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Original Research Paper

Assessment indicators of Soil Quality in Loess Gullied Hilly Region of China

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ABSTRACT

Agricultural soil quality evaluation is essential for economic success and environmental stability in Loess gullied hilly region of China. The objective of this study was to develop a suitable soil index from the existence soil indices which were suitable for Loess gullied hilly region of China. A simplified indicator system of soil quality evaluation has been established. Selected soil parameters include aggregation rate, soil organic matter, total N, available P, available K, $CaCO_3$, catalase and invertase. The proposed simplified soil quality index incorporates all important properties of soils mainly physical, fertility and healthy, which are able to give adequate information on the soil quality status. Match analysis showed a high linear correlation between simplified indicator system and original indicator system. In conclusion, the proposed simplified indicator system for soil quality evaluation of different land-use type will help soil quality evaluator to study and describe the current quality status.

INTRODUCTION

Soil quality has historically been linked to soil productivity, the ability to promote plant or crop growth. Productivity and the function of soil can be illustrated by using soil quality indicators (Belotti 1998, Knoepp et al. 2000, Griffiths et al. 2010). When soil scientists try to incorporate all the properties of soil like physical, chemical and biological aspects to form a universally reliable and acceptable soil quality indicator, there is a problem due to the diversity interaction of these properties influenced by various types of soil and ecosystem location (Gardi et al. 2002, Rezaei et al. 2006). There are vast interpretations of soil quality, but the widely acceptable definition of soil quality was described by Doran (2002), which explained that soil quality is the capacity and ability of the soil at particular site land to contribute and function within ecosystem, cultivated land with regards to sustainability in biological productivity, environmental quality, flora and fauna conservation. So, the use of soil indicators for assessing soil quality at different land-use type is a good way (Karlen et al. 1997, Herrick 2000, Imaz et al. 2010). It means that the usage of soil indicators would be able to give an earlier indication and information on the current status of soil quality. Therefore, we will be able to address the current condition of the soil at different land-use type by examining a number of selected soil properties through soil quality evaluation. Moreover, farmer can be informed and suggested with a better approach in their land usage management in order to improve the soil productivity.

The objective of this study was to develop a suitable soil indicator system, which was suitable for different land-use type in Loess gullied hilly region of China.

MATERIALS AND METHODS

Description of study site: Soil samples were collected from six locations in Loess gullied hilly region of China. The six locations are: Feima River Valley (E107°28'-111°15', N33°43'-39°40') in Yanan City Shaanxi Provence, Gaoquangou Valley (E104°31'-104°34', N35°22'-35°25') in Dingxi City Gansu Provence, Nianzhuanggou Valley (E109º26'15'-109º37'30', N36º37'00'-36º45'00') in Yanan City Shaanxi Provence, Nihegou Valley (E108°10'-108°31', N34°43'-35°03') in Xanyang City Shaanxi Provence, Zhifanggou Valley (E109°13'-109°16', N36°42'-36°46') in Yanan City Shaanxi Provence, and Shanghuang village (E106°26'-106°30', N35°59'-36°02') in Guyuan City Ningxia Hui autonomous region.

Soil sampling and analyses: Every location has 5 different land-use type soil samples, i.e., farmland, orchard, woodland, grassland and wasteland. Each land-use type has 20 plots of 1m×1m. From each plot five soil samples were collected randomly. Each soil sample was collected at 0-20cm, 20-40cm and 40-60cm depths. The samples later were air-dried for 48 h and kept in polyethylene bags for further analysis. A total of 675 soil samples were collected. Protocol measurements for indicators selected in the study are given in Table 1.

Indicator standardization: Before assessing the soil quality, we should assess the good and bad of each indicator. So we build the membership function of soil quality indicator.

Because of different indicator units, a membership function (Karlen & Scott 1994, Andrews et al. 2002, Qiguo Zhao et al. 1997) was used to score soil indicators to use with each indicator method. Soil indicator standardization is usually using three kinds of membership functions: upper limit, lower limit and peak limit function (Cunzhu Wan et al. 1991, Jianguo Wang & Linzhang Yang 2001, Wei Wu et al. 2000).

For upper limit function, effect curve of soil properties and soil function is "S"mode, meaning that the evaluation factors and soil function have positive correlation, and the indicator value, which is below or above this range has a small influence of soil function. Those soil quality indicators are aggregation rate, organic matter, total N, available N, total P, available P, total K, available K, cation exchange capacity, catalase, urease, alkaline phosphatase, invertase and protease. When we build those membership functions, we use ascending half trapezoid replacing "S" mode curve (Fig. 1). This membership function is:

$$F(x)=\begin{cases}1 & (x\geq b)\\ \dfrac{x-a}{b-a} & (a<x<b)\\ 0 & (x<a)\end{cases} \quad ...(1)$$

Where, *F(x)* is themembership function, *x* is the actual value of assessment indicator, *a* is the lower limit value of indicator threshold, and *b* is the upper limit value of indicator threshold.

In this study, this function is simplified as:

$$F(x)=\begin{cases}1 & (x\geq x_0)\\ \dfrac{x}{x_0} & (x<x_0)\end{cases} \quad ...(2)$$

Where, *F(x)* is the membership function, *x* is the actual value of assessment indicator, and x_0 is upper critical value of assessment indicator. Based on previous studies and actual soil property of research area, those upper critical values of indicator are given in Table 2.

For lower limit function, effect curve of soil properties and soil function is "Ƨ"mode, i.e., evaluation factors and soil function were with negative correlation, and the indicator value, which is below or above this range, has a small influence of soil function. Those soil quality indicators are $CaCO_3$ and electrical conductivity. When we build those membership functions, we use descending half trapezoid replacing "Ƨ" mode curve (Fig. 2). This membership function is:

$$F(x_1)=\begin{cases}1 & (x\leq 2)\\ \dfrac{20-x}{20-2} & (2<x<20)\\ 0 & (x\geq 20)\end{cases} \quad ...(3)$$

$$F(x_2)=\begin{cases}1 & (x\leq 60)\\ \dfrac{200-x}{200-60} & (60<x<200)\\ 0 & (x\geq 200)\end{cases} \quad ...(4)$$

Table 1: Protocol measurements for indicators selected in the study.

Indicator	Protocol	References
Soil bulk density	The core cutter method	Shidan Bao (1999)
Soil porosity	The core cutter method	Shidan Bao (1999)
Field moisture capacity	The core cutter method	Shidan Bao (1999)
Saturated water capacity	The core cutter method	Shidan Bao (1999)
Soil texture	Master Sizer 2000 E analyzer	Shidan Bao (1999)
Microaggregate	Master Sizer 2000 E analyzer	Shidan Bao (1999)
Water-stable aggregate	Mechanical wet sieve method (30min)	Shidan Bao (1999)
Soil organic matter (SOM)	The dichromate volumetric method	Shidan Bao (1999)
Total N	Semi-micro Kjeldahl method	Shidan Bao (1999)
Available N	Alkali N-proliferation method	
Total P	$HClO_4$-H_2SO_4Molydenum antimony D iso ascorbic acid colorimetry	Shidan Bao (1999)
Available P	0.5mol/L $NaHCO_3$ Olsen method	Shidan Bao(1999)
Total K	Flame photometer	Shidan Bao (1999)
Available K	Flame photometer	Shidan Bao (1999)
pH	pH meter	Shidan Bao (1999)
Electrical conductivity (EC)	Conductivity method	Shidan Bao (1999)
$CaCO_3$	Gasometric method	Shidan Bao (1999)
Cation exchange capacity (CEC)	NH_4Cl-NH_4Ac ion exchange method	Shidan Bao (1999)
Catalase	$KMnO_4$ titrimetric method (0.1mol/L $KMnO_4$mL/g 25°, 24h)	Songyin Guan (1986)
Urease	Indophenol colorimetric method (NH_3-Nmg/g 37°, 24h)	Songyin Guan (1986)
Alkaline phosphatase	Disodium phenyl phosphate colorimetric method (P_2O_5mg/g 37°, 2h)	Songyin Guan (1986)
Invertase	$Na_2S_2O_3$titrimetric method (0.1mol/L $Na_2S_2O_3$mL/g 37°, 24h)	Songyin Guan (1986)
Protease	Ninhydrin titrimetric method ($Na_2S_2O_3$mL/g37°, 24h)	Songyin Guan (1986)

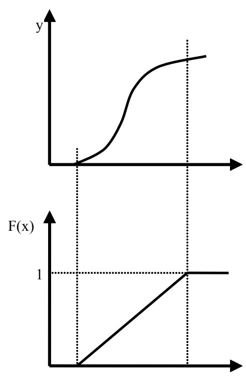

Fig. 1: Distribution of "S" curve and ascending half trapezoid.

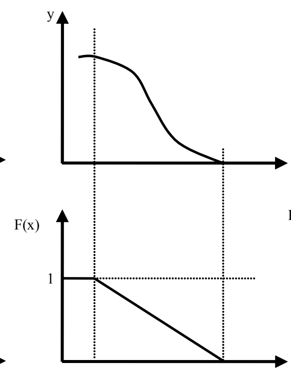

Fig. 2: Distribution of "Ƨ" curve and descending half trapezoid.

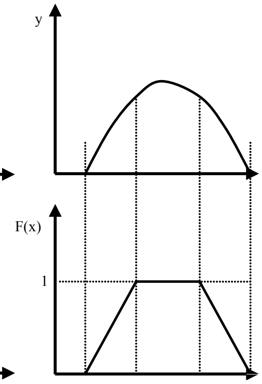

Fig. 3: Distribution of parabola trapezoid.

Where, $F(x_1)$ is the membership function of $CaCO_3$, 2(%) is the lower limit value of indicator threshold of $CaCO_3$, 20(%) is the upper limit value of indicator threshold of $CaCO_3$, $F(x_2)$ is the membership function of electrical conductivity, 60 (mS/cm) is the lower limit value of indicator threshold of electrical conductivity and 200 (mS/cm) is the upper limit value of indicator threshold of electrical conductivity.

For peak limit function, effect curve of soil properties and soil function is "⋂"mode, i.e., this type of evaluation factors have a best range for crop growth. Overstepping this range by the increase of deviation degree, the crop growth will restrained, even when it got a value, crop growth will be stopped. Those soil quality indicators are pH, bulk density, physical clay, clay, texture coarseness and water content. When we build those membership functions, we use trapezoid replacing "⋂" mode curve (Fig. 3). This membership function is:

$$F(x)=\begin{cases}1 & b_1 \le x \le b_2\\ \dfrac{x-a_1}{b_1-a_1} & a_1 < x < b_1\\ \dfrac{a_2-x}{a_2-b_2} & b_2 < x < a_2\\ 0 & x \le a_1 \ or\ x \ge a_2\end{cases} \quad ...(5)$$

Where, $F(x)$ is the membership function, x is the actual value of assessment indicator, and a_1, a_2, b_1 and b_2 are the critical values of assessment indicators. Based on previous studies and actual soil property of the research area, those upper critical values of indicator are given in Table 3.

Weight assignment: The contribution or importance to soil quality of each indicator is usually different, and can be indicated by a weighting coefficient. There are many ways to assign the weights for each indicator. This includes experience, mathematical statistics, or models (Wang 1994). In this study, the communality of indicator is calculated by multivariate statistical analysis in SPSS software. The weight of each indicator is calculated by the communality of each indicator. This weight function is:

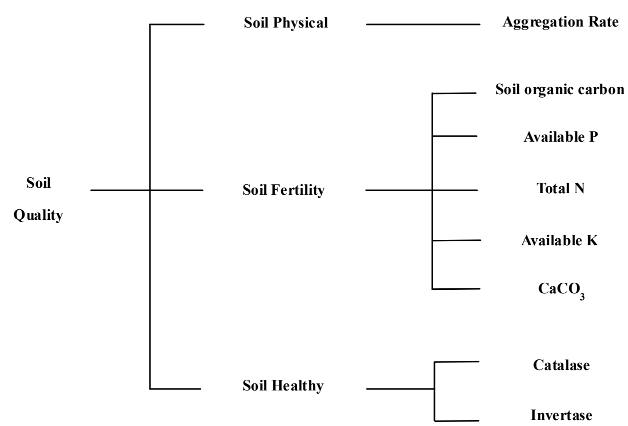

Fig. 4: Simplified indicators of soil quality evaluation.

$$W_i = C_i \Big/ \sum_{i=1}^{n} C_i \quad ...(6)$$

Where, W_i is the weight of indicator "i", C_i is the communality of indicator "i", and n is the number of indicators.

Calculation of soil quality indicator: After indicators were scored and weighted, soil quality indices were calculated using the Soil Quality Index (SQI) (Doran & Parkin 1994).

$$SQI = \sum_{i=1}^{n} W_i \times F_i \quad ...(7)$$

Table 2: Upper critical value of evaluation factors in membership function of "S" model.

Indicator	Upper critical value
Aggregation rate (%)	90.0
Organic matter (g/kg)	15.0
Total N (g/kg)	0.8
Available N (mg/kg)	70.0
Total P(g/kg)	0.8
Available P (mg/kg)	12.0
Total K(g/kg)	30.0
Available K (mg/kg)	200.0
Cation exchange capacity (cmol/kg)	25.0
Catalase (mL/g)	4.0
Urease (mg/g)	4.0
Alkaline phosphatase (mg/g)	0.8
Invertase (mL/g)	2.0
Protease (mg/g)	0.9

Table 3: Critical value of evaluation factors in membership function of parabola model.

Indicator	Turning point			
	a_1	b_1	b_2	a_2
pH	4.5	6.5	7.5	9.0
Bulk density(g/cm^3)	0.80	1.10	1.20	1.60
Physical clay (%)	15.0	35.0	40.0	65.0
Clay (%)	5.0	20.0	25.0	35.0
Texture coarseness	0.54	1.50	1.86	5.67
Water content (%)	5.0	15.0	20.0	25.6

Where, W_i is the assigned weight, F_i is the membership value, and n is the number of indicators.

RESULTS, DISCUSSION AND CONCLUSION

Simplified indicator system of soil quality evaluation: This simplified indicator system was made by the stepwise discriminant analysis in SPSS software. Land-use type is the grouping variable. Seven key soil quality evaluation indicators were selected by stepwise discriminant analysis. They are aggregation rate, total N, available P, available K, $CaCO_3$, catalase and invertase. Because of organic matter as an important indicator of soil quality, it was added into simplified indicator system. The discrimination function and simplified indicator system are given in Table 4 and Fig. 4.

Soil indicator membership values are given in Table 5. Soil indicator weight values are given in Table 6. Soil quality index of simplified indicator system of soil quality evaluation values is given in Fig. 5.

Original indicator system of soil quality evaluation: For test and verifying the result of simplified indicator system of soil quality evaluation, 22 original indicators were evaluated in the same way. Soil indicator membership values are given in Table 5, and soil indicator weight values in Table 7. Soil quality index of original indicator system of soil quality evaluation values is given in Fig. 6.

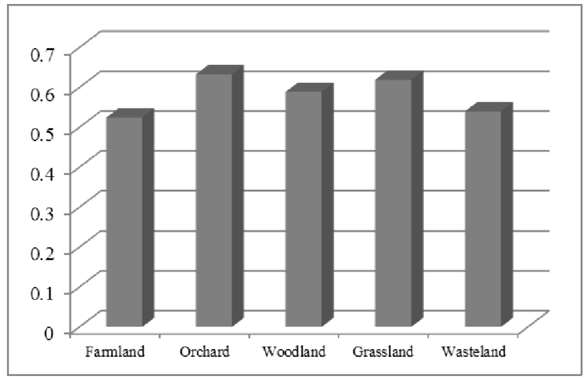

Fig. 5: Soil quality index (SQI) of simplified indicator.

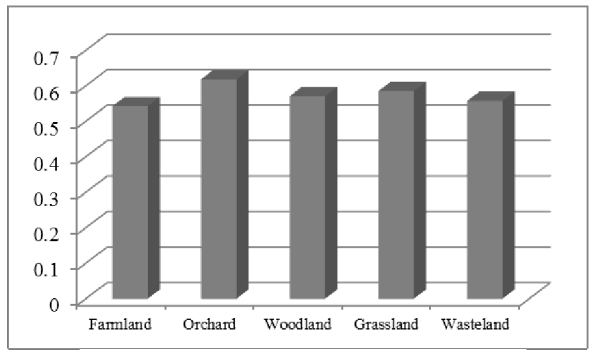

Fig. 6: Soil quality index (SQI) of original indicator.

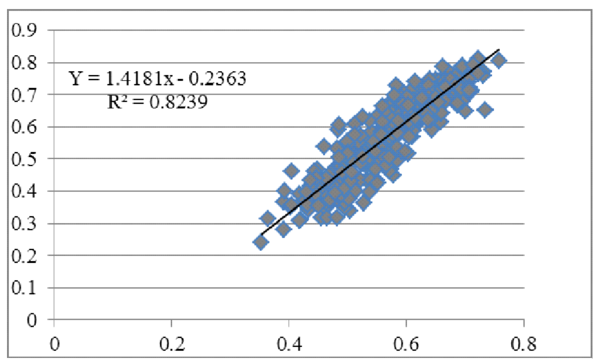

Fig. 7: Correlation of soil quality index between simplified indicators system and original indicators system.

Correlation analysis: Correlation of soil quality evaluation between by simplified indicator system and original indicator system is given in Fig. 7.

In different countries or regions, soil quality evaluation has different indexes. In recent years, a lot of soil quality indexes have been proposed and some of them have been tested and validated. Most of the soil quality evaluation

Table 4: Discrimination function of different land-use types.

Land-use type	Discrimination function		
	Soil physical quality	Soil fertility quality	Soil healthy quality
Farmland	$Y=-5.098+0.146X_4$	$Y=-6.836+4.637X_{10}+0.123X_{13}+0.019X_{15}+0.055X_{17}$	$Y=-15.475+8.589X_{18}+0.957X_{20}$
Orchard	$Y=-9.757+0.223X_4$	$Y=-11.380+5.227X_{10}+0.155X_{13}+0.032X_{15}+0.067X_{17}$	$Y=-20.185+9.699X_{18}+0.750X_{20}$
Woodland	$Y=-4.426+0.131X_4$	$Y=-6.269+6.980X_{10}+0.034X_{13}+0.016X_{15}+0.027X_{17}$	$Y=-15.178+7.435X_{18}+0.313X_{20}$
Grassland	$Y=-3.570+0.110X_4$	$Y=-5.012+6.110X_{10}+0.022X_{13}+0.010X_{15}+0.025X_{17}$	$Y=-14.921+7.379X_{18}+0.296X_{20}$
Wasteland	$Y=-6.679+0.176X_4$	$Y=-7.000+7.342X_{10}+0.003X_{13}+0.016X_{15}+0.039X_{17}$	$Y=-18.790+8.921X_{18}+0.218X_{20}$

Y means discrimination function, X_4 means aggregation rate, X_{10} means total N, X_{13} means available P, X_{15} means available K, X_{17} means $CaCO_3$, X_{18} means catalase, X_{20} means invertase.

Table 5: Measured value (mean) and membership values of soil quality indicators under different land-use types.

Indicator	Land-use type									
	Farmland		Orchard		Woodland		Grassland		Wasteland	
	Mea	Mem	Mea	Mem	Mea	Mem	Mea	Mem	Mea	Mem
PC (X_1)	27.40	0.52	38.67	0.79	26.00	0.50	22.65	0.38	31.58	0.65
TC (X_2)	2.98	0.65	1.72	0.79	3.06	0.66	3.48	0.58	2.44	0.74
CMR (X_3)	9.77	0.72	8.11	0.74	9.31	0.69	12.53	0.91	7.11	0.84
AR (X_4)	47.72	0.54	72.93	0.57	42.88	0.58	35.77	0.53	57.52	0.56
BD g/cm^3 (X_5)	1.28	0.36	1.25	0.32	1.25	0.69	1.17	0.64	1.21	0.55
SPT % (X_6)	50.86	0.61	51.84	0.68	51.99	0.77	54.87	0.78	53.30	0.71
SOM g/kg (X_7)	3.60	0.60	5.13	0.90	2.05	0.54	1.77	0.45	3.47	0.71
pH (X_8)	8.19	0.85	8.14	0.96	8.13	0.84	8.21	0.86	8.16	0.91
EC ms/cm (X_9)	147.67	0.32	104.84	0.33	92.16	0.15	90.45	0.16	99.98	0.24
TN g/kg (X_{10})	0.66	0.35	0.80	0.43	0.99	0.21	0.89	0.18	1.01	0.30
AN mg/kg (X_{11})	33.63	0.33	34.47	0.40	33.39	0.48	30.50	0.44	31.79	0.49
TP g/kg (X_{12})	0.71	0.47	0.79	0.49	0.58	0.47	0.60	0.44	0.61	0.45
AP mg/kg (X_{13})	11.30	0.84	16.33	0.88	4.78	0.73	7.04	0.74	5.85	0.75
TK g/kg (X_{14})	21.68	0.62	22.34	0.81	19.34	0.39	18.17	0.54	20.35	0.44
AK mg/kg (X_{15})	154.47	0.72	281.02	0.74	147.54	0.64	100.90	0.61	139.52	0.68
CEC cmol/kg (X_{16})	12.44	0.62	16.39	0.89	14.46	0.64	15.43	0.50	16.76	0.65
$CaCO_3$ g/kg (X_{17})	56.79	0.50	55.82	0.66	7.46	0.55	8.36	0.51	27.87	0.67
Cat. mL/g (X_{18})	3.47	0.43	4.06	0.59	3.49	0.74	3.46	0.73	3.94	0.70
Ure. mg/g (X_{19})	1.00	0.63	1.07	0.68	0.44	0.72	0.47	0.70	1.05	0.77
Inv. mL/g (X_{20})	2.16	0.63	2.97	0.52	3.70	0.65	3.65	0.64	3.49	0.64
A-pho. mg/g (X_{21})	0.36	0.15	0.44	0.11	0.41	0.14	0.36	0.20	0.47	0.09
Pro. mg/g (X_{22})	0.57	0.52	0.47	0.54	0.58	0.54	0.57	0.61	0.58	0.58

Mea means membership value, Mem means measured value, PC means Physical clay, TC means texture coarseness, CMR means characteristic microaggregate ratio, AR means aggregation rate, BD means soil bulk density, SPT means soil total porosity, SOM means soil organic matter, EC means electrical conductivity, TN means total N, AN means available N, TP means total P, AP means available P, TK means total K, AK means available K, CEC means cation exchange capacity, Cat. means catalase, Ure. meansurease, Inv. means invertase, A-pho. means alkaline phosphatase, Pro. means protease.

Table 6: Weight of soil quality indicatorsof simplified indicator system.

Indicator	AR	SOM	$CaCO_3$	TN	AP	AK	Cat.	Inv.
Farmland	0.132	0.100	0.143	0.111	0.112	0.138	0.126	0.139
Orchard	0.130	0.136	0.127	0.096	0.120	0.135	0.129	0.128
Woodland	0.095	0.112	0.135	0.136	0.096	0.122	0.143	0.160
Grassland	0.121	0.086	0.143	0.140	0.122	0.099	0.140	0.149
Wasteland	0.128	0.126	0.133	0.130	0.117	0.121	0.123	0.123

AR means aggregation rate, SOM means soil organic matter, TN means total N, AP means available P, AK means available K, Cat. means catalase, Inv means invertase.

Table 7: Weight of soil quality indicators of original indicator system.

Indicator	Weight				
	Farmland	Orchard	Woodland	Grassland	Wasteland
PC	0.056	0.054	0.058	0.054	0.046
TC	0.048	0.054	0.052	0.048	0.046
BD	0.048	0.037	0.034	0.036	0.050
CMR	0.036	0.051	0.019	0.045	0.043
SPT	0.050	0.037	0.043	0.043	0.051
AR	0.051	0.050	0.043	0.050	0.046
SOM	0.053	0.053	0.044	0.049	0.051
pH	0.040	0.046	0.044	0.042	0.040
$CaCO_3$	0.053	0.044	0.051	0.046	0.049
EC	0.033	0.049	0.038	0.043	0.049
TN	0.049	0.047	0.051	0.049	0.050
AN	0.037	0.046	0.052	0.049	0.044
TP	0.044	0.020	0.037	0.038	0.030
AP	0.046	0.044	0.048	0.043	0.042
TK	0.045	0.047	0.047	0.037	0.049
AK	0.044	0.047	0.050	0.042	0.047
CEC	0.042	0.044	0.054	0.048	0.045
Cat.	0.041	0.043	0.052	0.050	0.040
Ure.	0.047	0.044	0.045	0.048	0.049
Inv.	0.048	0.046	0.048	0.052	0.046
A-pho.	0.045	0.045	0.050	0.049	0.046
Pro.	0.042	0.051	0.043	0.038	0.042

PC-physical clay, TC-texture coarseness, CMR-characteristic microaggregate ratio, AR-aggregation rate, BD-soil bulk density, SPT-soil total porosity, SOM-soil organic matter, EC-electrical conductivity, TN-total N, AN-available N, TP-total P, AP-available P, TK-total K, AK-available K, CEC-cation exchange capacity, Cat-catalase, Ure.-urease, Inv.-invertase, A-pho.-alkaline phosphatase, Pro.-protease.

systems choose nearly 20 indexes. In this study, soil quality evaluation system was determined to be the most appropriate qualitative soil quality evaluation method, because it took all soil parameters into consideration and gave the most consistent results. However, in order for one method to become the standard for research and to facilitate discussion and cooperation, a standard should be rapid, reliable and economically feasible. For this reason, the simplified indicator system of soil quality evaluation has been established to replace original indicator system of soil quality evaluation. The simplified indicator system has 8 indicators: aggregation rate, soil organic matter, total N, available P, available K, $CaCO_3$, catalase and invertase. Match analysis showed a high linear correlation between simplified indicator system and original indicator system (Fig. 7). The correlation coefficient is 0.8239. The simplified indicator system of soil quality evaluation is an appropriate system of soil quality evaluation in Loess gullied hilly region of China.

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