RESEARCH ON CHANGES OF SOIL PROPERTIES AND QUALITY OF CULTIVATED LAND IN DIFFERENT UTILIZATION YEARS

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(Received 8th Jul 2023; accepted 1st Sep 2023)

Abstract. The development of wasteland is important to ensure the quantity of cultivated land and food security. It is of great significance to research the changes of soil property and quality with use. Taking the hilly area of the Taihang Mountains in China as the research area and the cultivated land of different utilization years as the research object, the spatio-temporal substitution method was used to explore the changes of soil properties and soil quality in different utilization years. The results showed that soil organic matter, alkali-hydrolyzed nitrogen, total phosphorus and total potassium were significantly correlated with the utilization years. The two indices of soil physical property large aggregate and water stability large aggregate were significantly correlated with the utilization years. There was no significant correlation between soil biological indices and utilization years. Through the established soil quality evaluation system, seven indices of soil organic matter, available phosphorus, alkali-hydrolyzed nitrogen, total nitrogen, available potassium, water-stable aggregates and microbial nitrogen were sensitive to the utilization years. The soil quality showed an overall trend of improvement with the utilization years. The soil quality was the best when the utilization years were 10 years, and the soil quality decreased and tended to balance after 15 years. This study can provide scientific guidance for land development and utilization and later management and protection.
Keywords: *soil physical properties, soil chemical properties, soil biological properties, spatio-temporal substitution method, soil quality evaluation, wasteland*

Introduction

Reasonable development of wasteland has become an important source of supplementary cultivated land, an important means to solve the problem of “Food security” and “Urbanization development”, and is of great significance for stabilizing the total amount of regional cultivated land (Dong, 2015). Countries and regions are actively guiding the development of wasteland to supplement cultivated land. However, in the current development and acceptance of wasteland, it is emphasized that the ratio of new cultivated land and the improvement of supporting facilities, the soil quality of new cultivated land is not fully considered, as a result, the soil fertility and productivity of new lands are low, and it is easy to cause serious ecological and environmental problems such as soil erosion.

On one hand, soil quality directly determines the level of soil productivity and affects the sustainable development of regional agriculture; on the other hand, soil quality determines the quality of regional ecological environment. At present, there are many research studies on the influence of land consolidation on soil quality, and most of them focus on the study of the temporal and spatial change of soil quality after land consolidation and the analysis of the influence mechanism. However, there are

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

relatively few studies on the evolution of soil quality after land development in different terrain areas and soil types.

There is a large amount of wasteland in the hilly area of Taihang Mountain in China, and the thin soil layer is the main limiting factor for development. The implementation of alien earth engineering is the main engineering means to develop it into cultivated land, and it is equipped with corresponding slope and ladder engineering, road engineering, irrigation, drainage engineering and farmland protection engineering. There are a large number of secondary loess distributed in this area, and the loess parent material is the main source of guest soil. Due to the soil characteristics of the loess parent material itself, there are often soil quality problems, such as poor soil nutrients, easy soil erosion and other ecological environmental problems in the early stage of development into cultivated land. Therefore, in order to realize the rational development of wasteland, it is of great significance to master the change law of soil physical, the analysis of the utilization years required for each index to reach the stable state has important guiding significance for the future soil fertilizer cultivation and agricultural production. In order to clarify the changes in soil properties and quality with the utilization years of cultivated land, and serve the scientific utilization and management of cultivated land, this study selected cultivated land with different utilization years as the research object, analyzed the chemical, physical, and biological indicators of soil properties of cultivated land with different utilization years, and constructed a soil quality evaluation system for soil quality evaluation.

Materials and methods

Overview of the research area

The research area is located in Tang County, Hebei Province, with east longitude 114°28’~115°03’ and north latitude 38°38’~39°10’. The county plains, hills, mountains, rivers and other landforms are complete, is an important ecological barrier in the Beijing-Tianjin-Hebei region, arable land is less and known as “seven mountains, one water and two fields” laudable name. The Taihang Mountains in the northwest and the North China Plain in the southeast of Tang County are the transitional zones from the mountains and hills to the plain. The general terrain features are high in the northwest and low in the southeast. There are many landform types in the county, and the northwest is mainly low mountainous area with steep mountain potential and high elevation. The central part of the county is mainly hilly area with relatively gentle terrain. The southeast is an alluvial plain with flat terrain. The altitude of the county is between 52 and 1869.8 m. There are many rock types in the county, mainly gneiss, limestone and shale. The climate of Tang County is warm temperate continental monsoon climate, which shows the characteristics of hot and rainy summer, cold and dry winter, rain and heat in the same period. The annual average temperature is 13.3℃, the annual average precipitation is 521.5 mm, the annual average sunshine duration is 2251 h, and the frost-free period is 257 days (Tang County People’s Government, 2022).

Plot selection

In addition to the different utilization years, the source of the guest soil, planted crops and development project types are the same, and the factors such as elevation and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

slope direction in the topographic area are consistent to ensure the comparability of the sample land. To ensure the representativeness of the sample plot, the area of each plot is not less than 400 m^2 (Ministry of Natural Resources, PRC, 2022). The source of guest soil comes from the same location, with a deep soil layer that is in a natural state, similar to raw soil, and is rarely affected by animal and plant activities. In research, it can be considered that the soil properties are stable and have not changed.

Through project data collection, field visits and surveys, the cultivated land with a use life of 1 year, 3 years, 6 years, 10 years, 15 years and 20 years was finally selected. Two to three plots of cultivated land for each use life were selected, and 17 plots were finally selected as research objects. The climatic conditions, topographic and geomorphic conditions, types of development projects and field management measures of the selected plots are relatively consistent. The source of the developed alien earth in the sample plots is the same, all of which are loess parent material. The thickness of the alien earth layer is 40~50 cm. Summer corn is planted in single season, and the varieties of corn planted in the study area are the same, the fertilizer is urea, applied at a rate of 1.5-1.8 t/ha, irrigation method for reservoir + agricultural well. The sample site information is shown in *Table 1*.

Table 1. *Basic information of selected sample sites*

Plot number	Utilization years	Longitude	Latitude	Altitude (m)	Crop	Plot number	Utilization years	Longitude	Latitude	Altitude (m)	Crop
1-1	1 year	114°51’4.23”	38°53’0.21”	170	Weed	10-1	10 years	114°51’23.90”	38°52’34.16”	145	Corn
1-2	1 year	114°51’9.93”	38°52’59.49”	170	Weed	10-2	10 years	114°51’24.58”	38°52’35.54”	145	Corn
1-3	1 year	114°51’5.73”	38°52’57.33”	187	Weed	15-1	15 years	114°48’55.51”	38°53’32.1”	270	Corn
3-1	3 years	114°48’57.70”	38°53’38.87”	274	Corn	15-2	15 years	114°48’56.76”	38°53’33.01”	275	Corn
3-2	3 years	114°48’57.30”	38°53’37.38”	265	Corn	15-3	15 years	114°48’58.02”	38°53’31.09”	257	Corn
3-3	3 years	114°48’55.84”	38°53’36.69”	260	Corn	20-1	20 years	114°48’54.03”	38°53’41.94”	245	Corn
6-1	6 years	114°48’49.65”	38°53’40.82”	262	Corn	20-2	20 years	114°48’54.79”	38°53’41.13”	249	Corn
6-2	6 years	114°48’49.81”	38°53’39.97”	265	Corn	20-3	20 years	114°48’55.23”	38°53’39.68”	252	Corn
6-3	6 years	114°48’50.61”	38°53’39.96”	280	Corn	Source of alien earth	0 year	114°49’0.32”	38°53’33.45”	260	-

The origin of the alien earth is recorded as 0 years

Sample collection

(1) Collection of undisturbed soil

The sampling time of soil samples was in early October 2018, after the harvest of summer corn, when soil nutrients and other indicators were relatively stable. Take the whole piece of undisturbed soil, cut off the deformed part of the surface of the soil block directly in contact with the spade, and evenly take the undeformed soil sample (about 2 kg) inside, and bring it back to the laboratory for the determination of soil aggregate and soil particle composition.

(2) Collection of dry and fresh soil samples

Soil samples ranging from 0 to 20 cm were collected with a soil drill which is in accordance with the five-point sampling method for each sample plot. Samples were randomly taken from the alien earth source, the sampling depth is also 0 to 20 cm, mixed into sealed bags and brought back to the laboratory. One kilogram of dry samples were retained for the determination of soil nutrients, and 500 g of fresh samples were

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

retained for the determination of soil microbial biomass carbon and nitrogen. During the sampling process, we pay attention to avoid areas where fertilizer has accumulated, and try to avoid special terrain areas such as fields and roads (NATESC, 2006).

Determination items and methods

For the experimental determination methods of soil chemical properties, refer to Soil Agrochemical Analysis (Bao, 2000), and for the determination methods of soil physical and microbial properties, refer to Soil Science Experiment (Lv and Li, 2010).

(1) Soil chemical property index determination

Soil pH was measured by potentiometric method, and the ratio of soil to water was 2.5:1. Organic matter was determined by potassium dichromate volume-external heating method. Soil total nitrogen was determined by semi-micro Kelvin method. Alkali-hydrolyzed nitrogen was determined by alkali-diffusion method. Soil total phosphorus was determined by NaOH melt-molybdenum-antimony resistance colorimetric method. The available phosphorus was determined by 0.5 mol·L^{-1} $NaHCO_3$ extraction-molybdenum-antimony resistance colorimetric method. The total potassium in soil was determined by NaOH melting and flame spectrophotometry. The available potassium was determined by NH_4OAc flame spectrophotometry.

(2) Soil physical property index determination

(1) Soil bulk density: the ring knife method is measured, repeated three times, and the arithmetic average of the three values is taken as the result. Calculation formula:

$$\rho b = (m_1 - m_2) \times D / V \tag{Eq.1}$$

In the formula, ρb -- soil bulk weight (g·cm^{-3}), m_1--soil bulk weight + ring cutter mass (g), m_2 -- ring cutter mass (g), D -- moisture coefficient (D = dry soil weight/wet soil weight), V-- ring cutter volume (cm^3).

(2) Field water capacity: Wilcox method was used to determine field water capacity, and the parallel measurement results were expressed as the arithmetic average. The calculation formula was as follows:

$$X = (m_1 - m_2) / (m_2 - m_0) \times 100 \tag{Eq.2}$$

where X—soil field water capacity (%), m_0—mass of dried empty aluminum box (g), m_1—mass of aluminum box + wet soil sample before drying (g), m_2—mass of aluminum box + dry soil sample after drying (g).

(3) Total soil porosity: According to the measured soil bulk density and density, calculated according to the following formula:

$$\text{Void fraction} = (1 - \text{volume weight/density}) * 100\% \tag{Eq.3}$$

Most soils have a density of 2.6~2.7 g/cm^3, soil density is averaged 2.65 g/cm^3 (Chen, 2018).

(4) Soil particle composition: simple hydrometer method was used.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

(5) Soil aggregates: non-water stable aggregates were determined by dry sieve method, and water stable aggregates were determined by Savinov wet sieve method (Zhang et al., 2000).

(3) Soil biological property index determination

Soil microbial biomass carbon (SMBC) was extracted by chloroform fumigation and volumetric analysis. Soil microbial biomass nitrogen (SMBN) was fumigated by chloroform and oxidized by ultraviolet spectrophotometry.

Soil quality evaluation methods

Sensitivity of soil quality evaluation indices

With the increase of utilization years, long-term tillage and fertilization, all soil quality indicators will change to different degrees and in different directions. In order to reflect the sensitivity of each soil quality index over time, the sensitivity of each index is reflected by identifying the coefficient of variation of each index. The greater the coefficient of variation, the index is more sensitive to the reflection of utilization years (Zhang, 2015). When constructing the evaluation index system, two levels of sensitivity, high and medium, were selected.

Soil quality index weight

In order to avoid the influence of human factors on the weight of indicators, this study uses the principal component analysis in multivariate statistical analysis to determine the weight of each indicator (Li et al., 2017). Based on the variance contribution rate, cumulative variance contribution rate and factor load of each principal component factor, the effect size of each component factor is calculated, and the weight value of each factor is calculated.

Determination of membership degree value of evaluation index

Due to the different dimensions of each index and the different directions of the effects of each index on soil productivity, fuzzy mathematics principle was applied to establish membership functions between each soil quality index and the evaluation purpose (Hu et al., 2001; Wang et al., 2001; Liu and Leng, 2019), and the established membership functions were used to achieve the standardization of the values of each index, that is, the measured values with units of each index were converted into dimensionless values between 0 and 1. The more commonly used membership functions are divided into three types: S-type (the more the better), trapezoid (the best range), and anti-S-type (the less the better). The seven soil evaluation indices selected in this study, including organic matter, total nitrogen and alkali-hydrolyzed nitrogen, all belong to S-type membership function for soil function (productivity) (Zhao et al., 2023), whose expression is as follows:

$$f(x)=\begin{cases}1 & x\geq b\\ \dfrac{x-a}{b-a} & a<x<b\\ 0 & x\leq a\end{cases} \qquad \text{(Eq.4)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

where, *f (x)* is the membership function, x is the actual index value of the evaluation index, a and b are the lower limit and upper limit of the index threshold respectively. In this study, the membership functions of the above evaluation factors are simplified as follows:

$$f(x)=\begin{cases}1 & x\geq x_0\\ \dfrac{x}{x_0} & x<x_0\end{cases} \quad \text{(Eq.5)}$$

where x_0 is the upper critical value of the evaluation index.

Soil quality evaluation

After calculating the membership degree and weight of soil evaluation indices, a single selected evaluation index is transformed into a soil quality index. By comprehensively comparing the advantages and disadvantages of various soil quality evaluation methods (Li et al., 2021; Han, 2016; Burger and Kelting, 1998), this study selected the weighted sum method evaluation model to evaluate the soil quality in the study area, and its calculation formula is as follows:

$$SQI=\prod_{i=1}^{n}W_i\times F_i \quad \text{(Eq.6)}$$

where *SQI* is the soil quality index, *Wi* is the weight of the i index, F_i is the membership value of each evaluation index, and *n* is the number of evaluation indicators.

Data analysis and processing

The study used EXCEL 2017 (Microsoft, USA) and SPSS18.0 (SPSS Inc., Chicago, USA) for data processing and statistical analysis.

Results

Soil property analysis

Soil chemical property index analysis

Soil chemical properties include soil nutrients, pH, salt content and soil pollutants, among which organic matter, pH, nitrogen, phosphorus and potassium content and their availability are common indices to measure soil fertility, which have a great impact on crop growth and development. Therefore, eight major soil chemical indices, including organic matter, pH, total nitrogen, alkali-hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium and rapidly available potassium, are selected. The spatio-temporal substitution method was used to analyze the changes of the above 8 indices with different utilization years, which provided theoretical basis for land development and rational fertilizer cultivation. The analysis results are shown in *Table 2*.

The organic matter content of the alien earth source is very low, which is commonly known as “raw soil”, and cannot meet the normal growth needs of crops. There was a significant positive correlation between surface organic matter content and utilization years, and the correlation coefficient was 0.969, respectively, and the content showed an increasing trend.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

***Table 2.** Correlation between topsoil chemical properties and utilization years*

Year	Organic matter (g/kg)	pH	Total nitrogen (g/kg)	Alkali-hydrolyzed nitrogen (mg/kg)	Total phosphorus (g/kg)	Available phosphorus (mg/kg)	Total potassium (g/kg)	Rapidly available potassium (mg/kg)
0 year	1.99	8.08	0.27	14.96	0.54	5.48	22.49	123.80
1 year	4.69	8.12	0.43	20.09	0.51	4.92	20.56	102.80
3 years	4.66	8.13	0.55	21.42	0.45	5.23	18.61	110.90
6 years	5.06	8.18	0.47	29.66	0.49	4.02	17.14	97.34
10 years	8.42	8.26	0.77	82.08	0.61	16.21	15.05	217.55
15 years	10.39	8.15	0.93	53.20	0.57	3.71	13.03	104.78
20 years	11.49	8.05	0.99	69.59	0.66	2.09	16.43	102.52
Correlation coefficient	0.969*	-0.059	0.958**	0.819*	0.760*	-0.109	-0.790*	0.032

**Significant correlation at the 0.01 level (bilateral); *significant association at the 0.05 level (bilateral). The utilization period of alien earth source is 0 year (the same below)

The pH of the surface layer changed little with the use years, and there was no significant correlation with the use years, showing a trend of increasing first and then decreasing. Soil pH is mainly affected by the condition of soil base and the content of organic matter. The watershed of pH change appears at about 10 years of utilization, which is related to the large increase of organic matter content after 10 years of utilization, and the increase of H + in soil leads to the decrease of pH.

The total nitrogen content of the soil source of the alien earth is very low, which belongs to the level of shortage. Total nitrogen content in the topsoil showed an increasing trend with the increase of utilization years, and showed a significant positive correlation with the utilization years, and the correlation coefficients were 0.958, respectively.

The content of alkali-hydrolyzed nitrogen in the source of the alien earth is very short, which affects the direct absorption and utilization of nitrogen by plants. The content of alkaline hydrolyzed nitrogen in the surface layer was positively correlated with the utilization years, and the correlation coefficient was 0.819.

The total phosphorus content of the source of the alien earth is slightly short, which can be properly supplemented during the development or cultivation process. Total phosphorus content in the topsoil fluctuated significantly with the utilization years, but the change amplitude was small. The total phosphorus content in the first year of utilization was 0.51 g/kg, which was 6% less than that of the alien earth source, and the total phosphorus content in the 20th year was 0.66 g/kg, which was 22% more than that of the alien earth source.

Soil available phosphorus is the part that can be directly absorbed and utilized by plants. The available phosphorus content of the alien earth is slightly deficient. There was no significant correlation between the available phosphorus content in the surface layer and the utilization years, and the correlation coefficient was -0.109, but the overall trend was decreasing.

The total potassium content of the alien earth is relatively abundant. The total potassium content in the topsoil showed a decreasing trend with the increase of utilization years, and showed a significant negative correlation with the utilization years, and the correlation coefficients were -0.790.

The available potassium content of the alien earth is of high grade, which can reduce the application of quick available potassium fertilizer in the process of development and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

cultivation. From the perspective of use years, except for 10 years of use, the available potassium content in the topsoil is slightly lower than that of the alien earth source, and changes with a certain range of use years, but the change range is small and there is no significant correlation.

Soil physical property index analysis

The physical properties of soil, including soil porosity and structure, have an important impact on the coordination of soil fertility factors, crop root spread, soil water retention ability, aeration status and microbial activity, and are crucial to soil productivity. Soil porosity and structure are easily affected by natural factors and human activities, which are the basic properties of soil fertility and soil fertilization. In the process of land development, the alien earth engineering and land leveling engineering have a great influence on the physical index of soil bulk density, and the tillage and fertilization will also affect the soil aggregate structure. In this study, soil bulk density, soil porosity, field water capacity and other indicators were selected for analysis, and the analysis results of each index are shown in *Table 3*.

Table 3. *Correlation between physical properties of topsoil and utilization years*

Year	Unit weight (g/cm^3)	Soil porosity (%)	Field capacity (%)	Mechanical composition			Water stable large aggregate (%)	Macroaggregate (%)
				Sand (%)	Silt (%)	Clay particle (%)		
0 year	1.24	51.99	22.41	12.11	58.00	29.88	2.50	60.50
1 year	1.33	50.93	22.32	9.11	54.01	36.89	4.86	74.04
3 years	1.44	43.67	18.19	7.11	52.01	40.89	7.66	80.50
6 years	1.27	53.24	23.95	4.11	51.00	44.89	9.41	80.22
10 years	1.39	46.08	21.79	9.12	49.99	40.89	6.47	82.00
15 years	1.34	49.61	20.47	2.11	51.01	46.89	14.28	93.07
20 years	1.32	49.78	21.28	4.11	57.01	37.89	10.21	88.18
Correlation coefficient	-0.322	-0.073	-0.346	-	-	-	0.762*	0.811*

The soil bulk density of the cultivated land is higher than that of the alien earth source, and the correlation between the use years was not significant. Because the surface layer is greatly affected by artificial cultivation, the bulk density changes in a certain range. The density value of topsoil varied from 1.27 g/cm^3 to 1.44 g/cm^3, which increased by 2% to 16% compared with the alien earth source. The bulk density of the topsoil is higher than that of the alien earth source, which may be caused by mechanical compaction during development on the one hand, and soil compaction caused by soil erosion on the other hand.

The total soil porosity of the cultivated land is lower than that of the alien earth source, except the cultivated land of 6 years, and the correlation with the use years is not significant. The surface soil is greatly affected by human cultivation, and the total soil porosity changes within a certain range. The decrease in total soil porosity may be caused by mechanical compaction during development, on the one hand, and may be caused by precipitation or irrigation, which compacts the soil.

Field water capacity of the cultivated land is smaller than that of the alien earth source, except the cultivated land of 6 years. The correlation coefficients between the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

topsoil and the use years were -0.346, and the variation amplitude with the use years was small, but did not reach the significant level.

Soil mechanical composition is closely related to nutrient conditions required for plant growth, which affects soil water retention, fertilizer retention and soil erosion (Zou et al., 2008). The grain composition of the alien earth is silt (58.00%) > clay (29.88%) > sand (12.11%), and the soil texture is loam. After cultivated land was developed, the content of different grain grades was silt > clay > sand, the soil texture was loamy, and the soil mechanical composition changed slightly. The change of soil mechanical composition is affected by a variety of factors, such as soil erosion, precipitation and irrigation will also bring small particles from the surface layer to the bottom layer, and tillage and fertilization will also lead to changes in soil mechanical composition. Under the combined influence of several factors, soil mechanical composition has no obvious characteristics in its evolution and distribution.

The large aggregate content of the soil source is low, and the mechanical stability is relatively poor. There was a significant positive correlation between large aggregate of topsoil and utilization years, and the correlation coefficient was 0.811, which showed an increasing trend. There was a significant positive correlation between the large aggregate content of soil water stability and the use years, and the correlation coefficient was 0.762. The mechanical stability and water stability of the soil aggregates from the alien earthare poor. After the development of cultivated land, the mechanical stability and water stability of the soil aggregates are enhanced through long-term tillage and fertilization. The quantity and stability of soil aggregates indicate the degree of soil maturation to a certain extent. Tillage and application of organic fertilizer can promote the formation of aggregate structure, thereby improving the nutrient status of soil structure.

Analysis of soil biological property index

Soil microorganisms should be more sensitive to changes in the external environment and play an important role in soil nutrient cycling and regulating supply, etc. Their quantity and species are considered to be an important basis for evaluating soil quality (Paz-Ferreiro and Fu, 2016; Chodak et al., 2013; Schulz et al., 2013).

The correlation coefficient between soil microbial biomass carbon and utilization years was -0.271, which did not reach the significant level and showed a certain fluctuation. The correlation coefficient between soil microbial nitrogen content and utilization years was -0.497, which did not reach the significant level. On the whole, the soil microbial nitrogen content was lower than that of the alien earth source. The soil microbial nitrogen content was the highest (12.30 mg/kg) after 1 year of utilization, and the lowest (0.89 mg/kg) after 10 years of utilization. With the increase of utilization years, SMBC and SMBN showed a gradually decreasing trend and did not show a significant positive correlation with organic matter. This research result was consistent with Bao Yaoxian's research results (Bao, 2008) on soil quality in dam land and hills of the Loess Plateau, which showed that SMBC and SMBN were significantly related to the number of bacteria, fungi and actinomycetes in soil. Its evolution and distribution law need to be further studied (*Table 4*).

Soil quality evaluation and analysis

For the evaluation of soil quality, a single evaluation factor is not enough to fully reflect the overall evolution law of soil quality, and the status of soil quality can only be

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

understood through comprehensive evaluation of various soil quality evaluation factors (Cheng, 2022; Zhang et al., 2010). We studied soil quality of newly added cultivated land from three aspects of soil physics, chemistry and biology, thereby revealing regional soil quality status and soil quality evolution law, and providing theoretical basis for maintaining and improving regional soil quality (Du et al., 2020; Ding et al., 2020).

Table 4. *Correlation between soil biological properties of topsoil and use years*

Year	Microbial carbon (mg/kg)	Microbial nitrogen (mg/kg)
0 year	681.01	13.51
1 year	654.75	12.30
3 years	884.76	6.36
6 years	592.23	8.13
10 years	797.92	0.89
15 years	468.32	1.34
20 years	702.75	3.20
Correlation coefficient	-0.271	-0.497

Sensitivity of soil indices and weight of evaluation indices

Sensitivity analysis was performed on 16 indices including organic matter, total nitrogen, alkali-hydrolyzed nitrogen, total phosphorus, available phosphorus, total potassium, rapidly available potassium, pH, bulk density, field water capacity, water-stable aggregates, large aggregates, clay particles, total porosity, microbial biomass carbon and microbial biomass nitrogen, and *Table 5* was obtained.

Table 5. *Variation coefficient of soil quality index*

Index	Coefficient of variation	Index	Coefficient of variation	Index	Coefficient of variation	Index	Coefficient of variation
Organic matter	48.26%	Available phosphorus	72.59%	pH	0.80%	Water stable aggregates	47.20%
Total nitrogen	39.98%	Total potassium	16.98%	Unit weight	3.84%	Macroaggregate	12.49%
Alkali-hydrolyzed nitrogen	59.47%	Rapidly available potassium	32.14%	Field capacity	7.79%	Microbial carbon	18.30%
Total phosphorus	12.11%	Total porosity	4.02%	Clay particle	14.18%	Microbial nitrogen	71.92%

According to the calculation results of the variation coefficient of each index, the variation coefficient > 50% is classified as highly sensitive, the variation coefficient between 30% and 50% is classified as moderately sensitive, and the variation coefficient < 30% is classified as low sensitive. Accordingly, the sensitivity classification results of 16 evaluation indicators are obtained, as shown in *Table 6*. When constructing the evaluation index system, two levels of sensitivity, high and medium, were selected.

Based on the sensitivity of each soil quality index with utilization years, available phosphorus, microbial biomass nitrogen, alkali-hydrolyzed nitrogen, total nitrogen, available potassium, water-stable aggregates and organic matter were selected to

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

establish a soil quality evaluation index system covering soil physics, chemistry and biology. The weights of evaluation indices are shown in *Table 7*.

Table 6. *Ranking and classification of sensitivity of soil quality index*

	Sensitivity of index	Index
>50%	Highly sensitive	Available phosphorus, SMBN, alkali-hydrolyzed nitrogen
30%-50%	Moderately sensitive	Total nitrogen, available potassium, water stable aggregates, organic matter
<30%	Low sensitive	SMBC, total K, total P, field capacity, clay, total voidage, large aggregate, bulk weight, pH

Table 7. *Weight of soil quality evaluation index in component matrix*

	Organic matter	Total nitrogen	Alkali-hydrolyzed nitrogen	Available phosphorus	Rapidly available potassium	Water stable aggregates	SMBN
Weight	0.1592	0.1592	0.1892	0.1805	0.1898	0.1086	0.0135

Membership degree value of evaluation index

With reference to other relevant studies (Bao, 2008; Xu, 2003; Pan et al., 2006) and combined with the actual soil properties in the study area, the critical values of the above indicators were determined, as shown in *Table 8*.

Table 8. *Upper critical value of the evaluation index*

Index	Organic matter (g/kg)	Total nitrogen (g/kg)	Alkali-hydrolyzed nitrogen (mg/kg)	Available phosphorus (mg/kg)	Available K (mg/kg)	Water stable aggregate (%)	SMBN (mg/kg)
Threshold	15.0	0.8	70.0	10.0	200.0	15.0	20.0

Soil quality evaluation results

The evaluation results are shown in *Figure 1*. The soil quality index (SQI) of the alien earth is 0.3582. From the perspective of utilization years, the SQI of topsoil increased first, then slightly decreased, and finally tended to be stable. In the first year of utilization, SQI is 0.4224, which is 17.92% higher than that of the alien earth source. In the tenth year of utilization, SQI is 0.8612, which is 140.42% higher than that of the alien earth source. The evolution process and trend of soil quality have important guiding significance for directional cultivation of soil and help guide agricultural production at the same time.

Discussion

Soil organic matter includes various animal and plant residues, microorganisms, and various organic substances decomposed and synthesized in the soil. The source of the guest soil is covered with wild grass, with a small amount of vegetation and is in a natural state without artificial input. After becoming the soil of cultivated land, the organic matter content rapidly increased through the implementation of projects such as guest soil fertilization. In the first year, the cultivated land was not cultivated, resulting in the accumulation of organic matter. With continuous cultivation and application of organic fertilizer, the soil continued to ripen, and the organic matter gradually

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2106_56575673

accumulated to a relatively stable state. This is consistent with the results of soil quality research on dam land and terraced fields in the Loess Plateau (Bao, 2008). The sensitivity of pH value to changes in external conditions is relatively low, mainly related to the properties of the soil itself. The soil parent material is loess, which is weakly alkaline. In addition, many factors such as the type and quantity of fertilizers, planting years, etc. can also cause certain changes (Zheng et al., 2022).

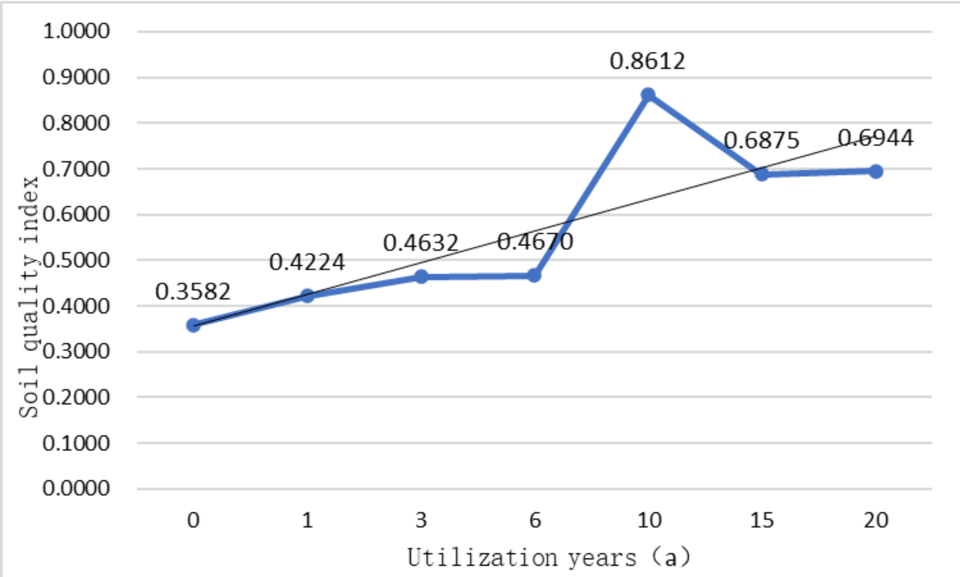

Figure 1. *Evolution characteristics of soil quality in different utilization years*

The nitrogen in the soil comes from biological nitrogen fixation, rainwater, and irrigation water bringing in nitrogen and fertilization (organic and chemical fertilizers). The nitrogen content of cultivated soil is not only influenced by natural factors, but also by human cultivation and management. The total nitrogen content in the soil reflects the level of nitrogen supply in the soil, while the alkali hydrolyzed nitrogen content reflects the amount that can be directly utilized by plants (Yan et al., 2007). There is a high similarity between the changes in total nitrogen and organic matter in soil, indicating that the changes and distribution of total nitrogen are greatly influenced by organic matter. As the development period increases, through cultivation and fertilization, it ultimately shows a fluctuating and increasing pattern of change.

The phosphorus content in natural soil mainly depends on the type of parent material (Liu and Han, 2002), while cultivated soil is mainly influenced by factors such as cultivation and fertilization (Xu, 2003). The loss of phosphorus in soil mainly includes surface runoff and leaching loss, while in low mountain and hilly areas with low groundwater levels, less phosphorus is lost through leaching, and following runoff loss is the main way of its loss (Guan, 2016). In the early stages of land development, the soil quality is relatively loose, and soil erosion is severe, which may be an important reason for the decrease in total phosphorus content. Compared to the source soil, the available phosphorus content in the soil has decreased. This may be due to the fact that local farmers mainly apply organic fertilizer and urea in the field, with a lower amount of phosphorus fertilizer applied. Secondly, the formation of soil organic matter and the activity of microorganisms cause a considerable amount of phosphorus to be fixed,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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resulting in a decrease in phosphorus availability. In addition, the loess parent material contains more calcium carbonate and has strong phosphorus fixation ability, It can also cause significant differences in phosphorus content in the soil.

The potassium in natural soil mainly comes from potassium minerals in the parent material of the soil, and the potassium content varies greatly in different regions, soil types, and climatic conditions (Zhang et al., 2007). The content of available potassium shows a relatively stable evolution trend with the development years, which is similar to the research on soil quality of slope farmland in the loess hilly area (Ma, 2018). The reason may be that the loess parent material itself has a high content of available potassium, and on the other hand, the application of fertilizers supplements available potassium.

The soil bulk density is influenced by internal factors such as soil texture and structure, as well as external environmental factors. For example, in the process of land development, land leveling, mechanical compaction, and other projects can cause changes in soil bulk density (Li, 2018). During the cultivation process, changes in organic matter content through tillage, irrigation, and fertilization can also cause changes in soil bulk density. After the implementation of land development projects, the soil bulk density increased, and during the research period, the soil bulk density of cultivated land was still higher than that of guest soil sources. This may be due to mechanical compaction during the development process and soil compaction caused by soil erosion; Due to these two reasons, the total porosity of the soil has decreased (Xu et al., 2022).

The field water capacity is mainly influenced by soil structure, texture, and organic matter content. The soil texture will not change significantly in the short term with the number of years of cultivation, so the overall change in the field capacity of cultivated soil is relatively small. The mechanical composition of soil affects its water holding capacity, fertilizer retention capacity, and soil erosion status (Zou et al., 2008). The changes in soil mechanical composition are influenced by various factors, such as soil erosion, precipitation and irrigation, which can also bring small particles from the surface layer to the bottom layer. Farming and fertilization can also cause changes in soil mechanical composition. The combined effects of several factors result in no obvious characteristics in the evolution and distribution of soil mechanical composition (Hao, 2019).

Soil aggregates reflect the overall fertility status of the soil (Wang et al., 2013). Through long-term cultivation and fertilization, the mechanical stability and water stability of soil aggregates are enhanced, which is consistent with the research results of Ma Tiantian (Ma, 2018). The quantity and stability of soil aggregates to a certain extent characterize the degree of soil maturation. Through cultivation and application of organic fertilizers, the formation of aggregate structure can be promoted, thereby improving soil structure (Chen et al., 2017; Xu et al., 2022).

With the increase of utilization years, SMBC and SMBN show a gradually decreasing trend, without showing a significant positive correlation with organic matter. This research result is consistent with Bao Yaoxian’s research on soil quality in loess plateau dam land and hills. SMBC and SMBN are significantly related to the number of fine bacteria, fungi, and actinomycetes in the soil, and their evolution and distribution patterns need further research.

With the increase of utilization years, SMBC and SMBN show a gradually decreasing trend and do not show a significant positive correlation with organic matter. This research result is consistent with the results of soil quality research in the dam land

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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and hilly areas of the Loess Plateau (Bao, 2008). SMBC and SMBN are significantly related to the number of bacteria, fungi, and actinomycetes in the soil, and their evolution and distribution patterns need further research.

Conclusion

Aiming at the scientific problems of soil quality evolution of newly developed cultivated land and the practical needs of guiding the rational development and utilization of unused land, taking loess parent material as the guest soil source land as the research object, the spatio-temporal substitution method was adopted to analyze the changing characteristics of soil physical, chemical and microbial properties from the perspective of different utilization years. Based on the sensitivity analysis of each soil quality index, a soil quality evaluation model was built to evaluate the quality of cultivated soil in different utilization years. The main conclusions are as follows:

Soil chemical properties showed obvious changes with the age of use. The contents of organic matter, total nitrogen, alkali-hydrolyzed nitrogen and total phosphorus in topsoil increased gradually with utilization years. The total potassium content decreased gradually with the utilization years, but pH, available phosphorus and available potassium content had no significant relationship with the utilization years.

In the physical properties of soil, there was no significant correlation between bulk density, total soil porosity, field water capacity and soil mechanical composition and use years. Compared with the soil source of the guest soil, the soil bulk density of the newly cultivated land increased, the total porosity and field water capacity decreased, the number of soil large aggregates increased, and the number of micro-aggregates decreased. Through long-term tillage and fertilization, the mechanical stability and water stability of soil aggregates were enhanced.

In terms of soil biological properties, SMBC content showed a certain fluctuation in the topsoil, and SMBN showed a gradually decreasing trend in the topsoil, and neither reached a significant level.

Sensitivity analysis of soil chemical, physical and biological property indices showed that seven indices of available phosphorus, microbial biomass nitrogen, alkali-hydrolyzed nitrogen, sensitive total nitrogen, available potassium, water-stable aggregates and organic matter were highly sensitive and were used as soil quality evaluation indices. According to the evaluation results, the topsoil quality showed an overall trend of improvement with the utilization years, and the soil quality was the best when the utilization years were 10 years, and the soil quality decreased and tended to balance when the utilization years were 15 years. When wasteland is developed into cultivated land, the soil quality is continuously improved due to cultivation and fertilizer cultivation in the initial stage. When the soil quality reaches a certain level, it may be caused by soil erosion due to unreasonable utilization methods and insufficient soil fertilizer cultivation, resulting in quality decline. In the process of farmland utilization, long-term management and quality improvement of farmland utilization should be achieved through strengthening soil and water conservation, avoiding excessive compaction, formulating fertilization based on nutrient characteristics, and increasing organic fertilizer application.

Acknowledgements. This research was Funded by Science and Technology Project of Hebei Education Department (QN2023085).

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