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Cultivated land quality improvement to promote revitalization of sandy rural areas along the Great Wall in northern Shaanxi Province, China

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ABSTRACT

The sandy area along the Great Wall in northern Shaanxi Province of China, is located in the transition zone between the Maowusu Desert and the loess hills and gullies region, with a vast territory and large per capita of cultivated agricultural land. However, the cultivated land quality is generally poor due to the local natural conditions. It is of practical significance to find ways to improve the quality of agricultural land and put forward targeted measures for its improvement. Through the analysis of farmland gradation results in the study area, we calculated an improvement potential index with a model to determine the primary limiting factors of agricultural land quality in the study area. The results indicate that both singe-factor and combined-factor limitations exist in the region. The single-factor limiting types include soil thickness, organic content, irrigation, salinization, etc., while the combined-factor limiting types include the combinations of the irrigation water source and irrigation firm probability, soil structure and organic matter, soil thickness and soil texture, and so on. Through the analysis of the potential index model results, we determined the main limiting factors in agricultural production, which vary spatially throughout the region, and suggested targeted measures to improve the cultivated land quality. These measures will then promote revitalization of sandy rural areas along the great wall in northern Shaanxi Province, China.

1. Introduction

The proportion of people living in urban areas around the world increased from 33% in 1960 to 54% in 2016, with particular growth in Asia and Africa. This rapid urbanization has seriously affected rural areas, leading to the intensification of 'rural disease' issues and cultivated land losses (Liu, 2018). Cultivated land is necessary for the sustainable development of agriculture (Cao et al., 2017). As the most basic agricultural production component, cultivated land quality is directly related to the security of national food and agricultural product quality (Shen et al., 2012; Jarosław and Jarosław, 2018). Land engineering can improve farming conditions and yields, and consequently improve the production and living conditions in rural areas (Liu and Li, 2017; Przemysław, 2018). From 2003 to 2015, China's food production achieved 12 significant continuous growth periods, but it also faced serious problems with regard to the decline of cultivated land quantity and quality (Zhang et al., 2015; Xu et al., 2016). With ongoing reformation of the land management system, quality management of cultivated land has gradually become the focus of Chinese and foreign governmental policy makers and scholars (Ma, 2016; Liu et al., 2014, 2018). The Bulletin on the Status of Cultivated Land Quality Grade in China, issued by the Ministry of Agriculture in 2014, pointed out that China's middle-to-low-grade cultivated lands accounted for 27.9% of the total cultivated land in China, mainly distributed along the Loess Plateau and the Great Wall. These middle-to-low-grade cultivated lands are located in different geographical, environmental, and climatological locations, with complex issues affecting their quality and limiting factors, causing difficulties in managing and improving the cultivated land quality and restricting food output (Chen et al., 2011; Lv et al., 2015).

Research on cultivated land quality mainly focuses on the selection

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of an evaluation index of cultivated land quality (Zhang et al., 2002; Yang et al., 2017), the establishment of a cultivated land quality monitoring system (Ma et al., 2013, 2018; Zhang et al., 2001; Du et al., 2016), the dynamic balance of cultivated land quality (Zheng and Feng, 2003; Li et al., 2016; Zhang et al., 2016), the improvement of cultivated land quality (Xu, 2003; Song et al., 2017; Gao et al., 2016; Liu et al., 2018.), etc. For research on the limiting factors of cultivated land quality, academia has adopted the index method and the regression analysis method. The index method is widely used in soil adaptability, cultivated land fertility evaluation, and farmland gradation, among which the exponential sum method (weighted sum method) is the most common (Bai et al., 2005; Zheng and Liu, 2007; Feng et al., 2014). In the evaluation of red soil resource quality in Zhejiang, Yueming et al. (1999) adopted the exponential sum method, exponential product extraction method, and fuzzy comprehensive evaluation method. They compared the evaluation results, among which the exponential product extraction method was found to have the most ideal evaluation effect (Hu et al., 1999). When applying the exponential sum method to evaluate and calculate the quality grade score of evaluation factors, the Delphi method is also commonly used in determining the grade and weight of index factors (Zhang et al., 2008). The regression analysis method was first presented as a method for measuring productivity in this field (Li et al., 2014). Xing et al. conducted a field sampling survey and analysis by setting up representative sample regions of cultivated land, then selecting and determining the main factors and weights of regional cultivated land quality evaluation through stepwise multiple regression analysis (Xing et al., 2002, 2003). Based on the accuracy of cultivated land quality grades in Huixian City of Henan Province Song et al. (2015) explored the main factors affecting the quality of cultivated land in Huixian via regression analysis and principal component analysis. Primarily through the monitoring of cultivated land, soil, and natural resources and the investigation of land resources, scholars worldwide realized that, by scientifically selecting soil quality indexes and improving soil quality (Chu et al., 2006; Busscher et al., 2007), the cultivated land quality could be better evaluated.

The sandy area along the Great Wall in northern Shaanxi has a relatively large area and an abundant reserve of cultivated land, but the quality of the cultivated land is generally low (Han et al., 2015). Therefore, research on improving the quality of the cultivated land in this area can effectively enhance its overall quality and provide support for the requisition-compensation balance of cultivated land and high-standard basic farmland construction in Shaanxi. Based on cultivated land gradation results, this paper combines cultivated land limiting factors with cultivated land gradation results and clarifies the priority sequence of quality-limiting factors with the use of a national natural grade improvement potential index model. It also proposes targeted methods and measures for improving the quality of the cultivated land for various limiting factors and provides a theoretical basis for exploring efficient and economical quality improvements to cultivated land. It also aims to fully realize the potential productivity of cultivated land and increase the effective food supply, thus improving the quality of cultivated land by scientifically implementing guidelines for its development and management.

2. Overview and data source of study area

2.1. Overview on study area

The sandy area along the Great Wall in northern Shaanxi is located in the northern part of the Shaanxi Loess Plateau and the southeast edge of the Maowusu Desert; its northern latitude is 36°57′–39°34′, and its east longitude is 107°28′–111°15′. Its elevation is 1000–1500 m high in the northwest and low in the southeast. It's a transition zone between the Maowusu Desert and the Loess Plateau. With the Great Wall as the boundary, its northern edge is the sandy beach, while its southern boundary is the loess hills and gullies region, including three counties, two districts, and a city: Fugu County, Shenmu City, Yuyang District, Hengshan District, Jingbian County, and Dingbian County. The land area is relatively broad, and the per capita cultivated land possession is large. It has a temperate semi-arid continental climate, with a regional annual average temperature equal to or lower than 8 °C, a mean annual precipitation equal to or less than 400 mm, annual dryness greater than 2 g/m^3, and abundant sunlight and rich light energy resources. The surface water system is an inland river system, and the groundwater stock is small, mainly including aeolian-deposit, alluviated, lacustrine-deposit groundwater of medium-fine sand, silty-fine sand, and sandy loam gaps, as well as deep phreatic water buried 45–100 m below and deeper. The soil mainly includes sandy soil, chestnut soil, and alluvial soil, with serious wind erosion, desertification, and poor fertility.

The sandy study area belongs to the secondary index zone of the primary index zone of the Loess Plateau. In spring, corn is planted; in summer, wheat is planted; and, in winter, rice, corn, and soybeans are planted. The standard crops are spring corn and potatoes, and the multi-cropping pattern is one crop per annum. According to the quality grade survey and evaluation results of cultivated land issued by the Ministry of Land and Resources on December 24, 2009, the national cultivated lands were assessed by means of 15 quality grades, with Grade 1 indicating the best quality of cultivated land and Grade 15 indicating the worst. Cultivated lands across the country were divided into four grades, with Grades 1–4 being excellent land, Grades 5–8 being high-grade land, Grades 9–12 being middle-grade land, and Grades 13–15 being low-grade land. The resulting data were updated annually according to the *Regulations on Farmland Quality Gradation* and the cultivated land quality grade of Shaanxi in 2014. The present cultivated land in the study area is mainly middle-to-low-yield farmland, with a low national natural grade, mainly belonging to Grades 12–14 (Fig.1).

In 2014, the total area of cultivated land in the study area was 473,153 hm^2, of which the common cultivated land area was 436,504 hm^2, including paddy fields of 4,610 hm^2, accounting for 1.06% of the common cultivated land area; irrigable land of 129,845 hm^2, accounting for 69.20%; dry land of 302,049 hm^2, accounting for 29.75%; and temporarily cultivated land (including steep hills with more than 25° gradients) of 241,449 hm^2. The distribution of the cultivated land in the study area is shown in Table 1.

Meanwhile, in the study area, Grade 12 land accounted for only 11.87% of the total cultivated land area, while Grade 13 land accounted for 8.45%, and Grade 14 land accounted for 79.69%. That is, middle-grade land only accounted for 11.87% of the total cultivated land area, while low-grade land occupied 88.13%, indicating poor cultivated land quality in the study area. However, the per capita cultivated land area was larger, with greater cultivated land improvement potential.

2.2. Data sources

The research data in this paper mainly come from the updated evaluation and analysis report on the cultivated land quality grade in Shaanxi in 2014, the cultivated land quality grade change database in Shaanxi in 2014, the cultivated land quality gradation parameters in Shaanxi, the *Yulin Statistical Yearbook in 2015,* and other relevant statistics data.

3. Research methods

3.1. Delphi method

The Delphi method was first proposed by Helm and Dalke and has been applied in many areas of decision-making (Yuan et al., 2011). Based on system procedures, expert discussion, and connections with investigators, experts' views are surveyed for several rounds before being summarized into a consensus after repeated consultation, induction, and modification, to serve as the basis for decision-making.

Based on the collected data about the quality and utilization status of

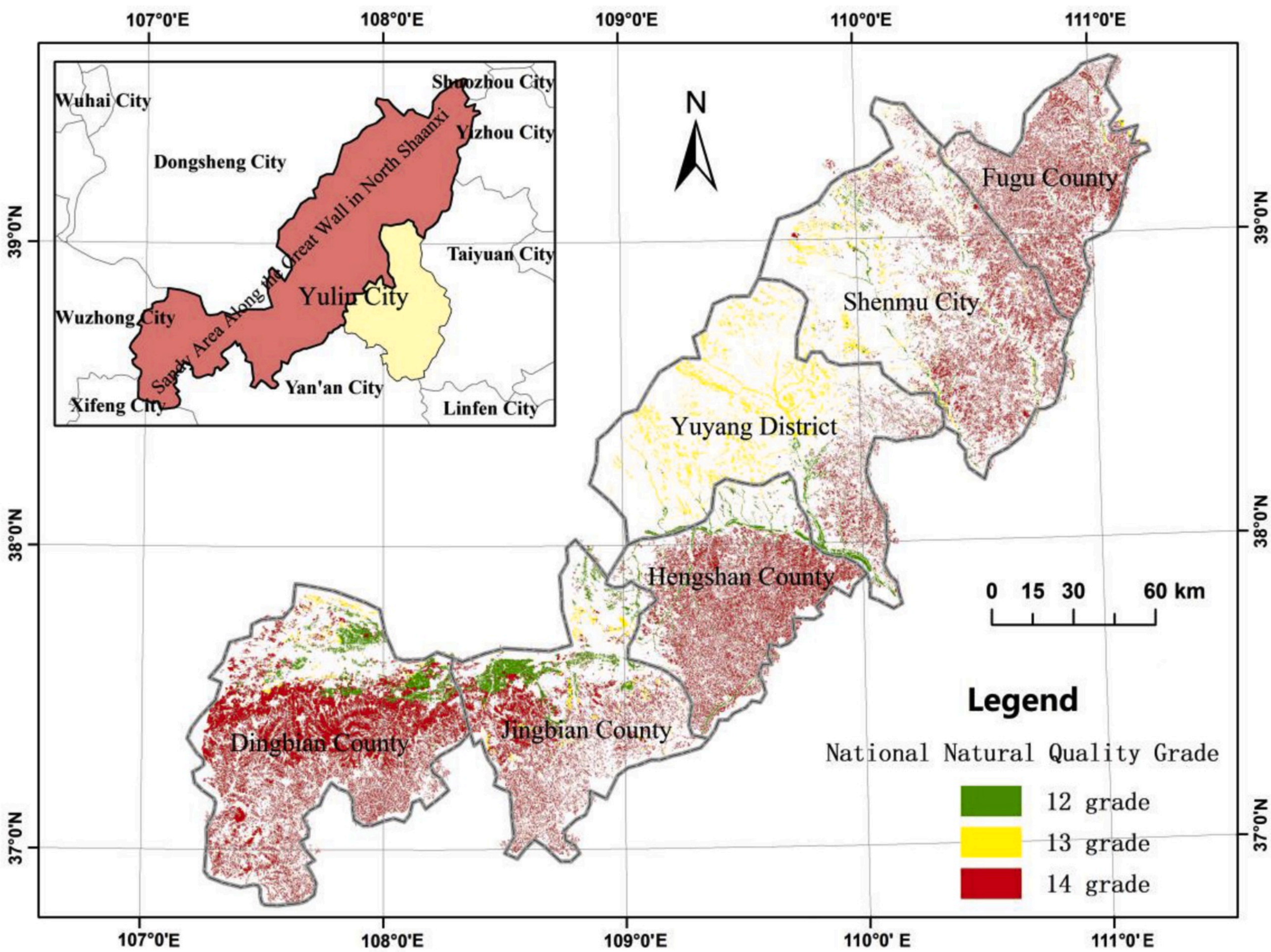

Fig. 1. Spatial distribution of the national natural quality grade of the cultivated land in the sandy area along the Great Wall in northern Shaanxi Province, China.

Table 1
Summary of cultivated land area in the study area.

County (district, city)	Common cultivated land area (hm^2)			
	Paddy field	Dry land	Irrigable land	Total
Yuyang District	1861	21077	42131	65069
Shenmu City	0	27650	20824	48474
Fugu County	0	40923	2340	43263
Hengshan District	2728	46665	11226	60619
Jingbian County	21	47,693	32440	80154
Dingbian County	0	118041	20884	138925
Total	4610	302049	129845	436504
Proportion of area (%)	1.06	69.2	29.75	–

cultivated land in the study area and the comprehensive consideration of the content and characteristics of the cultivated land quality, experts established an index system that combined the gradation index and cultivated land change field monitoring in the *Regulations on Farmland Gradation* (GB/T28407-2012), according to principles of stability, production, comprehensiveness, and spatial distribution difference. Finally, evaluation indexes of the quality of cultivated land were determined to be soil organic content, topsoil texture, salinization degree, irrigation water source, irrigation firm probability, and effective soil thickness. The Delphi method and principal component analysis were used to assign different weights to different indexes while planting various crops (Table 2).

Table 2
Evaluation index and weight of cultivated land quality.

Index name	Index code	Weight	
		Spring corn	Potato
Effective soil thickness (cm)	o	0.27	0.29
Topsoil texture	p	0.08	0.10
Soil salinization degree	q	0.14	0.14
Soil organic content (g/kg)	r	0.08	0.08
Irrigation firm probability	s	0.30	0.26
Irrigation water source	t	0.13	0.13

3.2. Natural grade improvement potential index model

This paper adopts the natural grade improvement potential index model to calculate the potential index of each gradation factor, and the determination of limiting factors is based on the calculated potential index(Ma et al., 2013, 2018). The specific method is as follows:

(1) Maximum contribution value of the gradation factor

The maximum contribution value of the gradation factor is used to indicate the maximum extent of the natural grade score of cultivated land under the corresponding conditions, calculated using the following formula:

$$R_{ik} = \frac{\sum_{j=1}^{j} W_{ij} \times 100 \times \alpha_j \times \beta_j}{100} \tag{1}$$

where R_{ik} is the maximum contribution value of the k-th gradation factor of the i-th gradation unit to the natural index of that unit; W_{jk} is the k-th gradation factor weight of the j-th designated crop; k refers to the gradation factor number; α_j indicates the photo-thermo (climate) potential productivity index of the j-th designated crop; and β_j is the productive ratio coefficient of the j-th crop.

(2) Actual contribution value of the gradation factor

The actual contribution value of the gradation factor indicates its effect on the natural quality score of the cultivated land under the corresponding conditions, calculated using the following formula:

$$r_{ik} = \frac{\sum_{j=1}^{j} W_{ij} \times f_{ij} \times \alpha_j \times \beta_j}{100} \tag{2}$$

where r_{ik} is the actual contribution value of the k-th gradation factor of the i-th gradation unit to the natural index of such unit; W_{jk} is the k-th gradation factor weight of the j-th designated crop; k refers to the gradation factor number; α_j indicates the photo-thermo (climate) potential productivity index of the j-th designated crop; and β_j is the productive ratio coefficient of the j-th crop.

(3) Potential index calculation model of the gradation factor

The potential index calculation model of the gradation factor refers to its theoretical improvement potential of the natural quality of cultivated land under the corresponding conditions. The larger the potential index, the larger the corresponding gradation factor and the better the improvement of cultivated land quality, calculated using the following formula:

$$P_{ij} = \frac{(R_{ik} - r_{ik})}{R_{ik}} \times 100 \tag{3}$$

where P_{ik} is the natural grade improvement potential index of the k-th gradation factor of the i-th gradation unit; R_{ik} is the maximum contribution value of the k-th gradation factor of the i-th gradation unit to the natural index of such unit; and r_{ik} is the actual contribution value of the k-th gradation factor of the i-th gradation unit to the natural index of such unit.

P, the natural grade improvement potential index, is calculated based on the above models. The greater the P value, the large the promotable potential. The closer to the top in the spectral order, the stronger the limitations. The maximum value of P indicates the primary limiting factor of the land.

4. Analysis of results

4.1. Analysis of the main and combined limiting types

Based on the natural grade improvement potential index model, the natural grade improvement potential indexes of 363,033 cultivated land plots in the study area were calculated to define the main limiting factor of each cultivated land plot (Table 3). The dry land in plot number one had a natural Grade 14 with a maximum natural grade improvement potential index of 50%. Therefore, its main limiting factors were irrigation water source and irrigation firm probability.

Through the statistical analysis of model calculation result, the main limiting types of cultivated land quality in the sandy area along the Great Wall in north Shaanxi were found to be the single-factor limiting type and combined limiting type. The single-factor limiting type includes soil thickness, topsoil texture, salinization, organic matter, water source, and irrigation firm. The combined limiting type comprises two other types: effective soil thickness-topsoil texture and irrigation firm probability-irrigation water source.

Based on the unique natural condition and agricultural production condition in the sandy area along the Great Wall in north Shaanxi, through the analysis of two gradation indexes with similar features of effective soil thickness-topsoil texture and irrigation firm probability-irrigation water source, it can be understood that these two gradation indexes are strongly interrelated after the correlation analysis and qualitative analysis. Therefore, these two gradation indexes can be classified and merged into the same cultivated land quality limiting type. As a result, the main limiting types of cultivated land in the sandy area along the Great Wall in north Shaanxi (Table 4) are soil structure, salinization, organic matter, and irrigation.

4.2. Spatial distribution of the main limiting factor types

Through statistical analysis of the main limiting factor types in the study area, the proportional area of each type of limiting factor was statistically determined, and the degree of influence of each type clarified (Table 5, Fig.2).

Through the analytical statistics of the area ratios of each main type of limiting factor, it can be determined that the single-factor limitation with the largest influence scope in the sandy area along the Great Wall in north Shaanxi is irrigation, whose affected cultivated land accounts for 33.8% of the total study area, followed by organic matter, which affects for 14.2% of the total study area.

In terms of combined-factor limitations, irrigation and organic

Table 4
Limiting types and gradation indexes of cultivated land quality.

No.	Gradation index	Limiting type	Effect
1	Effective soil thickness Topsoil texture	Soil structure	Affects crop root system development so as to influence cultivated land quality
2	Soil salinization	Salinization	Indirectly affects absorption of moisture in the crop growth and root respiration process
3	Soil organic content	Organic matter	Affects crop growth and output status
4	Irrigation firm probability Irrigation water	Irrigation	Affects whether the basic need for water by crops is satisfied

Table 3
All-factor natural grade improvement potential index.

Plot No.	Land type	Nature grade	Effective soil layer (%)	Topsoil (%)	Salinization (%)	Organic matter (%)	Irrigation water (%)	Irrigation firm probability (%)	Main limiting factor
1	Dry land	14	39.93	76.06	0.00	25.00	50.00	50.00	p
2	Dry land	14	39.93	76.06	0.00	25.00	50.00	50.00	p
…	…	…	…	…	…	…	…	…	…
363019	Dry land	14	10.00	0.00	0.00	25.02	50.00	50.00	s-t
363020	Irrigable land	12	10.00	0.00	30.00	37.52	10.00	10.00	r
…	…	…	…	…	…	…	…	…	
363033	Irrigable land	13	30.00	0.00	0.00	37.51	10.00	30.00	s

Table 5
Quantitative analysis results for the main types of limiting factors.

Main type of limiting factor	Area/hm^2	Proportion in the total area (%)
Irrigation	221,883	33.8095
Salinization	7,564	1.1526
Organic matter	93,198	14.2011
Soil structure	49,060	7.4755
Irrigation and organic matter	282,336	43.0211
Organic matter and soil structure	2,233	0.3403

matter have the largest area ratio influence, accounting for 43% of the total study area. The soil structure and salinization influence area accounts for 8.5% of the total cultivated land, which is a relatively small ratio. The above statistical results indicate that the main limiting factors affecting the cultivated land quality in the sandy area along the Great Wall in north Shaanxi are irrigation conditions and soil organic content.

Through the analysis and statistics on the distribution and area ratio of the main limiting factors, a quantitative analysis was carried out on the improvement potential of cultivated land quality, and the key area for improvement and management of cultivated land quality was determined. Our analysis shows that the main limiting factor type in Yuyang District is soil structure, accounting for 58% of the total area of county cultivated land. The second limiting factor type is combined irrigation and organic matter. The combined irrigation and organic matter factor in Shenmu City accounts for 61% of the total area of county cultivated land, followed by the single-factor limitations of organic matter and irrigation. The main limitation in Fugu County is irrigation, accounting for 78% of the total area, followed by organic matter. There is primarily a combined-factor irrigation and organic matter limitation in Hengshan District and Jingbian County, accounting for 85% and 46% of the total area, respectively, followed by organic matter. The main limitation in Dingbian County is irrigation, accounting for 66% of total area, followed by organic matter. Meanwhile, Dingbian County and Jingbian County are the only areas in the study area where there are salinization limiting factors.

In the field investigation of the evaluation of cultivated land quality, local farmers often talked about ’fertilizing land by water’. Such perceptual knowledge from the experience of local farmers also indicates that irrigation water and irrigation probability are the main factors restricting the cultivated land quality in the study area, which also speaks to the anecdotal accuracy of the research results.

4.3. Corresponding conditions and improvement advice regarding the main types of limiting factors of cultivated land quality and national natural grade

The main limiting factors and ratios of each grade are defined through the statistical analysis of grade and limiting factors of cultivated land quality. Statistical analysis found that there is a defined relationship between the natural quality grade of cultivated land and their limiting factors (Table 6).

Grade 12 land is primarily limited by irrigation and salinization, accounting for 68% of the total area of Grade 12 land, while organic matter and soil structure limitations only occupy 32% of the total area of Grade 12 land. Through the previous analysis, we know that Grade 12 land only accounts for 11.87% of the total cultivated land area of the study area, and it is mainly distributed around the rivers and reservoirs in the northern parts of Jingbian County and Dingbian County, with high underground water levels. The local ’fertilizing land by water’ axiom makes the quality of the irrigated land (and a small amount of the paddy fields) significantly better than that of other lands. However, long-term

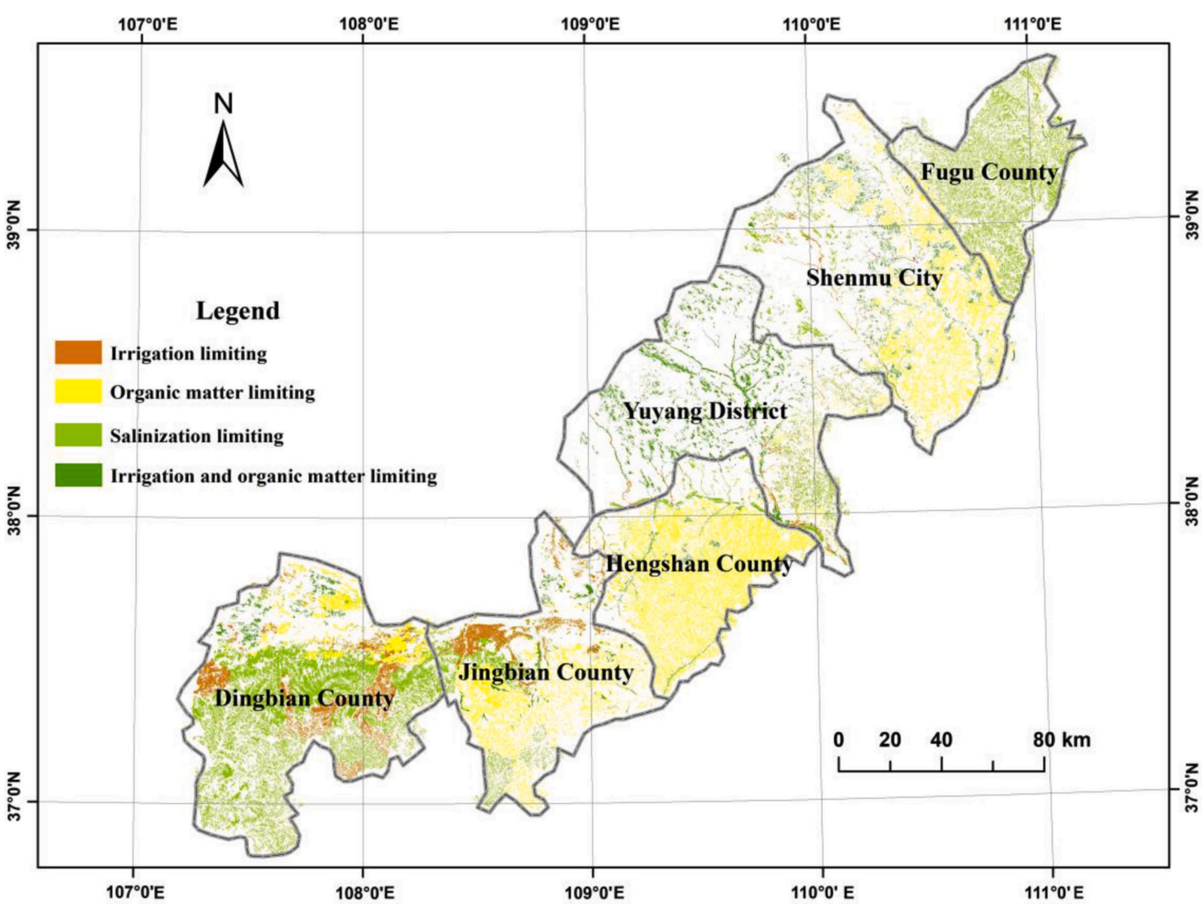

Fig. 2. Spatial distribution of the main types of limiting factors of cultivated land quality.

Table 6
The area and proportion of natural grades and limiting factor types.

Main limiting factor type	Area/ Ratio	Grade 12	Grade 13	Grade 14	Total
Soil structure	Area (hm^2)	6,378.06	45,763.64	28,240.74	80,382.45
	Ratio (%)	8	74	5	11
Organic matter	Area (hm^2)	20,716.13	10,459.72	225,041.70	31,3463.77
	Ratio (%)	24	17	38	43
Salinization	Area (hm^2)	26,209.47	4,277.82	44,305.19	255,529.00
	Ratio (%)	30	7	8	35
Irrigation	Area (hm^2)	33,053.81	959.02	282,287.92	78,318.02
	Ratio (%)	38	2	49	11
Total	Area (hm^2)	86,357.47	61,460.21	579,875.56	727,693.24

irrigation also leads to the hardening and salinization of soil, which restricts further improvement of the cultivated land quality.

Grade 13 land is primarily limited by soil structure, accounting for 74% of the total area of Grade 13 land, while organic matter and irrigation limitations only account for 26%. Through the previous analysis, we know that Grade 13 land is largely distributed in the northern area of Yuyang District, which is in the sandy zone, bordering the Maowusu Desert. Its topsoil is mostly sandy soil or loam with a relatively low agglomeration degree and serious desertification. It is hard for soil structure with desertification to preserve moisture and fertility, so soil structure is the main limiting factor type in this area.

Grade 14 cultivated land area accounts for 79.69% of the total study area, which is primarily limited by irrigation and organic matter. Irrigation factor limitations account for 49% of the Grade 14 cultivated land area, while organic matter accounts for 38%. It also validates the poor quality of the cultivated land in the study area and the truth behind the farmers' statements about fertilizing land by water.

Based on the above analysis, there is a complex relationship between the cultivated land quality and the limiting factor type. The limiting factor types of Grade 12 land are more diverse than those of Grades 13 and 14, and its limiting factor types are more diversified, including irrigation, salinization, and organic matter. Grade 13 land is mainly limited by soil structure, while Grade 14 land is majorly limited by irrigation, both of which are primarily single-factor limitations.

On the basis of the results above, we can determine that the main limiting types of cultivated land quality are irrigation, organic matter, soil structure, and salinization. Some measures to improve the quality of the cultivated land are proposed below—specifically, soil improvement, scientific fertilization, water-saving irrigation, and salinization improvement. In addition, according to the cultivated land quality improvement, we can promote revitalization of sandy rural areas along the great wall in northern Shaanxi Province, China.

(1) Soil improvement

Soil improvement occurs mainly from changing the topsoil texture, increasing the effective soil thickness, and other related issues. Studies have shown that organic fertilizer can improve soil physical properties, reduce soil bulk density, increase soil porosity, and have an important impact on soil moisture and salt movement. Similar to light loam, fly ash grain can reduce the clay content of cohesive soil, increase sand grain content, reduce bulk density, increase the total porosity, promote plant growth, and improve plant biomass, because fly ash can improve the soil, increase trace elements in soil, improve soil microbial activity, and is conducive to soil organic matter decomposition. Sand can increase the total porosity, reduce the soil bulk density, and improve the permeability of the soil, and it is also the common material used in the improvement of clay land and saline-alkali soil, because of its convenience and low price. In recent years, local studies have been conducted to improve the cultivated land quality by using local feldspathic sandstones, sandy soil, and clay to improve the texture of soil by mixing different components. It is of great practical significance to realize the sustainable development of agricultural production to monitor soil nutrient changes while improving soil structure, to master the changing guidelines for soil nutrients during its cultivation and utilization, and to explore and formulate reasonable land utilization methods and improvement measures.

(2) Scientific fertilization

In order to improve the organic content of cultivated land in the study area, soil organic content can be improved by planting green manure crop, straw returning, and reasonable fertilization in areas of organic matter limitations. Meanwhile, deep ploughing can be combined with straw returning and planting green manure crops, and the use of organic fertilizers is encouraged to promote soil maturation, improve soil water retention of the fertilizer, and improve soil organic content. In addition, a regional soil testing and fertilization expert system can be established based on the local agricultural research institutes and related scientific and technological forces, which can conduct precise quantitative analyses of soil nutrients within the region. Combined with the scientific advice provided by the system, scientific, rational, timely, and appropriate fertilization can be carried out to increase the efficiency of regional agricultural output and increase farmers' income.

(3) Water-saving irrigation

Limited by small amounts of annual precipitation and limited surface runoff in the study area, new types of water-saving irrigation techniques, such as drip irrigation and sprinkler irrigation, should be actively promoted in the study area, so as to overhaul the traditional extensive irrigation modes. In the meantime, according to the actual conditions in each region, irrigation should be carried out through the construction of water storage and diversion works, making full use of rainwater, surface water, and shallow groundwater. Water delivery and drainage works can be mainly achieved by irrigating rivers and ditches. The existing rivers and ditches should be arranged to establish irrigation and drainage systems for regional water systems and form a complete irrigation drainage system, so as to fully improve the water-saving capabilities of irrigation ditch-water delivery and field irrigation.

(4) Salinization improvement

Digging drainage ditches will allow the alkali components to move with the water to reduce soil salinization. In addition, it is necessary to change the broad irrigation and other traditional extensive irrigation methods to drip irrigation and sprinkler irrigation to reduce cultivated land salinization. Additionally, sand and ash can be added to the soil. Sand can increase the total porosity of the soil and reduce its bulk density, thereby improving soil permeability. The peat and base create a complex state, thereby inhibiting the salt increase, with accelerated desalination and salt resistance effects, which are also effective measures to improve saline-alkali soil.

5. Discussion and conclusion

5.1. Discussion

Based on farmland gradation results, with the limiting factor types of various land evaluation systems at home and abroad for reference, combined with the actual conditions in the study area, the natural quality grade of farmland was connected with the limiting factors of cultivated land quality, according to the cultivated land natural grade improvement potential index model, so as to directly reflect the limiting factors affecting cultivated land quality grade. It is known that the main limiting factor types of cultivated land quality in the study area are single-factor limiting types (soil organic matter, salinization, and irrigation) and combined-factor limiting types (irrigation–soil organic matter and soil structure–soil organic matter). There is an association between the natural quality grade of cultivated land and the limiting factor types. The limiting factor type spectral order calculated by the natural grade improvement potential index model reflects the limiting degree and natural grade improvement potential in an overall comparable dimensionless form. The main limiting factor types of Grades 13 and 14 land are more single-factor than those of Grade 12 land. The main limiting factor types of Grade 12 are irrigation, organic matter, and salinization, whereas that of Grade 13 land is soil structure, and those of Grade 14 land are irrigation and soil organic matter.

Through the analytical statistics of the spatial distributions and area ratios of the main limiting factor types of cultivated land quality, we can conclude that the scope of the influence of irrigation and organic matter was wide and distributed throughout the study area. The salinization limiting factor is mainly distributed in Dingbian County and Jingbian County, with a small scope of influence. The organic matter limitation is mainly distributed in Shenmu City and Hengshan District, whose affected areas account for 16% of the total study area. The range of influence of irrigation is large and distributed throughout all counties and districts, with the affected areas accounting for 33% of the total study area. The combined limiting factor area of irrigation and organic matter accounts for 43% of the total area, while soil structure and salinization occupies about 8%, with a smaller scope of influence. Measures such as water-saving irrigation, soil improvement, scientific fertilization, and deep-ditch alkali discharge are proposed based on the main limiting factor types of cultivated land quality in the study area. In addition, the degree of restriction of the limiting spectral order is combined to provide a theoretical basis for the land quality grade monitoring and the demarcation of key areas of land remediation projects in the study area, thus realizing reasonable space and timing arrangements.

5.2. Conclusion

Based on the improvement potential index model of natural cultivated land quality, this paper analyzed the main limiting factors of cultivated land quality, clarified the spatial distribution of various limiting factor types, analyzed the association between the different natural quality grades of cultivated land and the main limiting factor types, and proposed different improvement modes for cultivated land quality on the basis of diverse limiting factors. The findings clearly show that the content of soil organic matter, the degree of soil salinization, and irrigation conditions are the key factors restricting the improvement of cultivated land quality in this region. There are significant differences in the spatial distribution of restriction factors, and measures such as water-saving irrigation, soil improvement, scientific fertilization, and deep-ditch alkali discharge play an important role in the study area.

The sandy area along the Great Wall in northern Shaanxi is located in the transition zone between the Loess Plateau and the Maowusu Desert. Land desertification severely restricts the agricultural development in this area, and the overall restrictive factors are the main factors affecting the improvement of regional cultivated land quality. Identifying and tackling the main obstacle factors to improvement of cultivated land quality in the study area will help to promote regional rural and agricultural development, which is key to improving the income of farmers in the region. In the research process, the application of a geographic detector makes quantification of the influence of restriction factors on the quality of cultivated land more scientific and reasonable.

However, the maximum potential value calculated by the natural grade improvement potential index model is often output in the ideal stateconsequently, the actual improvement effect is still subject to further quantitative research. Conducting research on the main limiting factors of cultivated land quality with other new methods, such as geographic detection, and comparing and analyzing both results to obtain more applicable research results is vital. The natural grade index presented in this paper was calculated based on the *Regulations on Farmland Quality Gradation* (GB/T28407-2012). People's land utilization mode, however, also affects the cultivated land quality. In additional studies, more factors that affect cultivated land quality, such as land utilization mode, should be considered.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2019.10.011.

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