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Calculating and Classifying Agricultural Land Consolidation Based on Planning Guidance Rules and the Constraints of Arable Land Quality

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Abstract. Against a background of heavy regulation, estimating and grading the potential benefits of agricultural land consolidation in terms of extent and quality is vital to promote the efficient use of land resources in China. Taking Yanbian Korean Autonomous Prefecture (now referred to as Yanbian Prefecture) as an example, this paper uses the township as an evaluation unit. It analyses the factors that influence agricultural land consolidation potential. It uses a multi-factor evaluation model, an analytic hierarchy process (AHP), and system clustering to establish an adequate mathematical model. We use ArcGIS10.2 and SPSS19.0 to determine the theoretical size and spatial distribution of agricultural land consolidation potential in each township of Yanbian, providing a scientific basis for deciding critical areas for any future real-life agricultural land consolidation. The results showed that the potential for agricultural land consolidation in Yanbian Prefecture was very high: the place of arable land was 11777.34 ha, with the prospect of 475324.13 $\times$ 10^3kg. We divided Yanbian Prefecture into four areas with varying potentiality. Still, mainly II-level and III-level potential areas, and our conclusions are that the authorities should focus on improving the quality of arable land and optimizing its layout according to the calculation results provided here. The basic idea underlying the paper, and especially the calculation method, could guide national agricultural land consolidation in the future, provide technical support and optimize the chances for its success.

Keywords: Agricultural land consolidation · Quantitative potential · Quality potential · Potential zoning · Planning guidance rules · Yanbian Korean Autonomous Prefecture1

1 Introduction

The land is an essential limited natural resource [1]. The Party Central Committee, with Comrade Xi Jinping at the core, has made “rural rejuvenation” in the work of “agriculture, rural areas, and farmers” a primary strategic goal [2]. Successful rural revitalization depends on land resources shouldering the essential role of providing support; with its intrinsic versatility, land plays a multi-faceted role in protecting rural

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residents' production, living standards, and ecological space needs [3]. Land resource utilization in China is guided by national and local planning initiatives rather than the free market. In 2014, state officials issued a document promoting the so-called "Multiple Planning Integration" to efficiently use land resources [4]. In China, the combination of land rearrangement (Land rearrangement includes agriculture land consolidation, rural construction land consolidation, urban industrial and mining construction land consolidation, land reclamation, and arable reserved land resource reclamation.) and rural development (especially the construction of new settlements in rural areas) is a major strategic initiative, taking in the intensive use of land resources, protection of arable land, food security, the improvement of human settlements, and aiming overall at efficient urban and rural land allocation [5–7]. In contrast, traditional land rearrangement is aimed simply at stabilizing the amount of arable land and improving conditions for agricultural production, while planning hitherto has tended to overemphasize "Squared field, mesh road, coherent rivers and rows of threes" [8]. To make the goal of land rearrangement coincide with the multiple purposes of this new state-led rural revitalization, the best way of carrying out land rearrangement planning based on official guidelines, the inevitable arable land quality constraints, and ecological upgrading has become a hot topic for scholars.

Protecting arable land is the primary task in preparing land rearrangement plans under the new situation. However, attempting to tap and release the full potential of agricultural land consolidation has now become the basis of planning [9]. The merger of agricultural land is essentially a process to improve the quality of arable land, production conditions, and the ecological environment while increasing the area of arable land through a series of engineering measures. It is a meaningful way to promote arable land's practical, rational, and sustainable use. The main target of agricultural land consolidation in China is primarily arable land, which involves farmland rearrangement. The main objectives of rearrangement are to increase the area of arable land, improve its quality, and boost total agricultural production capacity; to a certain extent, ensuring agrarian production levels, farmers' incomes, and food safety are also the goals of rearrangement. The potential of agricultural land consolidation refers to the possibilities for improving the quality and extent of arable land, increasing the output rate of arable land, and developing it by comprehensively arranging and distributing roads, forest areas, ditches, graves, construction sites, and unused land rationally. There are specific inherent potentials in the scale of planting and other agricultural activities; therefore, the potential for agricultural land consolidation includes quantitative and qualitative measures. Several scholars have researched how to calculate the potential quantity and quality of agricultural land consolidation in a given area. Wang et al. [10] constructed a comprehensive analytical model for increasing the size of arable land, increasing the coefficient of arable land, and creating an index for the consolidation of agricultural land in low hilly basins. Chen et al. [11] – basing their work on the results of agricultural land classification, using the combination of arable land factors as the unit and GIS software as the support – calculated the potential of arable land consolidation in their study area. Liu et al. [12] and Wang et al. [13] used a set of agricultural land capacity calculation results to analyze the quality potential of arable land. Yang, meanwhile, used the quality comprehensive index method to explore the possibility of agrarian land rearrangement of high-standard bare farmland [14]. Zhang et al. [15] adopted the revised plan for arable land to measure and study the quality potential. Jin Xiangmu used the GIS global spatial analysis method to evaluate the potential efficiency of new arable land [16]. And based on various limiting factors and using hotspot analysis, Zhao et el. Considered how the quality potential of arable land rearrangement could be measured [17]. In sum, we can see from the work of these scholars that there are many methods for calculating the potential of agricultural land consolidation (especially for arable land consolidation), and there are different degrees of subjectivity [18]. This article takes Yanbian Prefecture as its example. It uses ArcGIS 10.2 and SPSS19.0 as a platform, a multi-factor comprehensive evaluation method, AHP, and system clustering to establish a complete model for evaluating agricultural land. Organize the potential calculation, determine the scale of agricultural land consolidation in each township of Yanbian Prefecture, sort out the possible size and spatial distribution, and provide a scientific basis for the distinction and formulation of the agricultural land consolidation area. We hope to provide an ideal reference point for future decision-making in this field.

2 The Study Area

Yanbian Prefecture is located in the eastern part of Jilin Province, between 41°59′47″N ~ 44°30′42″N and 127°27′43″E ~ 131°18′33″E (Fig. 1). It is located at the junction of China, Russia, and North Korea. It is named the Asian "Golden Triangle." Yanbian is an essential window for communication between these areas. It is, in effect, also a meeting point for three Chinese national strategies: the development of the western region, the revitalization of the northeast, and the development of the Tumen River. Yanbian Prefecture is located in the Changbai Mountain area; the terrain is high in the west and low in the east. The mountain area accounts for 54.8% of the total area of the whole state, the plateau accounts for 6.4%, the valley for 13.2%, the valley plain for 12.3%, and the hills for 13.3%. The principal rivers are the Tumen River, the Second Songhua River, the Suifen River, and the Mudanjiang River. The natural drainage area covers the whole state. The region's climate is mid-temperate humid monsoon type; the annual sunshine hours are between 2150 and 2480 h, and the average yearly temperature is between 2 and 6 °C. As things stood out at the end of 2015, data from the Yanbian Prefecture land use change survey shows that the state's total land area is 43329.34 km2, with eight cities (counties), 51 towns, and 15 townships.

2.1 Status of Arable Land

In 2018, the arable land area of the whole state was 437,233.38 ha, including 46,122.95 ha of paddy fields (10.55% of the arable land), 2479.27 ha of irrigated land (0.57%); and 388,631.16 ha of dry land (88.88%). Among the eight cities (counties) in Yanbian, Dunhua has the largest arable land area, some 167,062.16 ha, accounting for 38.21% of the arable land area of the whole state; Dunhua is followed by Wangqing County and Antu County, with arable land areas of 71357.46 ha and 59804.48 ha, respectively. It accounts for 16.32% and 13.68% of the arable land area in Yanbian Prefecture, respectively.

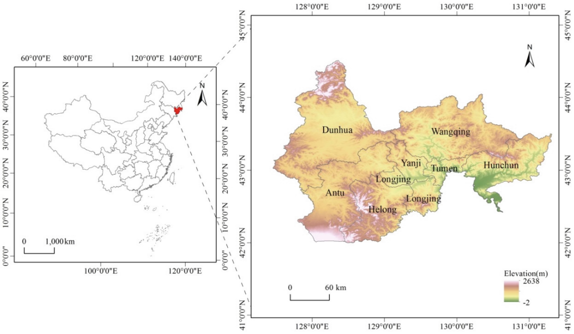

Fig. 1. Location of Yanbian Korean

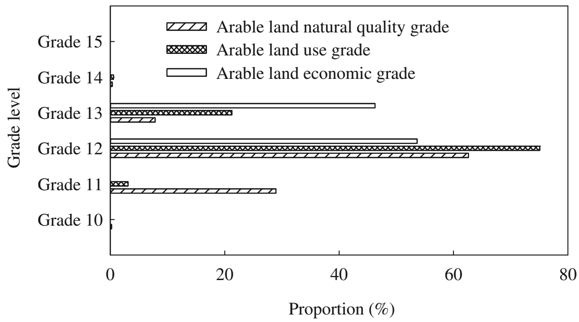

Fig. 2. Proportion of land according to gradings of natural quality, land use, and land economic value in Yanbian in 2018. (In China, the quality evaluation of arable land is divided into 15 grades, Grade 1 is the best quality of arable land, Grade 15 is the worst.)

2.2 Status of Arable Land Quality

The overall quality of arable land is usually described according to the following three graded criteria, which, it should be noted, are considered to have a national rather than purely local dimension: natural quality, use, and economic value. As expected, the overall arable land quality reflects its inherent natural quality and utilization level [19]. The results of the arable land quality update in Yanbian Prefecture in 2014 provide relevant statistics for the whole state (Fig. 2). It will be seen that Grade 11 of arable land accounted for 28.95% of the total arable land area, while Grade 12 accounted for 62.65% of the total arable land area. Regarding its grading according to use, the size of Grade 12 arable land accounts for 75.09% of the entire arable land, with Grade 13 accounting for 21.25%. Concerning the economic measure, Grade 12 arable land accounts for 53.65% of the total arable land, and Grade 13 comes in at 46.30% of the entire arable land.

Because the soil on both sides of the Tumen River is fertile, the water source is sufficient, and the terrain is flat, Grade 11 lands are mainly distributed in Toudao Town, Bajiazi Town, Xicheng Town, and Dongcheng Town of Helong City; Grade 12 lands are distributed primarily in agricultural areas of the plains with relatively good arable land conditions, e.g., Guandi Town, Shaheyan Town, Dashi Town, Heishi Township and

Jiangnan Town of Dunhua City; Grade 13 lands are mainly distributed in Luozigou Town of Wangqing County, Mingyue Town, Songjiang Town, and Liangbing Town of Antu County; the lower quality Grade 14 lands are distributed in Mingyue Town, Liangjiang Town, Songjiang Town, and Yongqing Township of Antu County. The amount of arable land in these four places accounts for 94.09% of the total area of the Grade 14 land in the whole state. The overall level of arable land quality in Antu County is relatively poor.

3 Research Methods

3.1 General Thoughts on Estimating the Potential of Agricultural Land Consolidation

The intention behind agricultural land consolidation in Yanbian Prefecture is to devote all arable land and other land types scattered throughout the arable land area to agricultural production [9]; field roads with a width of more than 2m, ditches and fields of less than 1ha and a slope of less than 15o are all included, as are grasslands and other miscellaneous fragments of land scattered in cultivated areas. Considering the balance between the quantity and quality of arable land during the overall planning period, agricultural land consolidation potentially includes creating new arable land and improving the quality of existing arable land [20].

The potential for new arable land is mainly derived from two sources: First, the area of arable land may be increased through the comprehensive improvement and rationalization of roads, ditches, and fields, and the restoration to direct production of gutters, shelterbelts, and so forth, that are currently lying idle; secondly, and based on evaluation of its suitability, now non-arable land (e.g., construction land and otherwise unused land) distributed throughout the arable land area will be explicitly repurposed as arable land. The technical idea of increasing the potential of newly added arable land in existing agricultural land is shown in Fig. 3. Based on having divided the type of arable land, land consolidation projects that have already been implemented are analyzed, and the ridge-ditch-road area before and after finishing in the project area is compared. Determining the ridge-ditch-road area reduction coefficient(α_d) of each arable land type area, extracting other land types scattered in the area, and resolving different land types combined with typical land plot surveys are necessary to research steps. The results can be adjusted to the coefficient of arable land (α_t), and α_d are respectively multiplied by the area of arable land to be reorganized, which is the newly added arable land area and the newly added arable land area of the ridge-ditch-road consolidation. The sum of the two measurements gives the new arable land quantity potential for agricultural land consolidation.

The potential for improving the quality of arable land mainly comes about through two ways: raising the productive capacity of arable land by improving the infrastructure; and transforming and eliminating any limiting factors in farming. There are some obstacles inherent in arable land that limit its productive capacity -one thinks of impoverished and thin soil layers and the effects of heavy erosion. Agricultural land consolidation seeks to implement a series of engineering and biological measures to alleviate or even eliminate these and other restrictive factors, to increase production, and improve the quality of arable land. The technical aspects of improving the potential of arable land quality through land consolidation are shown in Fig. 4. The quality potential of agricultural land consolidation is expressed by increased productive capacity. This consists of two parts: one is the potentiality stemming from improving the original arable land grade; the other is releasing the potential in new arable land. In the actual arable land area, it is assumed that the average use grade of each township can be used as a means to achieve the highest use grade of the township; as to the newly added arable land, it is assumed that the average use grade of the township can be reached, and the potentiality of quality of the agricultural land consolidation is calculated in turn.

3.2 The Calculation Flow of the Quantity Potential of Agricultural Land Consolidation

The quantity and distribution of agricultural land to be rearranged.

Based on the general land use planning (2006–2020), the land rearrangement planning (2006–2020), and the 2015 land use change survey data, it has been determined that the scope of agricultural land to be rehabilitated in Yanbian Prefecture is within the designated restricted construction area. The scale of agricultural land consolidation is 411,835.27 ha. Some 396,025.84 ha of this is arable land, accounting for 96.17% of the size of agricultural land to be reorganized, mainly distributed in Dunhua City, Wangqing County, and Antu County. The grassland area of less than 1 ha and with a slope of less than 15° is 13565.29 ha, accounting for 3.29% of the size of agricultural land to be reorganized, mainly located in Dunhua City, Longjing City, and Wangqing County. The area of miscellaneous land is 1782.82 ha, accounting for just 0.43% of the size of agricultural land to be reorganized; this is mainly found in Dunhua City and Wangqing County.

Division of arable land type.

Dividing agricultural land where favorable consolidation conditions prevail is the basis for determining the theoretical potential of agricultural land consolidation. The landforms of Yanbian Prefecture have three gradients, which include mountains, hills, and basins (most of which are mountainous and hilly). To ensure the accuracy of our calculation, the land resource endowment, land use structure, bearing strength and mode, and socio-economic development of each sub-district must be relatively consistent. The four-level arable land type area is divided by constructing an indicator system, including arable land resource endowment, arable land use structure, load-bearing strength, topography, output capacity, and scale benefit (Table 1 and Table 2).

Calculation of α_d

In the four-level arable land type area, the completed agricultural land consolidation project is selected, and the area of the ridge, ditches, and roads in the project area before and after the consolidation is calculated; the α_d of the typical items before and after the consolidation is also calculated. The specific calculation method is as follows:

$$\alpha_d = \left(\Delta \mathrm{S_g} + \Delta \mathrm{S_d} + \Delta \mathrm{S_t}\right)/\mathrm{S_a} \tag{1}$$

$$\Delta \mathrm{S_g} = \mathrm{S_{go}} - \mathrm{S_g} \tag{2}$$

$$\Delta \mathrm{S_d} = \mathrm{S_{do}} - \mathrm{S_d} \tag{3}$$

Fig. 3. Schematic representation of the calculation for determining the quantitative potential of agricultural land consolidation.

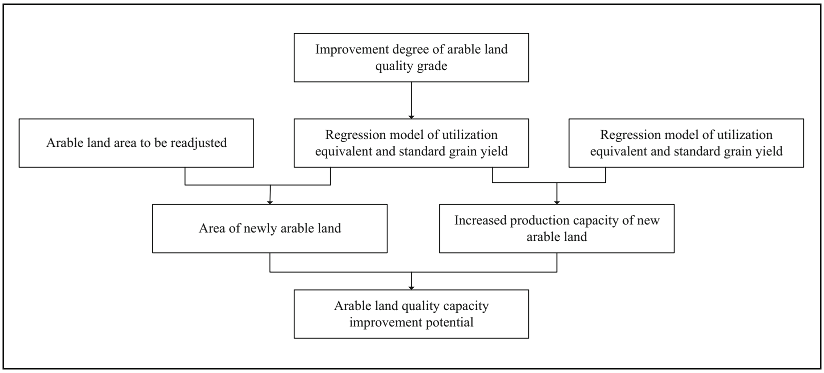

Fig. 4. Schematic representation of the calculation of the quality potential of agricultural land consolidation.

$$\Delta S_t = S_{to} - S_t \tag{4}$$

Table 1. Partition index system of arable land. (The weight value of each index and factor was determined by an AHP. Based on the 1: 10 000 scale land use status map of land change survey data in 2017, combined with the population survey, and agricultural land productivity data. Taking the township as our unit of analysis and based on ArcGIS software platform. The partition factors are selected from six aspects, and the level of each township was determined, which forms the basis for the calculation of agricultural land consolidation potential)

Purpose	Index	Index weight	Factors	Factor weight	Unit
Potential zoning of agricultural land consolidation	Resources endowment	0.35	Total arable land	0.25	ha
			Total reserve resources of arable land	0.75	ha
	Utilization structure	0.08	Effective irrigation ratio of arable land	0.50	%
			Ratio of arable land and land	0.50	%
	Bearing strength	0.05	Per capita arable land area	0.25	ha/ cap
			Per capita reserve resources of arable land	0.75	ha/cap
	Topography and geomorphology	0.12	Slope level of arable land	1.00	--
	Output capacity	0.24	Grain yield	1.00	kg/ha
	Scale effect	0.16	Regularity index	0.50	--
			Traffic convenience index	0.50	--

Table 2. Arable land partition of every township in Yanbian (taking Yanji City as an example)

Name of city (county)	Town name	Comprehensive score	Partition level
Yanji City	Xiaoying Town	0.4734	2
	Yilan Town	0.5067	2
	Sandaowan Town	0.3225	3
	Chaoyangchuan Town	0.5593	2

α_d is the coefficient of the reduction of farmland-ditch-road; ΔS_g, ΔS_d, and ΔS_t are the reductions in the area of ditches, rural roads, and ridges before and after the implementation of the project; S_{go}, S_{do}, and S_{to} are the area of ditch, rural road, and ridge before the implementation of the project; S_g, S_d, and S_t are the area of ditch, rural road, and ridge after the implementation of the project. The α_d values of arable land types in Yanbian Prefecture are shown in Table 3.

Calculation of α_t

Based on the land use map 2015 (scale of 1: 10,000), other land types distributed in the arable land area were extracted, and combined with the investigation of typical plots, the total land area which could be repurposed for arable land was determined. The size of newly added arable land in the arable land type area, adjusted by other types of land, is divided by the total area of arable land in the specific location, that is α_t [21, 22]. The αt of each township in Yanbian (Yanji City again taken as an example) is shown in Table 4.

Measuring the quantitative potential of agricultural land consolidation.

(1) Arable land area increased by ridge-ditch-road consolidation

$$\Delta S_z = \alpha_d \times S \tag{5}$$

ΔS_z is the area of arable land increased by ridge-ditch-road consolidation; S is the total area of arable land to be consolidated.

The area of arable land that can be increased in Yanbian Prefecture through ridge-ditch-road consolidation is -4975.46 ha, and the newly added arable land area of the first, second, third, and fourth grades of arable land type area is -1294.60 ha, -2628.93 ha, -1010.54 ha, and -41.39 ha respectively.

(2) Land type adjustment to increase arable land area

Table 3. The α_d value of arable land areas of different grades in Yanbian

Partition level	Reduced area of ditches, rural roads, and field ridges (ha)	Project construction scale (ha)	α_d (%)
1	-121.42	11550.28	-1.05
2	-169.38	12111.62	-1.40
3	-51.36	4931.46	-1.04
4	--	--	-1.20

Table 4. The α_t value of towns and townships in Yanbian

City (county)	Town name	Arable land partition level	α_t (%)
Yanji	Xiaoying Town	2	6.40
	Yilan Town	2	8.03
	Sandaowan Town	3	13.62
	Chaoyangchuan Town	2	4.33

$$\Delta S_t = \alpha_t \times S \quad (6)$$

ΔS_t is the increased area of arable land adjusted for other types of land.

The area of arable land that can be increased in Yanbian Prefecture through land use adjustment is 16752.80 ha, and the newly added arable land area of the first, second, third, and fourth grades of arable land type area is 3584.64 ha, 7804.50 ha, 5239.27 ha, and 124.39 ha respectively.

(3) Summary of arable land area increased by agricultural land consolidation

$$\Delta S = \Delta S_z + \Delta S_t \quad (7)$$

ΔS is the net increase in the total area of arable land. The newly added arable land coefficient is $\alpha = \Delta S/S$.

3.3 Quality Potential of Agricultural Land Consolidation

Methods for calculating the potential of arable land quality improvement.

Taking the townships of Yanbian as our unit, the formula is:

$$W_i = A \times T \times B + Q_i \times K_i \quad (8)$$

W_i is the quality potential (kg) produced by *i* township through rectification; A is the scale (ha) of the arable land to be organized in the *i* township; T is the degree to which the use of arable land in the *i* township is improved (for example, the average utilization of the township minus the maximum utilization of the township); B is the standard grain yield (kg/ha) increased for the grade; Q_i is the area (ha) of newly arable land in *i* township; and K_i is the standard grain yield corresponding to the average utilization of *i* township.

Utilization index and standard grain yield.

Based on the agricultural land capacity calculation report, a linear regression model using the utilization index and the actual standard grain yield is established using the standard grain yield sample data. Environmental factors, technical conditions and policies regarding light, heat, water, and soil are different in different regions, resulting in significant differences in agricultural land capacity. Therefore, a linear regression model is established for each city (county).

$$y'_i = cY_i + d \quad (9)$$

y'_i is the achievable yield value of the *i* unit standard grain; Y_i is the *i* unit utilization index; c and d are regression coefficient values. For example, the linear regression model of Dunhua City is:

$y = 11.597x + 4103.3$ ($R^2 = 0.6284$)(10).

By introducing the average utilization index of each township into the linear regression equation, the achievable standard grain yield can be obtained.

3.4 Summary of Agricultural Land Consolidation Potential Grading

Determination of index system and weight.

In this paper, the area of newly added arable land, the increasing levels of productivity, and the coefficient of newly added arable land are used as the index system for dividing the potential grade of agricultural land improvement in the Yanbian Prefecture [10, 23, 24]. The weight of the index system is determined by an AHP [25–27], in which the weight of newly added arable land area is 0.38; the weight of increasing productivity is 0.29; and the weight of newly added arable land coefficient is 0.33.

Determination of comprehensive scores and potential grades.

It is difficult to make comparisons because of the different index dimensions and orders of magnitude in the evaluation of the potential grade of agricultural land renovation, so it is necessary to carry out standardized treatment. In standardization, the maximum value of the positive correlation index is standardized, while at the same time the minimum value of the negative correlation index is also standardized, and each index value is unified between 0 and 1. The comprehensive score is the product of the standard value and the corresponding weight of each index after standardized processing, and the sum is obtained by the sum of the standard value and the corresponding weight:

$$Y = \sum_{i=1}^{n} X_i \times W_i \tag{11}$$

y is the comprehensive evaluation score of agricultural land improvement potential; X_i is the score of the I index; W_i is the weight of the I index; and n is the number of indexes.

Based on the comprehensive score of agricultural land consolidation potential obtained by SPSS19.0, a systematic cluster analysis was carried out to classify the potential grade of agricultural land consolidation in various townships.

4 Results and Analysis

In summary, based on collecting data using the results of remote sensing interpretation, the investigation of the mine geological environment in Heilongjiang Province was investigated. The distribution, type, scale, and current situation of mine geological environment issues of mineral resources in Heilongjiang Province were basically clarified, and through the investigation of mine geological disasters, aquifer damage, topographic and geomorphological landscape damage, land resources destruction, and water and soil environment pollution, and the impact of mining activities on the geological environment was evaluated, and suggestions for mine geological environmental protection and treatment countermeasures were put forward. It provides primary data for strengthening the supervision and management of the mine geological environment while providing a basis for the rational development and utilization of mineral resources in our province and the protection and treatment of the mine geological environment.

4.1 Quantitative Potential of Agricultural Land Consolidation

Agricultural land consolidation in Yanbian Prefecture increased the amount of arable land by 11777.34 ha; this was mainly distributed in Longjing, Dunhua, and Wangqing,

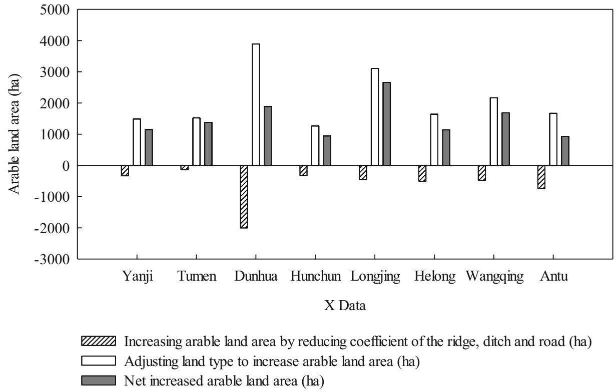

Fig. 5. Distribution of arable land quantity potential in Yanbian Prefecture

with an area of 2659.55 ha, 1887.37 ha, and 1668.42 ha, accounting for 22.58%, 16.03%, and 14.32% of the total newly added arable land. Newly added arable land in Tumen, Yanji, and Helong amounted to 1382.70 ha, 1150.62 ha, and 11.37.15 ha, respectively, accounting for 11.74%, 9.77%, and 9.66% of the overall total. The least amount of newly added arable land area is in Antu, with 931.25 ha, accounting for just 7.91% of the overall total (Fig. 5).

4.2 Quality Potential of Agricultural Land Consolidation

The potential for improving the quality of arable land in Yanbian Prefecture overall is 475,324.13 × 103 kg (Table 5). Mainly distributed in Wangqing, Longjing, and Antu, the arable land quality improvement potential is 103882.77 × 103 kg, 89026.65 × 103 kg, and 83730.39 × 103 kg, respectively, accounting for 21.86%, 18.73%, and 17.62% of the quality improvement potential.

4.3 Potential for Agricultural Land Consolidation in Various Zones

(1) I-level potential area

The only potential area for agricultural land consolidation is Laotougou in Longjing (Fig. 6).

The total score for Laotougou is 90.53 points, much higher than in other towns. However, the land resources of Laotougou are better, and the existing land use structure is also reasonable. The output capacity of the land is strong, and both the quantitative and quality potential of agricultural land consolidation are the highest in Yanbian. The area of arable land in the I-level potential area accounts for 3.20% of the total arable land resources in Yanbian, and the newly added arable land area is 1237.50 ha, accounting for 10.51% of the freshly added arable land potential; the potential for capacity improvement is 35045.99 × 10^3 kg, accounting for 7.37% of the new capacity potential of agricultural land consolidation (Table 6).

Table 5. Promotion potential of arable land productive capacity after agricultural land consolidation in Yanbian

City (county)	Original arable land to be consolidated (ha)	Grade promotion of original arable land (average land use grade)	The increase of productive capacity after consolidation of original arable land ($\times 10^3$kg)	Newly increased arable land (ha)	The increase of productive capacity of newly increased arable land ($\times 10^3$kg)	The sum of increased productive capacity ($\times 10^3$kg)
Yanji	24334.36	1.05	45685.43	1150.62	8580.68	54266.11
Tumen	12210.64	0.77	16635.09	1382.70	7444.65	24079.74
Dunhua	170849.34	0.04	13517.41	1887.37	16767.21	30284.62
Hunchun	25437.19	0.43	20268.64	942.27	7345.40	27614.04
Longjing	36291.54	0.99	64795.03	2659.55	24231.62	89026.65
Helong	38013.78	0.83	54815.17	1137.15	7624.63	62439.80
Wangqing	43285.13	1.27	93428.09	1686.42	10454.68	103882.77
Antu	61413.30	0.66	77741.36	931.25	5989.04	83730.39
Total	411835.27	——	386886.20	11777.34	88437.92	475324.13

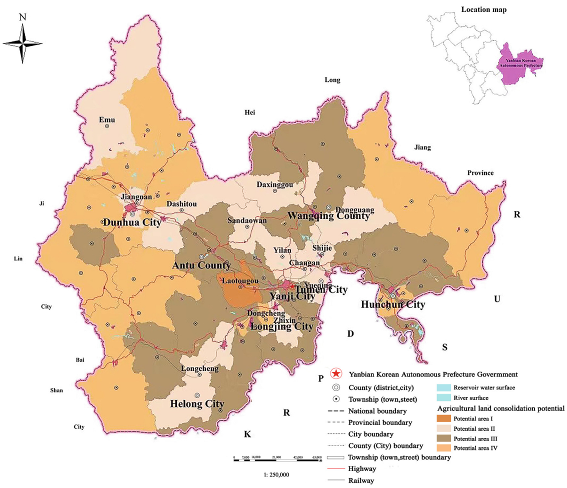

Fig. 6. Sketch map of the potential distribution of agricultural land consolidation in Yanbian Prefecture. Based on the ArcGIS10.2 software platform, and combined with the economic and social conditions of each city (county). Taking the township (town) as the unit, according to the comprehensive score, and using SPSS19.0 to carry out the systematic cluster analysis, the agricultural land consolidation potential of Yanbian Prefecture was divided into four grades.

(2) II-level potential area.

The II-level potential area includes Yilan and Sandaowan of Yanji; Yueqing, Chang'an, and Shijie of Tumen; Dashi, Emu, and Jiangnan of Dunhua; Zhizhi of Longjing; Xinzhen and Longcheng in Helong; and Dongguang and Daxinggou in Wangqing (Fig. 6). The potential areas of II-level land are widely distributed, but are concentrated in the integrated urban cluster area of Yanlongtu, the central part of Wangqing County, and the south-west of Helong City. The area of arable land in the II-level potential area accounts for 23.37% of total arable land, and the newly added arable land area is 4167.86 ha, accounting for 35.39% of the newly added arable land potential; the capacity increase potential is 137842.51 × 10^3 kg, thus accounting for 29.00% of the new capacity potential created by agricultural land consolidation (Table 3).

(3) III-level potential area

III-level potential areas are more widely distributed, except for the city of Tumen (Fig. 6). The arable land area of the III-level potential area accounts for 33.83% of total arable land resources, the newly added arable land potential area is 5055.46 ha, accounting for 42.93% of the newly added arable land potential; and the capacity increase potential is 245806.86 × 103 kg, which accounts for 51.71% of the capacity potential that would be released by agricultural land consolidation.

(4) IV-level potential area.

The spatial potential of the IV-level potential areas is mainly concentrated in the western part of Yanbian (Fig. 6), mostly in the townships in Dunhua and Antu. The arable land area of the IV-level potential area accounts for 39.61% of the total arable land resources; the newly arable land potential area is 1316.52 ha, accounting for 11.18% of the newly arable land potential; and the capacity increase potential is 56628.77 ×

Table 6. Summary of the calculation of the potential of agricultural land consolidation in Yanbian

Potential area	Index	Total arable land (ha)	Newly increased arable land (ha)	Newly increased productive capacity (× 10^3kg)
Potential area I	Amount	13174.04	1237.50	35045.99
	Proportion (%)	3.20	10.51	7.37
Potential area II	Amount	96236.33	4167.86	137842.51
	Proportion (%)	23.37	35.39	29.00
Potential area III	Amount	139308.63	5055.46	245806.86
	Proportion (%)	33.83	42.93	51.71
Potential area IV	Amount	163116.27	1316.52	56628.77
	Proportion (%)	39.61	11.18	11.91
Total		411835.27	11777.34	475324.13

Table 7. Potential calculation of agricultural land consolidation of the city (county) in Yanbian

City (county)	Total arable land		Newly increased arable land		Newly increased productive capacity	
	Amount (ha)	Proportion (%)	Amount (ha)	Proportion (%)	Amount ($\times 10^3$kg)	Proportion (%)
Yanji	24334.36	5.91%	1150.62	9.77%	54266.11	11.42%
Tumen	12210.64	2.96%	1382.70	11.74%	24079.74	5.07%
Dunhu	170849.34	41.48%	1887.37	16.03%	30284.62	6.37%
Hunchun	25437.19	6.18%	942.27	8.00%	27614.04	5.81%
Longjing	36291.54	8.81%	2659.55	22.58%	89026.65	18.73%
Helong	38013.78	9.23%	1137.15	9.66%	62439.80	13.14%
Wangqing	43285.13	10.51%	1686.42	14.32%	103882.77	21.86%
Antu	61413.30	14.91%	931.25	7.91%	83730.39	17.62%
Total	411835.27	100.00%	11777.34	100.00%	475324.13	100.00%

103 kg, thereby accounting for 11.91% of the capacity created as a result of agricultural land consolidation.

4.4 Analysis of the Potential of Agricultural Land Consolidation by Cities (Counties)

It can be seen from Table 7 that Longjing, Wangqing, and Dunhua show the most significant net increase in arable land in Yanbian, followed by Hunchun, Tumen, Yanji, Helong, and Antu. By comparing the new farmland scales and new capacities in each city (counties), it emerges that Longjing and Wangqing have the best input and output benefits of agricultural land consolidation.

5 Discussion and Conclusions

5.1 Discussion

Integrating multiple plans and schemes (such as national economic and social development planning initiatives, local urban and rural projects, land use schemes, and ecological environmental protection measures) in one area may be conveniently termed "multi-regulation." Its goal is to achieve "one plan, one blueprint," which overcomes fragmentation and the severe lack of planning convergence. The land space planning system is essential to attain "multi-regulation." It should – in theory at least – form a complete system with an overall plan for any space, with sufficient detail to cover, for example, complex ecological restoration and land consolidation. Land consolidation is the means for implementing the "multi-regulation" of spatial planning. It logically follows that the scientific formulation of land consolidation planning is a meaningful way to implement overall land use planning objectives and tasks. Research on the role of arable land in land consolidation planning has been steadily growing in recent years, and it is the fundamental basis for delineating key areas for arable land rearrangement and determining rearrangement projects and timings [15]. However, previous research on the potential of arable land rearrangement mainly focused on the quantitative potential of supplementary arable land [28–30]; the potential for improving the quality of arable land was insufficiently considered. The National Land Consolidation Plan (2011–2015) issued by the State Council in 2011 put forward the specific planning goal of raising the grade of arable land after improvement. Thus calculating the quality potential of arable land rearrangement has become an essential part of the planning process. The results of our agricultural land classification in Yanbian Prefecture (Fig. 2) show that the quality of arable land is not high, and indeed the quality of agricultural land overall needs to be improved: consolidation will help to improve the quality of arable land to a certain extent. According to the estimation of agrarian land consolidation potential (i.e., newly added arable land) and the average natural quality of the current arable land in each county (city), Yanbian Prefecture could enhance its arable land by consolidating agricultural land during the planning period. In the spatial distribution pattern, there is a contradiction between the protection and occupation of high-quality arable land in Yanbian Prefecture. Priority should be given to the intelligent arrangement of agricultural land in Grades I and II potential areas: this will increase the quantity of high-quality arable land, optimize its spatial distribution, and somewhat alleviate the contradiction between the protection of high-quality arable land and its occupation.

In addition to the initial practical applications, this paper's methods and ideas may assist further research in this field. While the significance of the methodology for other counties in particular, its application should, of course, be adjusted according to the actual situation(s) on the ground. For example, in the county areas with plains, the importance of dividing arable land types will be reduced, and in some places, it can even be ignored.

5.2 Conclusions

(1) Based on planning for potential agricultural land consolidation, this paper mainly measures the amount of newly added arable land, the degree of improvement, and productive capacity improvement. The ridge-ditch-road reduction coefficient and ground-type adjustment coefficient calculation methods support robust conclusions about agricultural land consolidation potential.

(2) as outlined here, agricultural land consolidation could increase the amount of arable land in Yanbian Prefecture by 11777.34 ha; the quality improvement potential is expressed by 475,324.13 × 103 kg. The land is mainly distributed in the potential areas of II-level and III-level quality land, among which the proportion of newly added arable land is 35.39% and 42.93%, respectively (accounting for 29% and 51.71% of new capacity).

(3) Our research on calculating and grading the potential of agricultural land consolidation in Yanbian Prefecture could effectively improve the efficiency of land rearrangement and realize the delicate balance that is necessary between the quantity and quality of farmland occupation and compensation; this has specific theoretical

implications and practical guiding significance for the design and site selection of land consolidation projects in the study area, and possibly beyond.

References

1. T Hrvoje, MI Siniša and R Miodrag Land consolidation suitability ranking of cadastral municipalities: Information-based decision-making using multi-criteria analyses of official registers' data *ISPRS International Journal of Geo-Information* **7(**2018)
2. R He Urban-rural integration and rural revitalization : Theory mechanism and implementation *Geographical Research* **37**(2018)
3. H Long, Y Zhang and S Tu Land consolidation and rural vitalization *Acta Geographica Sinica* **73**(2018)
4. L Tang, D Wang and Y Yang Optimization of land use structure based on "Multiple Planning Integration" and ecological footprint *Transactions of the Chinese Society of Agricultural Engineering* **35**(2019)
5. Y Liu Rural transformation development and new countryside construction in eastern coastal area of China *Acta Geographica Sinica* **62**(2007)
6. H Long, Y Liu, and Y Chen Building new countryside in China: A geographical perspective **Land Use Policy 27**(2010)
7. C Wu, L Fei and Y Ye The theoretical perspective, rational, paradigm and strategic solution of land consolidation *Economic Geography* **31**(2011)
8. W Yun Thoughts on accelerating land consolidation innovation *Journal of Huazhong Agricultural University(Social Sciences Edition)* **1**(2011)
9. H Wang, J Wang and X Li Study on quantitative and qualitative potential of farmland consolidation within county region in the northern hilly regions *Journal of Shandong Agricultural University (Natural Science Edition)* **46**(2015)
10. W Wang, Y Chen and H Wu Study on classification of farmland consolidation potentiality in low mountain and hilly basin areas *Research of Soil and Water Conservation* **18**(2011)
11. Y Chen, H Liu and H Xu Application of agricultural land classification in cultivated land consolidation potential predicting *Transactions of the CSAE* **254**(2008)
12. W Liu, Y Chen and X Huo Study on the quantitative and qualitative potential of farmland consolidation on production capacity——a case study on LuLong County *Research of Soil and Water Conservation* **17**(2010)
13. Q Wang, H Zhang and Z Hu Analysis of use potential of farmland productivity in different typical areas of GuangDong Province *Acta Pedologica Sinica* **48**(2011)
14. W Yang, D Xie and T Li Analysis of consolidation potential of agricultural land based on construction mode of high-standard basic farmland *Transactions of the Chinese Society of Agricultural Engineering* **29**(2013)
15. R Zhang, G Jiang and X Wang Calculation method of qualitative potential of farmland consolidation *Transactions of the Chinese Society of Agricultural Engineering* **29**(2013)
16. X Jin, C Li and Y OuYang Evalution for potential of newly-increased cultivated land in agriculture land consolidation on county or city scale——a case study of WenZhou City, ZheJiang Pvocine *Bulletin of Soil and Water Conservation* **35**(2015)
17. D Zhao, S He and Z Du Qualitative potential calculation of arable land consolidation based on limiting factors and hot spot analysis *Transactions of the Chinese Society for Agricultural Machinery* **48**(2017)
18. X Tang, B Chen and X Gu The evaluation method for the potentiality of farmland consolidation under the new situation *China Land Science* **25**(2011)

19. H Zhang, X Zhao and X Wang Multi-scale spatial autocorrelation analysis of cultivated land quality in China's southern hillside areas: A case study of Lichuan County, Jiangxi Province *Chinese Journal of Eco-Agriculture* **26**(2018)
20. J Zhu, Y Liu and X Deng Farmland consolidation conditional zoning and pattern analysis in Guangxi *Transactions of the CSAE* **28**(2012)
21. S Wang, A Zhang and Y Zhang Comprehensive benefits of farmland consolidation in Hubei Province *Resources Science* **35**(2013)
22. H Pan, W Jing and H Ma The sequence of farmland comprehensive consolidation under the guidance of plan and the constraint of cultivated land quality *China Land Sciences* **29**(2015)
23. Z Yang, C Wu and Y Ye County-level farmland reconsolidation planning in Longhai City *China Land Science* **25**(2011)
24. L Guo, F Zhang and T Zhu Farmland consolidation type zoning based on combination of grading factors *Transactions of the CSAE* **26**(2010)
25. H Romeijn, R Faggian and V Sposito Evaluation of deterministic and complex Analytical Hierarchy Process methods for agricultural land suitability analysis in a changing climate *ISPRS International Journal of Geo-Information* **5**(2016)
26. Q Chen, J Duan and X Kong Study on quantity promotion potential of Beijing basic farmland protection area *Research of Soil and Water Conservation* **19**(2012)
27. C. Jerzy, and C. Jakub Influence of arable land location incorporating its roughness on blue-sky albedo variation Journal of Quantitative Spectroscopy and Radiative Transfer **296**(2023)
28. S.D. Kamaanaa, A.G. Kwadwo, and I.D.K. Baah Peri-urbanisation and loss of arable land: Indigenes' farmland access challenges and adaptation strategies in Kumasi and Wa, Ghana Land Use Policy 126 (2023)
29. J. Zbyněk Optimal model utilization of arable land with regard to food self-sufficiency and soil protection *Journal of Maps* **18**, 2(2022)
30. K.S. Kishore A spatial framework for prioritizing biochar application to arable land: A case study for Sweden *Resources, Conservation & Recycling* **189** (2023)