients and the obvious assimilation of available nutrients, AP and AK content under *Caragana microphylla* were lower relatively (Niu *et al*., 2003). Qiu et al. (2004), studying soil nutrients in different land uses in a small catchment of the Loess Plateau, reported soil in shrub land had the lowest AP content.

Tab.2 Effects of land use types on selected chemical properties(0～20cm)

Land use		Organic matter (g/kg)	Total-N (g/kg)	Total-P (mg/kg)	Total-K (mg/kg)	Olsen-P (mg/kg)	Available K (mg/kg)	pH
Fallow land	maximum	6.378	0.848	536.43	2181.61	1.8689	72.00	8.59
	minimum	5.918	0.478	460.44	1562.81	0.8379	59.50	8.51
	mean	6.187	0.597	496.64	1815.49	1.5307	68.25	8.57
	C.V	0.031	0.273	0.060	0.148	0.307	0.086	0.004
farmland	maximum	6.931	0.677	617.02	1935.40	4.1793	70.75	8.68
	minimum	5.353	0.469	472.94	1506.35	1.9116	50.25	8.35
	mean	5.889	0.581	509.09	1735.18	2.7699	62.90	8.49
	C.V	0.113	0.172	0.119	0.093	0.444	0.121	0.016
Caragana microphylla	maximum	7.173	0.820	564.31	3572.06	1.9688	132.50	8.57
	minimum	6.052	0.489	349.58	2426.31	1.0049	70.50	8.53
	mean	6.450	0.624	461.72	3086.92	1.2644	97.80	8.55
	C.V	0.072	0.196	0.189	0.152	0.372	0.246	0.002
Mixed plantation of poplar and Caragana microphylla	maximum	9.061	0.149	502.52	3139.83	1.2197	172.50	8.60
	minimum	7.072	0.520	388.35	1470.87	0.7667	77.00	8.49
	mean	7.973	0.755	439.28	2222.50	1.0129	130.70	8.55
	C.V	0.122	0.337	0.115	0.269	0.184	0.262	0.005
poplar	maximum	7.755	0.831	519.36	2664.61	0.8907	125.75	8.64
	minimum	4.425	0.464	393.29	1382.40	0.3835	87.00	8.49
	mean	6.378	0.611	429.36	2253.40	0.6247	107.15	8.57
	C.V	0.237	0.264	0.123	0.222	0.365	0.149	0.008

Catalase and alkaline phosphatase activity in the upper soil layer were significantly higher than that in the lower layer (Table 3). In contrast with the lower layer, the surface soil can more easily exchange matter and energy with atmosphere and the organic matter entering soil gathers first at the surface. Therefore, in the upper layer the nutrient conditions are better, activity of soil microbes is blooming and the enzyme activity is higher (An et al., 2004).

Tab.3 Effects of land use types on soil enzyme activity

Land use	Catalase $0.1N KMnO_4 ml/100g.37℃.d^{-1}$		Alkaline phosphatase mg phenol/$100g.37℃.d^{-1}$	
	0～20cm	20～40cm	0～20cm	20～40cm
Fallow land	222.1^{b}	143.5^{c}	1214.8^{bc}	918.3^{b}
Farm land	288.4^{a}	203.2^{b}	1185.1^{c}	919.6^{b}
Caragana microphylla	267.3^{a}	214.3^{b}	1458.4^{a}	902.6^{c}
Mixed plantation of poplar and *Caragana microphylla*	277.0^{a}	255.2^{a}	1250.2^{b}	948.5^{a}
poplar	270.5^{a}	242.9^{a}	1227.3^{b}	924.7^{b}

Different letters above data represent statistically significant difference at $p<0.05$.

The top 20cm soil under *Caragana microphylla* had the highest soil alkaline phosphatase activity and there were significant differences between soil under *Caragana microphylla* and that under several other land use types (Table 3). The impact of *Caragana microphylla* roots and the decomposition and mineralization of litter improve soil physical condition and increase soil organic matter content. Good soil physical conditions and the high soil organic matter content induce an increase of diversity and number of soil microbes (Niu *et al*., 2003). This would have accounted for the higher alkaline phosphatase activity under *Caragana microphylla* and the mixed plantation. There were no significant differences of catalase activity among the five land use types, but the catalase activity of fallow land was the lowest (Table 3).

3.2 Calculation of soil quality

We mainly considered soil fertility quality when the evaluation indicators were selected.The evaluated indicators were: X1—OM、x2—TN、x3—TP、x4—TK、x5—AP、x6—AK、x7—pH、x8—Bulk density、x9—total porosity、x10—alkaline phosphatase、x11—catalase.

3.2.1 Membership functions for different evaluation indicators

There is no clear extension, nor uniform dimension among different evaluation indicators, so the values measured can not be used in soil quality evaluation directly. We should apply normalized transaction. First of all, we must select membership functions for the different evaluation indicators.

(a) Ascending half trapezoidal membership function.

Within a certain range, some indicators are positively correlated with soil quality (such as soil fertility status, soil health, *etc*), and there is little influence on soil quality whether the indicator is under the lower limit or above the upper limit. The membership function of these indicators can be approximated to the distribution of an ascending half trapezoid (Fig. 1). Its membership function model is as follows:

$$\mu(x)=\begin{cases}1 & (x\geq x_0)\\ x/x_0 & (x<x_0)\end{cases} \tag{1}$$

where x is the actual value of evaluated indicators, x_0 the upper limit and $\mu(x)$ is the membership function of x.

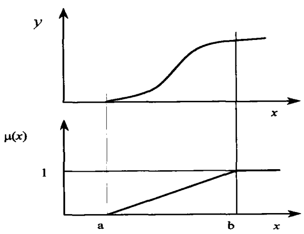

Fig.1 Distribution of "S" curve and trapezoid ascending half trapezoid

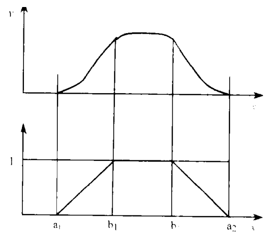

Fig.2 Distribution of parabola and

(b) Triangular membership function

There is an optimum range when soil pH and bulk density influence the soil function. Within this range, the soil function is optimal. Over the range, the bigger the deviation, the worse is the soil function. These indicators can be considered as a trapezoidal distribution (Fig.2). To simplify, we replaced optimum range with an optimum value; here the trapezoidal function is simplified to a triangular function (Fig. 3).

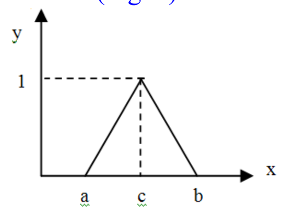

Fig. 3 Distribution of triangle

$$\mu(x)=\begin{cases}0 & (x \le a \text{ 或 } x \ge b)\\ \dfrac{x-a}{c-a} & (a < x < c)\\ \dfrac{b-x}{b-c} & (c < x < b)\\ 1 & (x = c)\end{cases} \qquad (2)$$

Where *x* is the actual value of the evaluation indicator, *b* is the upper limit value, *a* is the lower limit value, *c* is the optimum value of the evaluation indicator and $\mu(x)$ is the membership function of *x*.

Secondly, we ascertained the limit value of the indicators according to the actual value measured in this study area (Table 4).

Then, according to the limit value of the evaluation indicators, the membership values were calculated (Table 5,Table 6).

Tab.4 Limit values of evaluated indicators

Indicator	Upper limit		Medium limit		Lower limit	
	value	membership	value	membership	value	membership
Bulk density/g/cm^3	1.8	0	1.1	1	0.9	0
Total porosity /%	51.61	1	—	—	0	0
pH	9.5	0	8.5	1	7	0
AP/mg/kg	2.7699	1	—	—	0	0
AK/mg/kg	130.7	1	—	—	0	0
TN/g·kg^{-1}	0.755	1	—	—	0	0
TP/mg/kg	509.09	1	—	—	0	0
TK/mg/kg	3086.92	1	—	—	0	0
OM/g·kg^{-1}	7.973	1	—	—	0	0
Alkaline phosphatase /mg phenol /100g.37℃.d^{-1}	1458.4	1	—	—	0	0
Catalase/0.1NKMnO$_4$ml/100 g.37℃. d^{-1}	288.4	1	—	—	0	0

Tab.5 Membership function values of evaluated indicators

Land use	*OM*	*TN*	*TP*	*TK*	*AP*	AK
Fallow land	0.776	0.791	0.976	0.588	0.553	0.522
farmland	0.739	0.770	1.000	0.562	1.000	0.481
Caragana microphylla	0.809	0.826	0.907	1.000	0.456	0.748
Mixed plantation of poplar and Caragana microphylla	1.000	1.000	0.863	0.720	0.366	1.000
poplar	0.800	0.809	0.843	0.730	0.226	0.820

Tab.6 Membership function values of evaluated indicators

Land use	pH	Bulk density	Total porosity	Alkaline phosphatase	catalase
Fallow land	0.930	0.414	0.747	0.833	0.770
farmland	1.000	0.671	0.955	0.813	1.000
Caragana microphylla	0.950	0.914	1.000	1.000	0.927
Mixed plantation of poplar and *Caragana microphylla*	0.950	0.729	0.971	0.857	0.960
poplar	0.930	0.614	0.873	0.842	0.938

3.2.2 Determining the weightiness of evaluated indicators

In this paper we utilize principal component analysis to determine the weightiness of evaluated indicators.If the Eigen values of the principal component is greater than 1 and the cumulative contribution rate is 85％ or greater than 85％, the principal component can be extracted.

Tab.7 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.233	47.576	47.576	5.233	47.576	47.576
2	3.190	29.003	76.580	3.190	29.003	76.580
3	1.910	17.367	93.947	1.910	17.367	93.947
4	.666	6.053	100.000			
5	8.536E-16	7.760E-15	100.000			
6	4.504E-16	4.095E-15	100.000			
7	1.712E-16	1.557E-15	100.000			
8	-1.010E-16	-9.183E-16	100.000			
9	-2.283E-16	-2.076E-15	100.000			
10	-3.050E-16	-2.773E-15	100.000			
11	-6.928E-16	-6.298E-15	100.000			

Extraction Method: Principal Component Analysis.

Tab.8 Component Matrix

	Component		
	1	2	3
OM x1	0.762	-0.209	0.514
TN x2	0.751	-0.150	0.534
TP x3	-0.850	0.347	-7.009E-02
TK x4	0.747	0.178	-0.639
AP x5	-0.697	0.664	0.158
AK x6	0.935	-0.221	0.266
pH x7	-0.307	0.895	0.322
Bulk density x8	0.699	0.669	-0.252
Total porosity x9	0.618	0.783	7.569E-02
Alkaline phosphatase x10	0.587	0.253	-0.730
catalase x11	0.374	0.747	0.382

Extraction Method: Principal Component Analysis.

In Table 7, the cumulative contribution rate of the first three components is 93.947％. From this we can also see that the three components can almost reflect the information of all of the indicators. We can thus replace the 11 components with the first three components.

Dividing the data in Table 8 by the square root of eigenvalues, we can get the corresponding coefficient of the indicators in the first three principal components. The three principal components are as follows:

$$F1= 0.333x1 + 0.328x2 - 0.372x3 + 0.327x4 - 0.305x5 + 0.409x6 - 0.134x7 + 0.306x8 + 0.270x9 + 0.257x10 + 0.163x11 \quad (3)$$

$$F2= -0.117x1 - 0.084x2 + 0.194x3 + 0.100x4 + 0.372x5 - 0.124x6 + 0.501x7 + 0.375x8 + 0.438x9 + 0.142x10 + 0.418x11 \quad (4)$$

$$F3= 0.372x1 + 0.386x2 - 0.051x3 - 0.462x4 + 0.114x5 + 0.192x6 + 0.233x7 - 0.182x8 + 0.055x9 - 0.528x10 + 0.276x11 \quad (5)$$

The overall score model is calculated as follows:

$$Y=F1*47.576\%/93.947+ F2*29.003\%/93.947+ F1*17.367\%/93.947 \quad (6)$$

The overall score model is:

$$Y =0.201X1 + 0.212X2 - 0.138X3 + 0.111X4 – 0.019X5 + 0.204x6 + 0.130x7 +0.237x8 + 0.282x9 + 0.076x10 + 0.263x11 \quad (7)$$

In this model, the coefficient of every component is the weightiness of every indicator.

3.2.3 Calculating soil quality index

The soil quality index was calculated as follows:

$$SQI = \sum_{i=1}^{n} K_i \times C_i \quad (8)$$

Where *SQI* is soil quality index, *Ci* is the membership function value of indicators, *Ki* is the weightiness of indicators and *n* is the number of evaluated indicators.

The values of the soil quality index of *Caragana microphylla*, farmland, poplar, fallow land and the mixed plantation of Caragana microphylla and poplar were 1.410, 1.199, 1.284, 1.046, and 1.459, respectively (Fig. 4).

Compared with *Caragana microphylla* and the mixed plantation of Caragana *microphylla* and poplar, the value of the soil quality index of farm land was greatly reduced (Fig. 4), indicating that the soil degraded. Cultivation practices increased bulk density, and decreased enzyme activity, soil total nitrogen and organic matter content in soil. Although a lot of fertilizers including some available nutrients, e.g. Olsen P, were applied to the cropland, the soil quality could not be improved greatly. Application of fertilizer could only improve the contents of available nutrients.

The value of the soil quality index of fallow land was the lowest. In contrast with farmland, leaving land fallow could improve total nitrogen, total K, and organic matter content in soil. However, the comprehensive soil quality of fallow land was lower than that of farmland. Analyzing and comparing every soil properties, we can see that the soil under fallow land had higher bulk density and lower total porosity than that of farmland.

It was further shown that growing *Caragana microphylla* and the mixed plantation of *Caragana microphylla* and poplar were the most sustainable ways of developing the Loess Plateau.

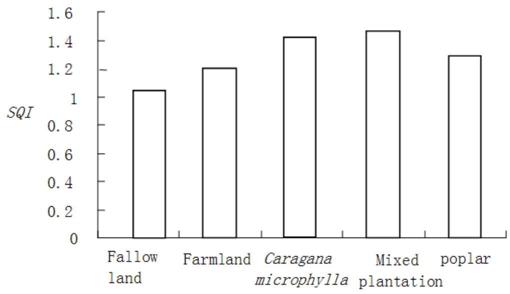

*Fig4.*Soil quality index values under different land use types

4. CONCLUSIONS

Plantations of *Caragana microphylla* and mixed plantations of *Caragana microphylla* and poplar can improve soil physical character, enzyme activity, and total nitrogen and organic matter content. The SQI of mixed plantations of *Caragana microphylla* and poplar was the highest of all and that of *Caragana microphylla* was the second highest. It was further shown that growing Caragana *microphylla* and the mixed plantation of *Caragana microphylla* and poplar provided the most sustainable ways of developing the Loess Plateau. Cropland soil was degraded, since cultivation practice increased bulk density, and decreased enzyme activity, soil total nitrogen and organic matter content in the soil. In contrast with farmland, land fallowing could improve total nitrogen, total K, and organic matter content in the soil. Considering the soil nutrient contents, land fallowing improved soil fertility to some extent.

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