STUDY ON THE EXTRACTION OF MARGINAL LAND IN CHINA AND ITS POTENTIAL EVALUATION FOR CORN PLANTING

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Abstract. Marginal land refers to areas with low agricultural productivity and economic returns due to soil limitations, severe constraints on water and thermal resources, and significant topographical challenges, making these areas ecologically fragile. Accurate identification and evaluation of the crop cultivation potential of marginal land are crucial for ensuring food security. Based on the concept of marginal land, this study classified and extracted eight types of land use: low-quality arable land, low-quality forest land, low-productivity orchards, cultivable grassland, cultivable saline-alkali land, cultivable mudflats, cultivable sandy land, and cultivable bare land. Considering factors such as topography, soil, water resources, climate, and transportation accessibility, we assessed the suitability of marginal land in China for maize cultivation. The results showed that the total area of marginal land in China was 2.27×10^6 km², of which low-quality arable land accounted for 26.3%, while non-arable land (including cultivable grassland, low-quality forest land, low-productivity orchards, cultivable saline-alkali land, cultivable mudflats, cultivable sandy land, and cultivable bare land) accounted for 73.7%. The Northwest region contains the largest proportion of marginal land, representing 29.9% of the national total. Among the marginal land, areas highly suitable for maize cultivation account for 30.0%. If fully utilized for maize production, the potential yield increase could range from 35.3 to 46.3×10^7 tons, compared with the average corn yield of each province over the past five years. These findings provide a theoretical frameworks and scientific data to support the sustainable utilization of marginal land and the optimization of crop planting patterns in China.
Keywords: *marginal land, suitability assessment, corn, cultivation potential, entropy weight method*

Introduction

Marginal land can serve as a strategic reserve resource for stabilizing arable land and addressing food shortages in China (Cao et al., 2021). Research on the rational development and efficient utilization of marginal land is crucial for tackling the interconnected challenges of water, arable land, and food security. It also supports a scientific and effective balance between enhancing the productivity of existing arable land and the prudent development of reserve arable land resources (Cai et al., 2022). However, despite the advancement of new technologies and evolving policy frameworks, there is still no universally accepted analytical framework for marginal land resources. This knowledge gap limits a comprehensive understanding of their characteristics and constrains the effective management and utilization of these resources (Dale et al., 2010; Robertson et al., 2013; Csikós et al., 2023). Therefore, developing a systematic analytical framework and clearly defining the concept and classification of marginal land are of significant importance for the investigation, management, and sustainable utilization of these resources.

The absence of a universally accepted definition of marginal land is primarily due to the multifaceted nature of the concept, which requires the consideration of four key factors: economic (e.g., rental costs, land value), geographic (e.g., temperature, slope, precipitation), ecological (e.g., ecosystem services, conservation value), and soil suitability (e.g., yield capacity, soil quality) (Csikós et al., 2023). However, existing definitions often focus on a single dimension. Initially, the concept of marginal land originated from Western land economics, where it was defined as land yielding returns just sufficient to cover production costs (Tang et al., 2010). Over time, as research expanded across different regions and objectives, the definition evolved to encompass additional dimensions. For instance, Shortall (2013) incorporated soil suitability into an economic framework, defining marginal land as areas unsuitable for food production, of low agricultural quality, or economically unviable. Hennenberg et al. (2008) considered yields, inputs, costs, the socioeconomic consequences, classifying marginal land as degraded areas with potential uses for bioenergy production or habitat conservation. Schroers (2006) approached the concept from a soil suitability perspective, defining marginal land as areas where cost-effective agricultural production is impractical due to poor soil quality or restrictive land-use policies. Liu et al. (2005) further refined the concept, describing marginal land as areas where the optimal combination of labor and capital inputs cannot cover production costs. In summary, while the definition of marginal land has evolved to account for multiple factors, there remains a lack of comprehensive understanding regarding the interactions between these factors and their combined impact on land use.

Current research on marginal land, both domestically and internationally, predominantly focuses on its potential for bioenergy crop production. Numerous studies assess the feasibility of utilizing marginal land to grow energy crops (Gopalakrishnan et al., 2011; Chen et al., 2017). For example, Dauber et al. (2012) evaluated the suitability of marginal land for bioenergy production by considering socioeconomic and ecosystem service factors. Khanna et al. (2021) identified potential bioenergy-producing marginal land, including biophysically degraded areas, fallow land, and cropland suffering from soil degradation, erosion, or loss of ecological value. Using a GIS-based model, Saha et al. (2015) assessed the availability of urban marginal land for bioenergy production in Boston. Zhuang et al. (2011) analyzed the spatial distribution of marginal land suitable for five energy crops across China, including Amur cork tree and Jerusalem artichoke. Despite these advances, research on the potential of marginal land for food crop production remains limited.

Food security remains a critical global concern, directly influencing public welfare and social stability (Bongaarts, 2021; Behnassi et al., 2022; Lee et al., 2024). In China,

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arable land is under intense cultivation, with limited scope for further increasing productivity on the existing 420,000 km² of high-yield farmland. In this context, marginal land offers a potential emergency resource to supplement arable land and mitigate food shortages (Cao et al., 2021). Corn, as one of China's three major staple crops, is particularly vital for national food security. China is a leading global producer of corn, with its cultivation accounting for 26.9% of the country's total grain-growing area and 19.7% of total grain output. Beyond its role in food production, corn is also a critical raw material for the feed, fermentation, and fine chemical industries, further underscoring its strategic importance (He et al., 2012; Ren et al., 2023).

The objectives of this study are to: (1) establish a classification system and extraction method for marginal land using multi-source spatial data; and (2) evaluate the suitability and economic benefits of corn cultivation on China's marginal land. The research findings aim to provide theoretical and technical support for optimizing the use of cultivated land resources and ensuring sustainable agricultural development.

Materials and methods

Definition and classification of marginal land

Marginal land refers to land with low agricultural productivity and economic returns, as well as ecological vulnerability, often resulting from severe soil constraints, limited water and thermal resources, or restrictive topographical conditions (Cao et al., 2021). In practical land use surveys, the classification of marginal land should consider both land use types and current land use conditions. Based on the sustainability classification framework proposed by Jiang et al. (2019), it is essential to comprehensively account for land use factors as well as physical and biological aspects. This study, drawing on the concept of marginal land and relevant literature, establishes a classification system that includes lower-quality cultivated land within arable land, low-quality forest land, low-productivity orchards, cultivable grassland, and cultivable saline-alkali land, sandy land, bare land, and mudflats. The specific definitions and classification criteria for each type of marginal land are presented in *Table 1*. In addition, natural protected areas were included in the determination of marginal land.

Data source

The data used in this study include China's 30-meter LUCC land-use remote sensing monitoring data, the China fractional vegetation cover (FVC) dataset, annual precipitation data for China, China MOD17A3H vegetation net primary productivity (NPP) data, Digital Elevation Model (DEM) data, the dataset of soil properties for land surface modeling over China, China river network data, China ≥10°C accumulated temperature data, and China road data, among others. The specific datasets are presented in *Table 2*.

Marginal land extraction methods

For the extraction of different types of marginal land, as shown in *Table 1*, existing remote sensing data products are utilized while considering both land use factors and physical and biological factors. Raster normalization was conducted using min-max scaling to unify data ranges. Reclassification was applied based on suitability thresholds, and overlay analysis integrated multiple factors using weighted linear combination

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(WLC). These methods are commonly used in land suitability analysis (Eastman, 2003; Malczewski, 2006). Marginal land types such as cultivable saline-alkali land, cultivable mudflats, cultivable sandy land, cultivable bare land, and low-quality forest land can be directly extracted from the China 30-meter LUCC land use remote sensing monitoring data. To extract cultivable sandy land, the China 30-meter LUCC land use remote sensing monitoring data is overlaid with the China fractional vegetation cover (FVC) dataset and national annual precipitation data. Areas with annual precipitation ranging from 200 mm to 400 mm and FVC > 10% are selected. Similarly, the extraction of low-productivity orchards requires overlaying the China fractional vegetation cover (FVC) dataset onto the China 30-meter LUCC land use remote sensing monitoring data to identify areas with FVC ≤ 50%. In addition, low-quality arable land, low-quality forest land, low-productivity orchards, cultivable grassland, cultivable saline-alkali land, cultivable mudflats, cultivable sandy land, and cultivable bare land are identified using these methods. Finally, low-quality arable land is classified into different productivity levels based on Net Primary Productivity (NPP) data, with classification standards following those for high, medium, and low-yielding farmland productivity zones (Ji et al., 2015; Bai et al., 2023). All data undergo preprocessing steps, including clipping, resampling, and defining projections, and are standardized to a resolution of 1 km, with projections defined using Krasovsky_1940_Albers.

Table 1. *Marginal land classification system*

Land use types	Types of marginal land	Specific meaning and classification criteria
Arable land	Low-quality arable land	Low-productivity farmland, with relatively poor basic soil fertility and prominent production constraints, is difficult to fundamentally improve in a short period of time
Forest land	Low-quality forest land	The current status is land with either no forest or poor forest growth conditions, with a vegetation coverage of less than 30%. After treatment, it can be developed into arable land from forest land
Orchard	Low-productivity orchard	Low-efficiency orchards refer to those with relatively poor management conditions, low yields, outdated varieties, low vegetation coverage, aging fruit trees, damaged or dead fruit trees, or low willingness of farmers to plant. With a fruit tree coverage of 50% or less, these orchards can be developed into arable land
Grassland	Cultivable grassland	Refers to uncultivated wasteland; grassland with a tree canopy coverage of less than 10% that can potentially be developed into arable land
Other land	Cultivable saline-alkali land	Currently unused but potentially convertible to arable land with improvement: reclaimable saline-alkaline land
	Cultivable sandy land	Reclaimable sandy land that can potentially be developed into arable land with improvement. The annual precipitation ranges from 200 mm to 400 mm, and the FVC (Fractional Vegetation Cover) is greater than 10%
	Cultivable bare land	Reclaimable bare land with a topsoil layer and minimal vegetation cover, which can potentially be developed into arable land with improvement
	Cultivable mudflats	Refers to the intertidal zone between the high and low tide levels along the coast. Reclaimable mudflats that can potentially be developed into arable land with improvement

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Table 2. *Data description*

Data title	Spatial resolution	Dataset usage period	Data source
China 30-m LUCC land use remote sensing monitoring data	30 m	The year 2020	Institute of Geographic Sciences and Natural Resources Research Chinese Academy of Sciences (http://www.igsnrr.cas.cn)
China fractional vegetation cover (FVC) dataset	250 m	The year 2020	China Tibetan Plateau Scientific Data Center (http:/data.tpdc.ac.cn)
China annual precipitation data	500 m	The year 2020	Resource and Environmental Science Data Center, Chinese Academy of Sciences (http:/www.resdc.cn)
China MOD17A3H vegetation net primary productivity (NPP) data	500 m – 1 km	The year 2020	United States Geological Survey (USGS) (http:/www.usgs.gov)
Digital elevation model (DEM) data	30 m	The year 2020	United States Geological Survey (USGS) (http:/www.usgs.gov)
Dataset of soil properties for land surface modeling over China	1 km	The year 2020	A Big Earth Data Platform for Three Poles (https://poles.tpdc.ac.cn)
China river network data	1:1 million	The year 2020	Tianditu (https://vgimap.tianditu.gov.cn)
China ≥10°C accumulated temperature data	500 m	The year 2020	Resource and Environmental Science Data Center, Chinese Academy of Sciences (http:/www.resdc.cn)
China road data	1:1 million	The year 2020	Tianditu (https://vgimap.tianditu.gov.cn)

Evaluation methods for corn planting suitability on marginal lands

Evaluation indicators and classification standards

Based on the regional distribution patterns and biological characteristics of corn in China, as well as data from expert recommendations and literature statistics (He et al., 2012; Liu et al., 2015; Fu et al., 2020; Yang et al., 2022; Zhang et al., 2022), nine indicators and classification standards (*Table 3*) have been determined from five factors: topography, soil, water resources, climate, and transportation accessibility. These indicators and standards serve as the basis for extracting marginal lands suitable for corn growth.

Method for determining weights

The entropy weight method objectively and accurately determines the weights of various indicators based on their variability (Ma et al., 2023). It effectively eliminates biases caused by subjective factors, determines indicator weights, and reduces the impact of extreme data values, thereby scientifically and objectively reflecting the level of regional resource and environmental carrying capacity (Li et al., 2019). The calculation steps are as follows:

Standardization: Due to the significant differences in dimensions among indicators, range standardization is used to normalize the indicators. Different normalization methods are applied for extremely large, extremely small, interval, and intermediate indicators.

For extremely large indicators, the normalization formula is:

$$X_{ij} = (x_{ij} - \min(x_j))/(\max(x_j) - \min(x_j)) \quad \text{(Eq.1)}$$

For extremely small indicators, the normalization formula is:

$$X_{ij} = (\max(x_j) - x_{ij})/(\max(x_j) - \min(x_j)) \quad \text{(Eq.2)}$$

where X_{ij} is the dimensionless value of the j-th evaluation indicator for the i-th evaluation object, x_{ij} is the raw value of the j-th evaluation indicator for the i-th evaluation object, max (x_j) is the maximum value observed for the j-th indicator, and min (x_j) is the minimum value observed for the j-th indicator.

Calculation of information entropy E_j:

$$E_j = -\frac{1}{lnn}\sum_{i=1}^{n}(p_{ij} lnp_{ij}) \quad \text{(Eq.3)}$$

where $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$, If $p_{ij} = 0$, then $\lim_{p_{ij}\to\infty} p_{ij} ln\, p_{ij} = 0$

Calculation of weights W_i for each indicator:

$$W_j = \frac{1-E_j}{n-\sum_{j=1}^{m} E_j} \quad \text{(Eq.4)}$$

Table 3. *Corn suitability evaluation index system and weights*

Evaluation indicators	Indicator factors*	Suitability score					Weights
		100	75	50	25	0	
Terrain	Slope /°	≤2	2-6	6-15	15-20	≥20	0.068
	Altitude /m	≤800	800-1500	1500-3000	3000-4000	≥4000	0.289
Soil	Soil organic matter g/kg	≥20	15-20	10-15	5-10	≤5	0.047
	Soil pH	6-7.5	5.0-6	7.5-8.5	≤5	≥8.5	0.154
	Soil depth /cm	≥100	60-100	40-60	20-40	≤20	0.035
Water resources	Distance to rivers and lakes /km	≤2	2-5	5-10	10-20	≥20	0.118
Climate	Annual precipitation /mm	500-800	200-500 or 800-1200	1200-2000	≥2000	≤200	0.074
	≥10°C accumulated temperature /°C	2000-3300	3300-5000	5000-7000	1000-2000	≤1000 or ≥ 7000	0.104
Transportation convenience	Distance to the road /km	≤ 5	5-10	10-30	30-50	≥ 50	0.111

*The slope, soil organic matter, and soil depth are primarily based on relevant Chinese regulations. Altitude, soil pH, annual precipitation, and ≥10°C accumulated temperature are primarily based on literature references (He and Zhou, 2012). Distance to river networks and road distance are primarily based on relevant survey data and literature regarding corn growth conditions (Yang et al., 2022; Zhang and Wu, 2022)

Comprehensive evaluation method

The comprehensive index method processes a set of identical or different numerical values, standardizing values of different natures and measurement units. This ultimately transforms them into a comprehensive index, allowing for a more complete and systematic reflection of the overall situation in a certain aspect (Yang et al., 2020).

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Using each grid cell as the smallest evaluation unit, the value under the multi-factor comprehensive evaluation is calculated. The evaluation formula is as follows:

$$S = \sum_{i=1}^{n}(W_i X_i) \quad \text{(Eq.5)}$$

where S is the total score of the evaluation unit after comprehensive evaluation through various factors, W_i is the weight of the i-th evaluation factor, and X_i is the score of the evaluation unit under the *i*-th evaluation factor.

After reclassifying the layers of each indicator according to quality grade standards, the entropy weight method is used to calculate the weights of each evaluation indicator (*Table 2*). The value S is then calculated under the multi-factor comprehensive evaluation, and the marginal land distribution is overlaid. Finally, according to the suitability grade standards (*Table 4*), the distribution of marginal lands suitable for corn planting in China is obtained.

Table 4. *Classification standards for marginal lands suitable for corn planting*

Suitability classes	Score
Highly suitable	75-100
Moderately suitable	50-75
Lowly suitable	25-50
Unsuitable	0-25

Methods for analyzing influencing factors in each region

By calculating the contribution rate of each indicator, the influencing factors in different regions can be measured. The contribution rate of an indicator typically refers to the degree of contribution each indicator makes to the overall set of indicators (Chen et al., 2010). The specific method is to use each grid cell as the smallest evaluation unit and calculate the contribution rate G_i of each indicator to the comprehensive evaluation value.

$$G_i = \frac{W_i X_i}{S} \quad \text{(Eq.6)}$$

Results

Characteristics of marginal land distribution in China

Following the marginal land extraction methods, the spatial distribution of marginal lands in China is obtained (*Fig. 1*), along with the proportion of marginal lands across different geographical regions (*Table 5*). The results reveal that the total area of marginal lands in China amounts to 2.27 × 10^6 km^2. The majority of these lands are uncultivated grasslands, low-grade arable lands, and low-quality forest lands, which occupy 0.96 × 10^6 km^2, 0.60 × 10^6 km^2, and 0.47 × 10^6 km^2, accounting for 42.6%, 26.3%, and 20.7% of the total marginal lands, respectively. These are followed by cultivable saline-alkali lands and barren lands, with areas of 0.11 × 10^6 km^2 and 0.10 × 10^6 km^2, contributing 4.7% and 4.3% of the total. In comparison, cultivable sandy lands

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and low-productivity orchards are less prevalent, covering 0.03 × 10⁶ km² and 593.1 km², representing 1.4% and 0.03% of the total marginal lands, respectively.

In terms of non-arable land types, cultivable grasslands are the most widely distributed, primarily located in the northwest, southwest, and north China regions. These areas are characterized by arid and semi-arid climates, predominantly sandy or rocky soils, and shallow soil layers, resulting in low vegetation cover and the predominance of drought-resistant herbaceous plants. For land types originally classified as arable, low-grade arable lands are mainly found in the northeast, central, and eastern China regions. Due to their proximity to the sea, these areas often face freshwater shortages and poor soil quality, particularly saline-alkali soils, which significantly reduce soil fertility (Li et al., 2023). Furthermore, the long history of agricultural activities in these regions, combined with excessive cultivation and unsustainable farming practices, has led to soil degradation and a decline in arable land quality (Xiao et al., 2015).

***Figure 1.** Distribution of marginal land in China*

Analysis of the proportion of marginal lands across different geographical regions (*Table 5*) indicates that the northwest region contains the largest share, accounting for 29.9% of the total, with cultivable grasslands as the dominant type. The southwest region follows, comprising 23.6% of the total, where cultivable grasslands and low-quality forest lands are the primary categories. The north China region accounts for 12.5% of the total, mainly consisting of cultivable grasslands and low-quality arable lands. In the east China region, which holds 15.0% of the total marginal lands, low-quality arable lands and low-quality forest lands are the principal types. The northeast

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region comprises 9.2% of the total, with low-quality arable lands as the dominant type. The central China region represents 7.3% of the total, primarily consisting of low-quality arable lands, while the south China region accounts for the smallest share at 2.5%, where low-quality forest lands are the primary type.

Table 5. *Proportion of marginal lands in different geographic regions of China (unit: km^2)*

Region \ Type	Low-quality arable land	Low-quality forest land	Low-productivity orchard	Cultivable grassland	Cultivable saline-alkali land	Cultivable mudflats	Cultivable sandy land	Cultivable bare land	Sum	Marginal land share in different regions
North China	70477.1	31416.2	35	130022.1	23721.2	100.7	24558.2	4560	0.28×10^6	12.5%
Northeast China	188323.6	9772.1	10.3	843.4	10188	77.1	0	221.7	0.21×10^6	9.2%
East China	179011.2	156088.6	47.5	3704.3	59.8	964.1	0	131.7	0.34×10^6	15.0%
Central China	102681.8	60704.2	5.4	559.3	999	0.4	0	45.4	0.16×10^6	7.3%
South China	16462.1	38803.2	46.1	131.6	11.7	226.2	0	50.9	0.05×10^6	2.5%
Southwest China	25402.2	141761.9	116.8	289961.9	10146	0	0	69589	0.54×10^6	23.6%
Northwest China	14215.1	30634.5	332	541913.3	61301.4	0	6908	23713.6	0.68×10^6	29.9%
Sum	0.60 ×10^6	0.47×10^6	593.1	0.96×10^6	0.10×10^6	1368.5	0.03×10^6	0.10×10^6	2.27×10^6	100%
Percentage of marginal land of different types	26.3%	20.7%	0.03%	42.6%	4.7%	0.1%	1.4%	4.3%	100%	/

Suitability distribution of marginal lands for corn planting

After reclassifying the indicator system outlined in *Table 3*, the suitability levels for each factor affecting corn cultivation were determined (*Fig.2*). The most suitable slope grades are primarily concentrated in the North China and Northeast regions. The elevation suitability map shows that the most favorable elevations are distributed to the east of the east-west transition zone. Soil factors exhibit significant regional variation and heterogeneity, with the soil property suitability map displaying a patchy distribution. The most suitable soil thickness grades are widely distributed, suggesting that soil depth does not present a major limiting factor for corn growth (Wang et al., 2018). In contrast, the soil pH suitability map reveals that the most suitable areas are limited and scattered. The most suitable annual precipitation grades for corn are found near the north-south transition zone, while suitability decreases in the southeastern coastal areas where excessive rainfall can negatively impact critical growth stages such as tasseling and grain filling. The most suitable accumulated temperature above 10°C is concentrated in the North China and Northeast regions. Additionally, the distribution of river networks and roads indicates that eastern China has a significantly better infrastructure density than western China.

Using each grid cell as the smallest evaluation unit, the contribution rate of each indicator to the overall suitability score was calculated, resulting in *Figure 3,* which highlights the dominant factors across different regions. In the Northwest region, the most influential indicators are elevation, distance to rivers and lakes, distance to roads,

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and accumulated temperature above 10°C. For the North China region, elevation, soil pH, and accumulated temperature above 10°C are the key factors. In the Northeast region, the primary indicators are elevation, soil pH, accumulated temperature above 10°C, and road accessibility. In the Southwest region, soil pH, distance to rivers and lakes, annual precipitation, and road accessibility play the most significant roles. For the Central China, East China, and South China regions, elevation, soil pH, and distance to roads are the most influential factors affecting corn suitability.

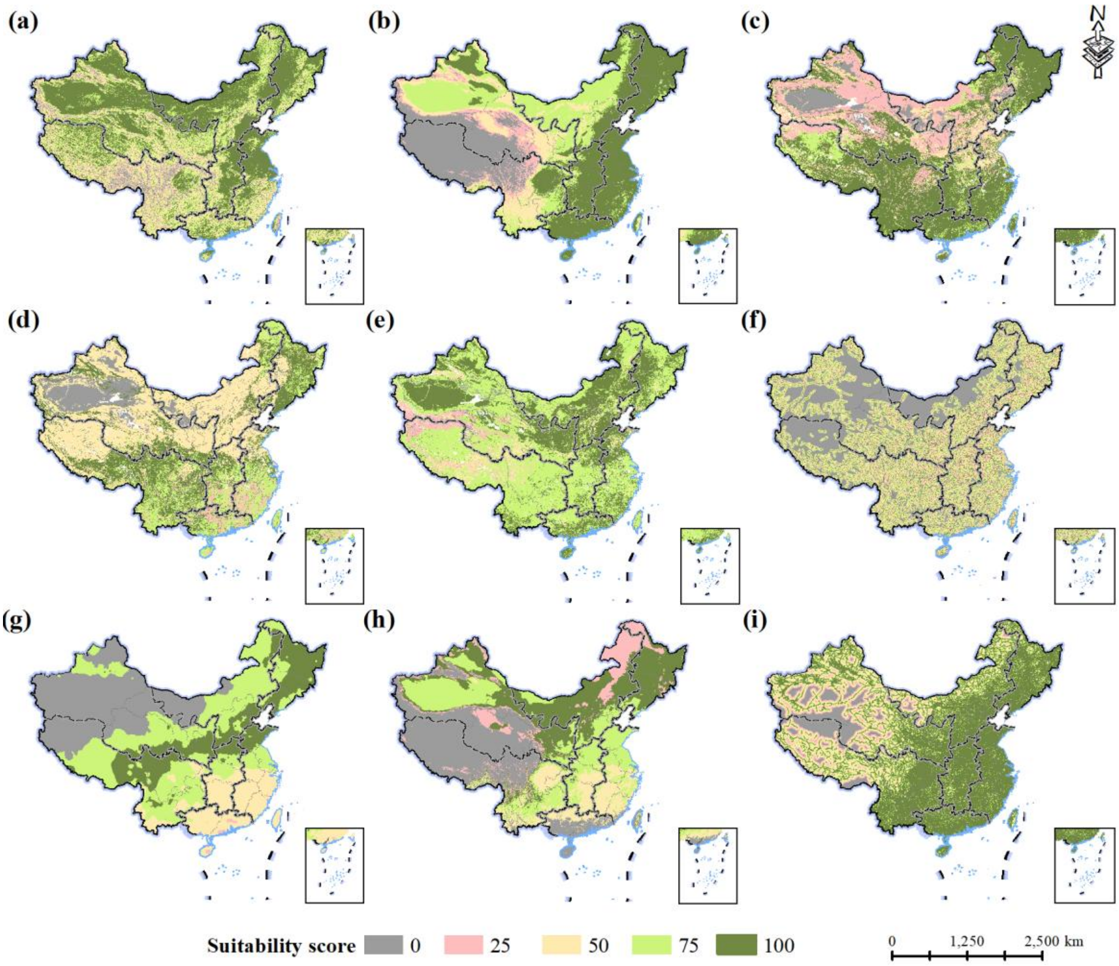

Figure 2. *Distribution of suitability levels for various indicators of corn, (a) Slope;(b) Altitude;(c) Soil organic matter;(d) Soil pH;(e) Soil depth;(f) Distance to rivers and lakes;(g) Annual precipitation;(h) ≥10°C accumulated temperature and (i) Distance to the road*

By integrating the multi-factor comprehensive evaluation with marginal land and geographical region data, the suitability distribution of marginal lands for corn cultivation in China was generated (*Fig. 4*), and the proportion of corn suitability across different geographical regions is presented in *Table* 6. Areas with high suitability are primarily located in the Northeast, Central China, and East China regions. Moderate suitability areas are mainly distributed across the Northwest, North China, Southwest, and South China regions. Low suitability areas are found in the Northwest and Southwest regions, while unsuitable areas are concentrated in the Southwest region. Specifically, high suitability grades account for 30.0% of the total marginal lands,

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moderate suitability grades account for 30.7%, low suitability grades account for 24.7%, and unsuitable grades account for 14.6%.

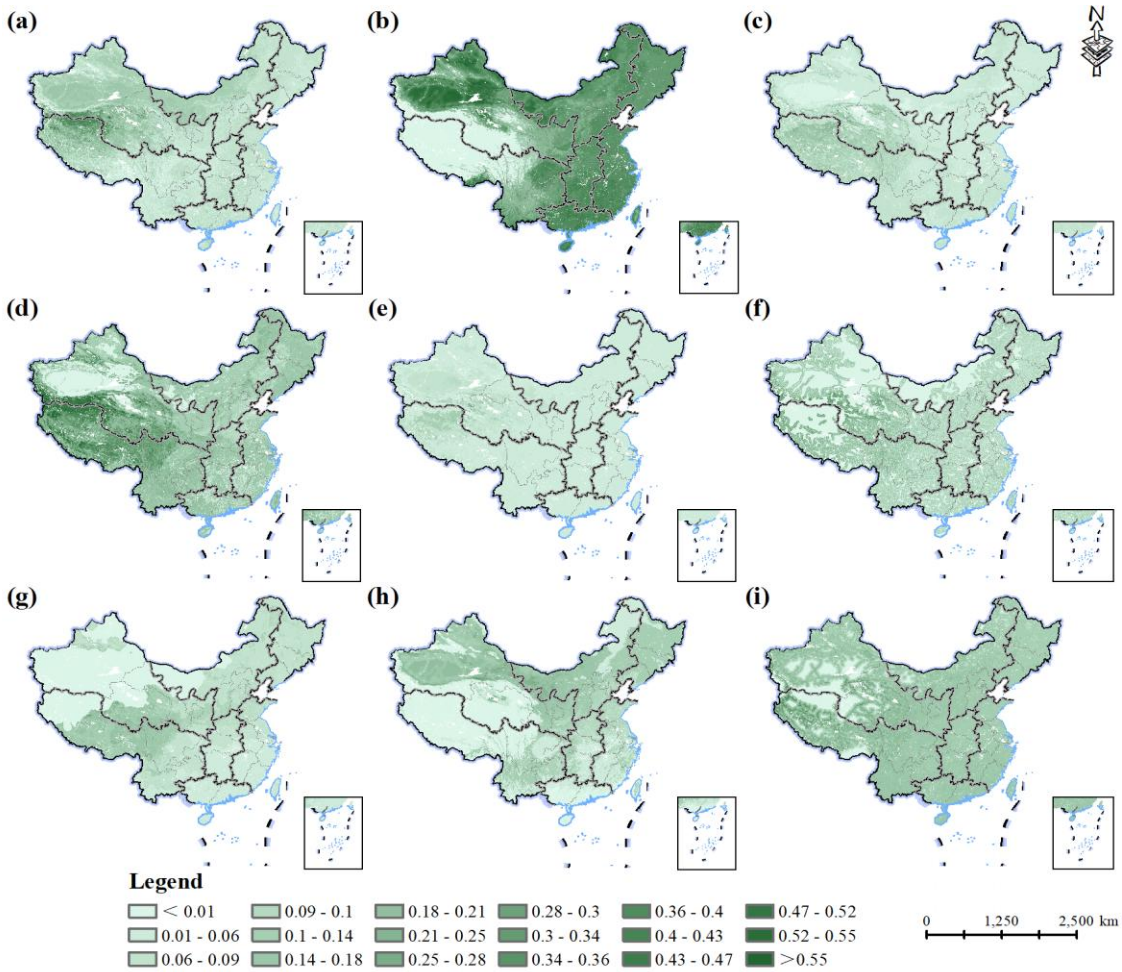

Figure 3. *Distribution of contribution rates of various indicators for corn, (a) Slope;(b) Altitude;(c) Soil organic matter;(d) Soil pH;(e) Soil depth;(f) Distance to rivers and lakes;(g) Annual precipitation;(h) ≥10°C accumulated temperature and (i) Distance to the road*

Table 6. *Area of corn planting suitability of marginal lands in different geographic regions of China (unit: km^2)*

Type / Region	Highly suitable	Moderately suitable	Lowly suitable	Unsuitable	Sum
North China	100719.6	174306.5	8257.7	1606.7	0.28×10^6
Northeast China	201359.2	6749.7	0	1327.3	0.21×10^6
East China	168659.3	47278.5	0	124069.3	0.34×10^6
Central China	117404.5	43416.2	0.9	4173.8	0.16×10^6
South China	22203.6	31907.8	2.0	1618.4	0.06×10^6
Southwest China	44175.9	116204.3	265809.0	110788.7	0.54×10^6
Northwest China	27480.5	276592.4	286720.9	88224.1	0.68×10^6
Sum	0.68×106	0.70×106	0.56×106	0.33×106	2.27×106
Percentage of different suitability classes	30.0%	30.7%	24.7%	14.6%	100%

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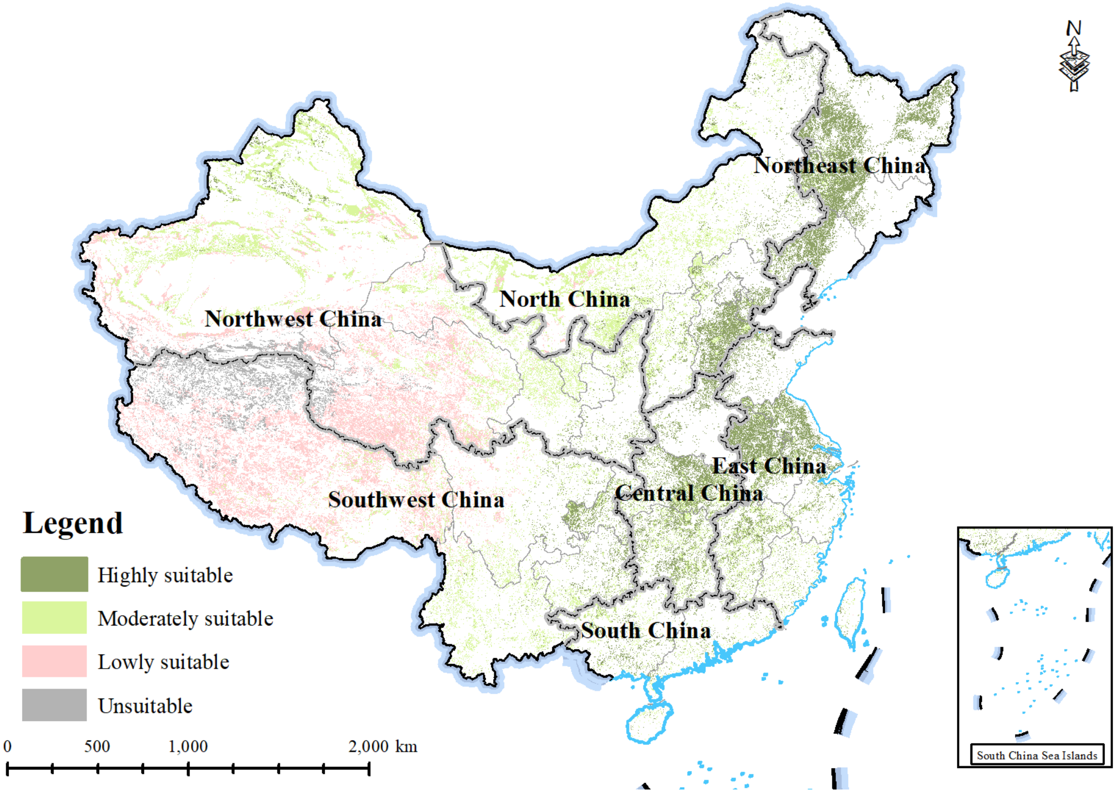

***Figure 4.** Distribution of corn suitability on marginal land in China*

Corn production potential of marginal lands

Based on the *Bulletin on the National Cultivated Land Quality Grade Situation* (2020) issued by the Ministry of Agriculture and Rural Affairs of the People's Republic of China ([2020] No. 1), combined with corn yield data from the past five years obtained from provincial corn statistical yearbooks published by the National Bureau of Statistics of China (https://www.stats.gov.cn/), as well as existing research findings (Meng et al., 2013; Feng et al., 2023; Jiang et al., 2023), the average corn yield for each province over the past five years was used as a benchmark. This data was utilized to calculate the potential corn yield on marginal lands across different geographic regions of China, excluding areas classified as unsuitable for corn cultivation.

Based on the suitability levels of marginal lands for corn cultivation in each province (*Table 6*), the potential corn yield on marginal lands in China was estimated (*Table* 7). The results indicate that if the high, medium, and low suitability marginal lands are fully utilized for corn cultivation, the total corn production could increase by 70.1×10^7 to 113.2×10^7 t. Specifically, the high suitability lands could contribute an additional 35.3×10^7 to 46.3×10^7 t, the medium suitability lands could add 24.4×10^7 to 41.5×10^7 t, and the low suitability lands could increase production by 10.3×10^7 to 25.4×10^7 t.

Among the different geographic regions, the Northwest region exhibits the greatest potential for increased corn production, with an estimated yield increase of 17.6×10^7 to 39.2×10^7 t, accounting for 25.0% to 34.7% of the total potential increase from marginal lands. This highlights the significant potential and development value of marginal lands in the Northwest region for enhancing corn production.

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Table 7. *Corn yield on marginal lands in different regions of China*

Region	Corn yield per square kilometer of marginal land (kg/km^2)			Yield (×10^7 t)			Sum
	Highly suitable	Moderately suitable	Lowly suitable	Highly suitable	Moderately suitable	Lowly suitable	
North China	558000-721500	408,000-571,500	258,000 -421,500	5.6-7.3	7.1-10.0	0.2-0.3	12.3-17.6 18.5%-15.5%
Northeast China	655500-706500	505,500-556,500	406,500-355,500	14.2-13.2	0.3-0.4	0	13.5-14.6 19.3%-12.9%
East China	426000-699000	276,000-549,000	126,000-126,000	7.2-11789.3	1.3-2.6	0	8.5-14.4 12.1%-12.7%
Central China	415500-585000	265,500 -435,000	115,500-285,000	4.9-6.9	1.2-1.9	0	6.0-8.8 8.6%-7.7%
South China	459000-468000	309,000 -318,000	159,000-168,000	1.02-1.04	0.98-1.01	0	2.0-2.1 2.9%-1.8%
Southwest China	451500-618000	301,500-468,000	151,500-318,000	2.0-2.7	3.5-5.4	4.0-8.5	9.5-16.6 13.6%-14.7%
Northwest China	513000-880500	363,000-730,500	213,000-580,500	1.4-2.4	10.0-20.2	6.1-16.6	17.6-39.2 25.0%-34.7%
Sum	/	/	/	35.3-46.3	24.4-41.5	10.3-25.4	70.1-113.2

Discussion

Water resources, energy, and food are strategic and fundamental resources that profoundly impact human production, daily life, and the ecological environment. Establishing a comprehensive system for extracting marginal land data and mapping the distribution of marginal lands in China provides a critical data foundation for the development of new agricultural productivity. Chinese scholars have also conducted extensive investigations and research on marginal lands across the country (Zhuang et al., 2011; Dauber et al., 2012; Chen et al., 2017; Cao et al., 2021; Khanna et al., 2021). For instance, Chen et al. (2017) investigated the quantity and distribution of marginal lands suitable for energy crop cultivation in China. This study utilized data from China's Second Land Use Change Survey and incorporated various land types, including other forests, other grasslands, inland wetlands, sandy lands, marshlands, coastal wetlands, shrublands, saline-alkaline lands, and bare lands. The feasibility of exploiting these lands was objectively assessed by defining their range and evaluating their actual potential supply.

In contrast, this study adopts a broader scope for marginal land extraction. This is primarily due to the inclusion of lower-grade cultivated lands in accordance with China's technical guidelines and policies. Moreover, following the Ministry of Land and Resources' "Notice on Improving Management Methods and Effectively Implementing the Balance of Arable Land Occupation and Compensation," this study also incorporates low-quality forestlands and low-productivity orchards.

Among the different geographic regions, Northwest China exhibits the most significant potential for marginal land development. The arid climate and limited water resources in this region contribute to the formation of extensive marginal lands (Shen et al., 2022). According to the findings of this study, Northwest China holds the largest share of marginal land, accounting for 29.9% of the national total, with cultivable grasslands being the dominant land type. These lands are typically characterized by low precipitation, poor soil fertility, and severe salinization, which pose challenges for

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conventional agricultural production. However, with the implementation of advanced agricultural techniques and improved water management practices, these marginal lands hold significant potential for utilization. For instance, the adoption of high-efficiency water-saving irrigation techniques, such as drip and sprinkler irrigation, has significantly increased the yield of summer corn in certain areas of Northwest China (Cao et al., 2022). If large-scale, rational development of marginal lands is coupled with optimized water resource management, it can boost agricultural output, stimulate related industries, promote economic growth in Northwest China, and improve local living standards.

Current research on marginal land productivity primarily focuses on its potential for energy crop cultivation (Zhuang et al., 2011; Dauber et al., 2012; Khanna et al., 2021). However, food security remains a pressing global concern. Maize, as one of the three major grain crops in China, serves as a crucial raw material for food, animal feed, the fermentation industry, and various fine chemical products. Therefore, this study classifies marginal lands and identifies suitable areas based on their suitability for maize cultivation. The objective is to enhance China's maize self-sufficiency rate and contribute to the sustainable development and utilization of marginal land resources.

Nevertheless, this study has certain limitations. First, the evaluation framework considers limited socio-economic indicators, focusing solely on road distance. Future studies could incorporate additional variables such as land rent, farmers' willingness to cultivate, and public acceptance. Second, the river network indicator does not account for agricultural irrigation projects. For example, the extensive canal irrigation systems in the Inner Mongolia Autonomous Region significantly influence land productivity and ecological benefits, which were not fully reflected in this study. Third, the maize yield data relies on statistical estimates, which may lack empirical accuracy due to subjective biases. Fourth, the marginal lands identified in this study represent the maximum potential area suitable for maize cultivation under ideal conditions. In practice, it is essential to consider the water-carrying capacity and other production factors in each region to determine the actual plantable area. Finally, it should be noted that the delineation of marginal land in this study did not exclude areas designated as nature reserves. This may lead to an overestimation of the available land for cultivation, as such areas are subject to strict ecological protection regulations and are not suitable for agricultural development. Therefore, the rational utilization of marginal lands should be tailored to local hydrological and environmental conditions (Gao et al., 2012; Yu et al., 2023; Li et al., 2024).

Conclusions

In terms of the spatial distribution of marginal land, China has a total of 2.27×10^6 km^2 of marginal land, with cultivable grassland, low-grade arable land, and low-quality forest land accounting for the largest proportions of the total, representing 42.6%, 26.3%, and 20.7% of the total marginal land, respectively.

Among the marginal lands in different geographic regions of China, the Northwest Region has the widest distribution of marginal lands, accounting for 29.9% of all marginal lands in China, with the predominant land type being cultivable grassland.

From the perspective of non-cultivated land types, cultivable grasslands have the widest distribution, concentrated in the Northwest, Southwest, and North China regions.

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Degraded forest lands also play a significant role, with distribution mainly in South China and the Southwest.

For lands that were originally cultivated, low-quality arable lands are found in the Northeast, Central, and East China regions. Due to their proximity to marine areas, these regions face constraints such as freshwater shortages and saline-alkaline soils, which reduce soil fertility. Furthermore, the long history of land use in these areas, combined with over-cultivation and unreasonable agricultural practices, has led to soil degradation and a decline in the quality of cultivated lands.

In China, marginal lands suitable for high-grade corn cultivation account for 30.0% of all marginal lands, those suitable for medium-grade corn cultivation make up 30.7%, low-grade suitability lands constitute 24.7%, and lands unsuitable for corn cultivation represent 14.6%.

If corn were planted on marginal lands of all suitability levels, the yield could be increased by 70.1×10^7 to 113.2×10^7 tons, with high-suitability lands expected to contribute an additional 35.3×10^7 to 46.3×10^7 tons of corn.

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REFERENCES

[1] Behnassi, M., El Haiba, M. (2022): Implications of the Russia-Ukraine war for global food security. – Nature Human Behaviour 6(6): 754-755.

[2] Bai, X., Zhang, J., Cui, Z., Wang, G. (2023): Advances in the Indicator and Assessment Approaches of Medium-low Yield Fields. – Acta Pedologica Sinica 60(4): 913-924.

[3] Bongaarts, J. (2021): FAO, IFAD, UNICEF, WFP and WHO The State of Food Security and Nutrition in the World 2020. Transforming Food Systems for Affordable Healthy Diets. – FAO, Rome.

[4] Cai, L., Wang, H., Liu, Y., Fan, D., Li, X. (2022): Is potential cultivated land expanding or shrinking in the dryland of China? Spatiotemporal evaluation based on remote sensing and SVM. – Land Use Policy 112: 105871.

[5] Cao, X., Sun, B.-M., Chen, H., Zhou, J.-M., Song, X., Liu, X., Deng, X., Li, X., Zhao, Y., Zhang, J.-B., Li, J. (2021): Approaches and research progresses of marginal land productivity expansion and ecological benefit improvement in China. – Bulletin of Chinese Academy of Sciences 36(3).

[6] Cao, Y., Cai, H., Sun, S., Gu, X., Mu, Q., Duan, W., Zhao, Z. (2022): Effects of drip irrigation methods on yield and water productivity of maize in Northwest China. – Agricultural Water Management 259: 107227.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_72617278

[7] Chen, Y. Q., Guo, X. D., Liu, J. J., Zhang, Z. J. (2017): Assessment of marginal land potential for energy plants in China. – Land Development and Engineering Research 2: 1-7.
[8] Chen, Y., Yu, J., Khan, S. (2010): Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. – Environmental Modelling & Software 25(12): 1582-1591.
[9] Csikós, N., Tóth, G. (2023): Concepts of agricultural marginal lands and their utilisation: a review. – Agricultural Systems 204: 103560.
[10] Dale, V. H., Kline, K. L., Wiens, J., Fargione, J. (2010): Biofuels: Implications for Land Use and Biodiversity. – Ecological Society of America, Washington, DC.
[11] Dauber, J., Brown, C., Fernando, A. L., Finnan, J., Krasuska, E., Ponitka, J., Zah, R. (2012): Bioenergy from "surplus" land: environmental and socio-economic implications. – BioRisk 7: 5-50.
[12] Eastman, J. R. (2003): IDRISI Kilimanjaro: Guide to GIS and Image Processing. Vol. 328. – Clark Labs, Clark University, Worcester.
[13] Feng, X., Sun, T., Guo, J., Cai, H., Qian, C., Hao, Y., Zhang, W. (2023): Climate-smart agriculture practice promotes sustainable maize production in northeastern China: higher grain yield while less carbon footprint. – Field Crops Research 302: 109108.
[14] Fu, J., Du, J. S., Jiang, D., Wang, D. (2020): Anglysis of the marginal land resources suitable for developing liquid biofuel in China. – Science & Technology Review 38(11): 31-40.
[15] Gao, Y. H., Guo, L. Z., Niu, J. Y., Yan, Z. L., Liu, J. H., Xu, R., Wang, Y. (2012): Effect of cultivation patterns on growth of maize root and water use efficiency. – Chinese Journal of Eco-Agriculture 20(2): 210-216.
[16] Gopalakrishnan, G., Cristina Negri, M., Snyder, S. W. (2011): A novel framework to classify marginal land for sustainable biomass feedstock production. – Journal of Environmental Quality 40(5): 1593-1600.
[17] He, Q., Zhou, G. (2012): The climatic suitability for maize cultivation in China. – Chinese Science Bulletin 57: 395-403.
[18] Hennenberg, K. J., Fritsche, U. R., Wiegmann, K., Haye, S., Hewson, J., Dragisic, C. (2008): Criteria and indicators to identify and map high nature value areas. – In: Joint International Workshop on High Nature Value Criteria and Potential for Sustainable Use of Degraded Lands. Paris, June 30-July 1.
[19] Ji, Y., Yan, H., Liu, J., Kuang, W., Hu, Y. (2015): A MODIS data derived spatial distribution of high-, medium-and low-yield cropland in China. – Acta Geographica Sinica 70(5): 766-778.
[20] Jiang, W., Jacobson, M. G., Langholtz, M. H. (2019): A sustainability framework for assessing studies about marginal lands for planting perennial energy crops. – Biofuels, Bioproducts and Biorefining 13(1): 228-240.
[21] Jiang, Y., Wang, X., Huo, M., Chen, F., He, X. (2023): Changes of cropping structure lead diversity decline in China during 1985–2015. – Journal of Environmental Management 346: 119051.
[22] Khanna, M., Chen, L., Basso, B., Cai, X., Field, J. L., Guan, K., Zipp, K. Y. (2021): Redefining marginal land for bioenergy crop production. – GCB Bioenergy 13(10): 1590-1609.
[23] Lee, C. C., Li, J., Zeng, M. (2024): Construction of China's food security evaluation index system and spatiotemporal evolution. – Environmental Science and Pollution Research 31(17): 25014-25032.
[24] Li, M., Sun, H., Singh, V. P., Zhou, Y., Ma, M. (2019): Agricultural water resources management using maximum entropy and entropy-weight-based TOPSIS methods. – Entropy 21(4): 364.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_72617278

[25] Li, Y., Fang, B., Li, Y., Feng, W., Yin, X. (2023): Spatiotemporal pattern of cultivated land pressure and its influencing factors in the Huaihai Economic Zone, China. – Chinese Geographical Science 33(2): 287-303.
[26] Li, Z. W., Wang, G. Y., Khan, K., Yang, L., Chi, Y. X., Wang, Y., Zhou, X. B. (2024): Irrigation combines with nitrogen application to optimize soil carbon and nitrogen, increase maize yield, and nitrogen use efficiency. – Plant and Soil 499(1): 605-620.
[27] Liu, C. W., Li, X. B. (2005): The character and diagnostic criterion for marginisation of the arable land. – Progress in Geography 24(2): 106-113.
[28] Liu Q., Qi, L. Q., Dong, S. C., Gui, Z. B., Hui, X. G. (2015): Methodology and certification criteria of non-food land suitable for energy plant production in China. – Journal of China Agricultural University 20(2): 11–20.
[29] Ma, X. F., Zhang, R., Ruan, Y. F. (2023): How to evaluate the level of green development based on entropy weight TOPSIS: evidence from China. – International Journal of Environmental Research and Public Health 20(3): 1707.
[30] Malczewski, J. (2006): GIS-based multicriteria decision analysis: a survey of the literature. – International Journal of Geographical Information Science 20(7): 703-726.
[31] Meng, Q., Hou, P., Wu, L., Chen, X., Cui, Z., Zhang, F. (2013): Understanding production potentials and yield gaps in intensive maize production in China. – Field Crops Research 143: 91-97.
[32] Ren, H., Zhou, P., Zhou, B., Li, X., Wang, X., Ge, J., Li, C. (2023): Understanding the physiological mechanisms of canopy light interception and nitrogen distribution characteristics of different maize varieties at varying nitrogen application levels. – Agronomy 13(4): 1146.
[33] Robertson, B. A., Doran, P. J. (2013): Biofuels and Biodiversity: The Implications of Energy Sprawl. – In: Levin, S. (ed.) Encyclopedia of Biodiversity. 2nd Ed. Academic Press, Cambridge, MA, pp. 528-539.
[34] Saha, M., Eckelman, M. J. (2015): Geospatial assessment of potential bioenergy crop production on urban marginal land. – Applied Energy 159: 540-547.
[35] Schroers, J. O. (2006): Zur Entwicklung der Landnutzung auf Grenzstandorten in Abhängigkeit agrarmarktpolitischer, agrarstrukturpolitischer und produktionstechnologischer Rahmenbedingungen: eine Analyse mit dem Simulationsmodell ProLand. – Inaugural-Dissertation zur Erlangung des Doktorgrades (Dr. agr.) des Fachbereichs Agrarwissenschaften, Ökotrophologie und Umweltmanagement der Justus-Liebig-Universität Gießen. http://dx.doi.org/10.22029/jlupub-15534.
[36] Shen, Q., Niu, J., Liu, Q., Liao, D., Du, T. (2022): A resilience-based approach for water resources management over a typical agricultural region in Northwest China under water-energy-food nexus. – Ecological Indicators 144: 109562.
[37] Shortall, O. K. (2013): "Marginal land" for energy crops: exploring definitions and embedded assumptions. – Energy Policy 62: 19-27.
[38] Tang, Y., Xie, J. S., Geng, S. (2010): Marginal land-based biomass energy production in China. – Journal of Integrative Plant Biology 52(1): 112-121.
[39] Wang, M., Ma, L., Strokal, M., Chu, Y., Kroeze, C. (2018): Exploring nutrient management options to increase nitrogen and phosphorus use efficiencies in food production of China. – Agricultural Systems 163: 58-72.
[40] Xiao, L., Yang, X., Cai, H., Zhang, D. (2015): Cultivated land changes and agricultural potential productivity in mainland China. – Sustainability 7(9): 11893-11908.
[41] Yang, S., Bai, Y., Alatalo, J. M., Wang, H., Tong, J., Liu, G., Chen, J. (2022): Spatial–temporal pattern of cultivated land productivity based on net primary productivity and analysis of influencing factors in the Songhua River basin. – Land Degradation & Development 33(11): 1917-1932.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_72617278

[42] Yang, Z., Yang, H., Wang, H. (2020): Evaluating urban sustainability under different development pathways: a case study of the Beijing-Tianjin-Hebei region. – Sustainable Cities and Society 61: 102226.
[43] Yu, H., Li, S., Ding, J., Yang, T., Wang, Y. (2023): Water use efficiency and its drivers of two typical cash crops in an arid area of Northwest China. – Agricultural Water Management 287: 108433.
[44] Zhang, X. T., Wu, X. Q. (2022): Cultivation and production potential evaluation of Cyperus esculentus L. in marginal land of Inner Mongolia. – Transactions of the CSAE 38(2): 289-295.
[45] Zhuang, D., Jiang, D., Liu, L., Huang, Y. (2011): Assessment of bioenergy potential on marginal land in China. – Renewable and Sustainable Energy Reviews 15(2): 1050-1056.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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