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ARTICLE

Identification of Limiting Factors and Engineering Selection for Agricultural Development of Barren Grassland: A Systems Engineering Approach

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ABSTRACT

Agricultural land development is a pivotal strategy for addressing the global food security crisis. Barren grassland, especially those in mountainous regions, constitutes critical areas where cultivation can substantially enhance land resources. This study highlights the necessity for a precise correlation between land development initiatives and constraints in order to optimize efficiency and enhance the effectiveness of such projects, with the core being the seamless integration of land development engineering and techniques to eliminate agricultural constraints. This study employs a systems engineering approach to classify improvement factors into mobile and fixed categories, elucidating the integration methods of constraint factors. Adhering to the Wooden Barrel Principle, these constraints were rigorously analyzed based on soil quality, land topography, water availability, and agricultural infrastructure. An innovative method of engineering type combination is proposed, which effectively explains the correlation between natural factors combination, project type combination, and target factors combination. It provides a convenient way for the selection of barren grassland development projects

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and lays a foundation for land planning, development project establishment, program selection, engineering design, and budget preparation. Taking Tang County of China as an example, it is divided into 19 factor improvement areas, a quick reference table of engineering types is established, and 14 main types of engineering combinations are obtained, which lays a foundation for the application of theoretical framework in practice.

Keywords: Barren Grassland; Land Development; Limiting Factors; Engineering Combination; Engineering Selection; Cultivated Land Reserve Resources

1. Introduction

Food is an important strategic resource for all nations globally. Achieving food security can be achieved, on one hand, by enhancing grain production capacity through the amelioration of arable land quality, and on the other, by expanding the agricultural land area via land development initiatives. This paper focuses on barren grasslands characterized by a canopy closure under 10%, a soil-dominated surface layer, and a predominance of herbaceous plant growth, with these grasslands notably absent of grazing activities [1]. Barren grasslands represent vast, untapped reserves of potential arable land within low-lying hilly regions. Typically constrained by one or more limiting factors, these lands can, however, be transformed into fertile cultivated fields through a series of engineered technical interventions. Grasslands deemed apt for agricultural conversion are those that meet the criteria for development under current economic and technological conditions. The process of land development is an intricate and multidimensional system that encompasses soil engineering, road construction, water management, along with various other factors, each exhibiting significant regional variations [2]. Currently, a limited comprehension of the conditions surrounding potential arable land reserves leads to a lack of specificity in the selection and design of engineering projects, resulting in diminished precision and practicability. With the diversity of grassland types and variability in land compositional elements, a scientific elucidation is imperative. This pursuit demands an exploration from the perspectives of theory, methodology, and instrumentation on how to adaptively engage with these lands and to unravel the engineering methodologies that can distill complexity into simplicity.

Land development is an important component of land consolidation [3]. Land development research has traditionally been a research hotspot for many scholars. Scholars will focus on land development suitability [4–6], land development benefit evaluation [7, 8], and environmental impact assessment [9–11]. Numerous countries, such as Japan, Germany, and Italy, have shown great importance to such land resources. The establishment of ICIMOD(International Centre for Integrated Mountain Development) has further expressed the concern of many scholars around the world [12–15]. Chinese scholar Yang Zhisheng pointed out in the National Symposium on the Development and Utilization of Land Resources and the Coordinated Development of Human and Land in China that land development in mountainous and hilly areas is bound to be an essential research direction for land scholars and land disciplines [16]. Over the years, numerous scholars have conducted extensive research on the development and utilization of undeveloped land from professional perspectives including ecological security [4, 5, 7], suitability assessment [7, 8, 11], reserve potential analysis [8, 10, 11], and potential zoning [7, 8]. Their significant academic achievements have established a theoretical foundation for land development initiatives. Land development activities are inherently limited by objective conditions such as local ecological environment protection requirements, resource distribution patterns, and territorial spatial planning regulations, resulting in distinct regional variations in engineering measures selection. While scholars have employed theoretical frameworks including environmental ethics, sustainable development theory, landscape ecology theory, and the theory of regional differentiation to advance the techniques and methodologies for land development project design, insufficient attention has been paid to suitability studies in project design and engineering layout [8–12]. Excessive land leveling practices involving massive excavation and filling operations have disrupted soil tillage layer structures, leading to frequent droughts and floods alongside severe soil erosion. Research suggests that improper site selection and engineering configuration not only result in inconsistent cultivated land quality but also cause high investment costs with low returns [2, 7, 8]. Furthermore, barren grassland maintains significant ecological value, and its irrational exploitation may induce irreversible ecological consequences [8, 10, 13]. The key issues that urgently need to be addressed at present are: developing region-specific land development engineering designs tailored to local resource endowments, optimizing planning and design frameworks, enhancing the rationality and operational feasibility of engineering designs, adopting location-appropriate approaches to maintain agricultural production system stability, and improving ecological quality in peri-urban areas [2–5, 7, 11]. These challenges necessitate systematic exploration to achieve balanced development between ecological preservation and land utilization efficiency. With the progress of land science and technology, the research on land engineering is gradually warming up. How to effectively develop the underutilized land resources and implement the project rationally will become an essential aspect for future scholars to explore.

Through land development, it can greatly improve the efficiency of land use, strengthen agricultural production capacity, and enhance agricultural economic benefits [17]. The engineering design of land development is a critical aspect of realizing tangible implementation intentions and represents a pivotal phase in the estimation and containment of project costs. The appropriateness of the project design in relation to the local environment crucially influences outcome efficacy and cost management. Discrepancies between the chosen engineering approach and the innate environmental conditions, along with excessive monetary outlays, can result in resource squandering and exacerbated ecological disturbances leading to potential ecological harm, soil erosion, and land degradation. These inefficiencies in land development challenge the prospects of sustainable utilization. In the era of fostering ecological civilization, it is a necessary to augment the role of land engineering technology in promoting the sustainable evolution of the ecological environment. Preceding the execution of development initiatives, it is essential to pinpoint the principal limiting factors impacting regional development. Subsequently, devising targeted measures to address each of these factors can significantly enhance the project's relevancy and success.

Land resource classification is the foundation and preliminary work for land resource investigation, evaluation, development, planning, and management. There are many methods for land classification, and due to differences in the purpose, basis, nature, and function of classification, different classification systems can be formed. One is the basic classification system, which treats land as a natural complex and classifies it based on its similarities and differences. The second is to apply a basic classification system, which considers land as a natural-socio-economic complex and selects the land attributes that are more closely related to specific purposes as the classification basis. The land attributes consider both the ecological attributes and the socio-economic attributes of the land. The third is the application of a classification system, which uses the direct representation of the relationship between land as a complex and production and utilization as the classification basis. The production department will directly apply the classification results obtained on this basis to fields such as land planning, land management, and land transformation. Therefore, based on the practical production needs and the characteristics of land development work, the classification method of analyzing the limiting factors of land agricultural development has high applicability. In land development work, the core content is to optimize terrain, soil, water conservancy, and transportation conditions based on agrarian production needs [3]. Therefore, terrain, soil, water conservancy, and production road engineering limiting factors should be identified as the main limiting factors for grassland agricultural development.

This paper investigates barren grasslands, selecting a mountainous region with a high agricultural presence and plentiful barren grassland resources for its study area. We devise a method for integrating regional limiting factors with diverse engineering types, offering an in-depth analysis of the obstacles to land development. Through a synthesis of regional attributes and these limiting factors, we determine suitable project types, combine them, and create a user-friendly quick reference table for project combinations. Building upon the current land development engineering technologies, this research aligns project choices with specific limiting factors to refine the applicability of engineering solutions. The outcome is a viable, straightforward system designed to guide the exploitation and management of barren grasslands while reducing their complexity. This work is pivotal for developing a theory of precise regional development and a working technological framework, furthering the advancement of scientific innovation and the meticulous development of land.

2. Materials and Methods

2.1. Study Design

Land development, a multifaceted and intricate systemic process, requires systematic and scientific vetting prior to the creation of regional land consolidation plans. This ensures the soundness of planning and project designs. Geographical environmental conditions heavily impact the selection of land development ventures, with divergent land types mandating distinct engineering and technical specifications. During planning and design stages, it is imperative to assimilate the land's specific context, crafting tailored strategies for varying circumstances following an exhaustive examination[18, 19].

The System Engineering Approach treats the land development system as a cohesive entity, stratifying it into distinct tiers to cater to macro-control and micro-management necessities. Simultaneously, clarify the relationship between layers and the relationship between the elements in the layer, so as to establish a complete, systematic and standardized system. This research delineates the procedure into three steps: "investigation and analysis—identification of limiting factors—selection of project types". In the analysis of limiting factors, this study categorizes land development constraints into factors related to mobility improvement and those pertaining to fixed improvement. The significance of each limiting factor is gauged in accordance with the "barrel principle", with explicit identification from aspects such as soil, topography, water resources, and agricultural infrastructure. Regarding the selection of engineering types, this research adopts a novel approach that melds land development engineering with technology aimed at mitigating limiting factors. It further clarifies a combination method for the selection of development engineering types, informed by both the distribution characteristics of the limitations and the engineering traits. The method for combining engineering types is introduced at two distinct scales: small-scale precision development and overarching macro-planning. Subsequently, a specific study area has been selected for a detailed case analysis (**Figure 1**).

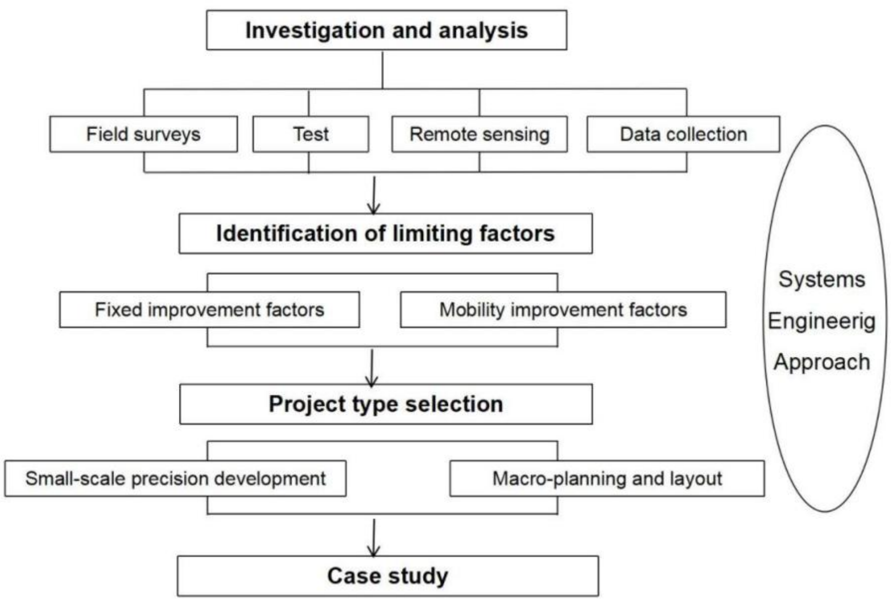

Figure 1. Technology roadmap.

2.2. Study Area

The study area is situated in Tang County, Hebei Province, China, which is one of the representative counties of Taihang Mountain (**Figure 2**). Located between 38°37′ 39°09′ north latitude and 114°27′ 115°03′ east longitude, the climate type is warm temperate continental monsoon climate. The average yearly precipitation is 539.2 mm, and the average yearly temperature is 12.1 °C. The frost-free period is 195 days. Tang County is a traditional agricultural county, and its agriculture mainly tends to focus on wheat and corn.The altitude of the study sample area is between 132–1012 m (**Figure 3**). The terrain is complex, and there are many micro-land forms. Predominantly, the landscape is adorned with low hills interspersed with occasional stretches of flat terrain and pockets of inland beaches. The Tang River meanders through the region, serving as a perennial source of high-quality water suitable for both irrigation and consumption. The soil is primarily categorised as cinnamon soil, known for its friable texture and conducive to cultivation. The region's agronomy is highly adaptable, rendering the majority of the area apt for cultivating a plethora of crops. In mountainous and hilly terrains, slope stands as a pivotal determinant in land development. Lands with hills >25° are highly likely to cause soil erosion, which can easily cause severe water and soil loss, and their development will face high ecological risks [20]. The development funds are enormous, and the engineering measures are complicated. Based on the consideration of environmental risk and development benefit, the "one-vote veto system" is adopted for barren grassland with a slope of >25°, which is not regarded as the research object. The barren grassland area of the research object was 5,074.70 hm^2.

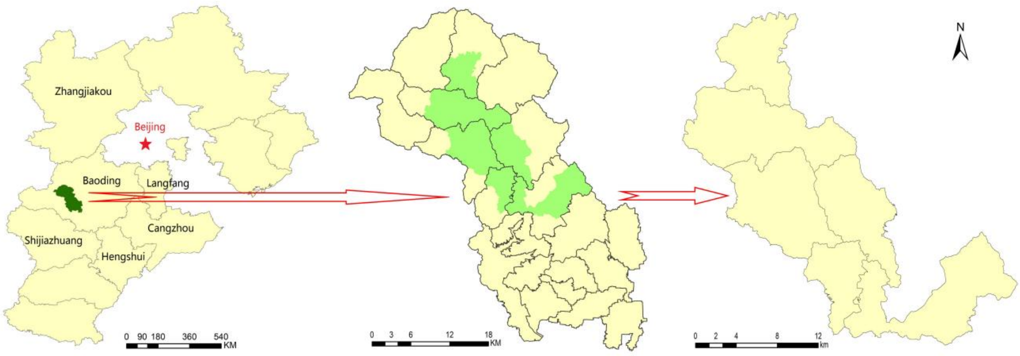

Figure 2. Location of the study area. The red star represents the location of the Chinese government; the arrow indicates an enlarged display of the research area.

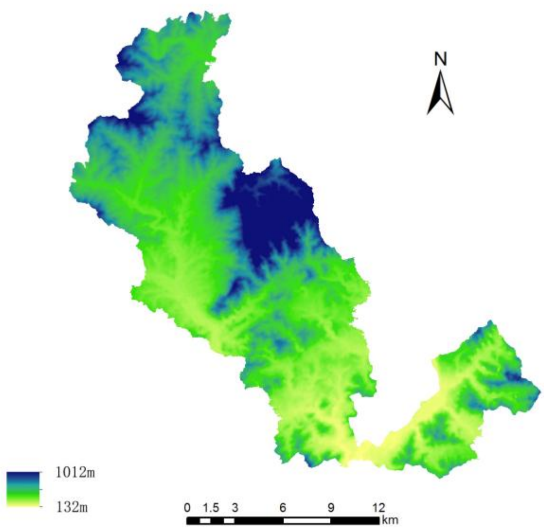

Figure 3. DEM data of the study area.

2.3. Data Sources

- Field survey data

The data is divided into two parts. Firstly, the survey of natural elements and surrounding resources and environment is carried out by laying out representative samples, including soil thickness, topsoil texture, rock outcrop, soil source distance, soil source type, soil parent material, bedrock characteristics, etc. Secondly, by visiting the people and consulting project leaders, they obtained information on some water resources, engineering conditions, and construction characteristics. Sample layouts are meticulously distributed to ensure consistency across the territory, accounting for variations in soil types and surface properties. To improve the accuracy of survey index information, more sample points are arranged in the regions and transition zones where remote sensing images have noticeable changes [21]. For the layout of sample points, please refer to reference [22].

- Test data

We collected the soil sample from typical sampling sites, and the organic matter content of each sample was measured indoors.

- Remote sensing data

Tang County elevation and slope data were obtained from the GDEMDEM 30M resolution DEM remote sensing image downloaded from the Geospatial Data Cloud (http://www.gscloud.cn/). The data identification is: ASTGTM_N38E114, ASTGTM_N38E115, ASTGTM_N39E114.

- Text data

It mainly includes the Tang County Land Use Master Plan, the administrative division map, the Tang County Land Survey Update Data , the Tang County Forestry Plan, and the Tang County 1:250000 soil map. Provided by Tang County Land and Resources Bureau.

2.4. Analysis of Land Development Limiting Factors

2.4.1. Combination Compilation Method of Limiting Factors

The dominant factor is one or more factors that play a vital role in the formation or development of things [23]. In barren grasslands, the limiting factor serves as the dominant determinant, critically influencing the potential for growth and utilization. This concept of a "limiting factor" is synonymous with the "dominant factor". It is the interplay of these limiting factors that establishes the foundation of an engineering combination system. This dynamic not only mirrors the backdrop of barren grasslands but also impacts the choice of engineering strategies and their integration. This paper adopts a Building Block construction system, which divides the factor types into mobility improvement factors and fixed improvement factors. Mobility improvement factors pertain to specific elements that exert a limiting influence only in certain regions, attributable to the distinctions in regional characteristics, necessitating selective enhancement based on local attributes. Conversely, fixed improvement factors encompass those that must be consistently regarded throughout the course of development (**Table 1**).

To visually express factor scores, this paper uses a numeric code to represent the scores of different factors. First of all, the scores of each factor (10–100 points) are respectively represented by the 10 codes of "1 to 9" and "+", and then are represented by the codes in accordance with the order of the factors. The corresponding codes are arranged successively according to the order of factors so that the compilation method can intuitively reflect the status of each element.

Table 1. Explanation of fixed improvement factors and mobility improvement factors.

Types	Factors	Explanation
Fixed improvement factors	Water source condition, drain condition, Road conditions ...	The barren grassland in mountainous areas does not have irrigation, drainage conditions and convenient traffic conditions, so it is necessary to consider eliminating the restrictions of water source conditions, drainage conditions and road conditions on agricultural utilization when carrying out engineering design, so water source conditions, drainage conditions and road conditions are fixed improvement factors.
Mobility improvement factors	Soil thickness, rock outcrop , topsoil texture, organic matter content, terrain slope ...	Specific to a certain plot, its soil thickness, rock outcrop, soil texture, nutrient content, terrain slope and other conditions are different, need to match the corresponding project according to the specific situation.

2.4.2. Analysis of Limiting Factors

The study focuses on a mountainous area, thoroughly examining the limiting factors that impede the development of barren grassland. It defines the vital elements within these constraining factors based on the unique traits of different areas. This paper selects development limiting factors from two aspects of natural conditions and development conditions, involving soil, topography, water resources, and farmland facilities. Specific indicators are determined through field investigation, expert discussion or reference to relevant materials [19, 24].

The limiting degree of factors is ascertained utilizing the Barrel Principle. We establish local factor combination types through the delineation of regional fixed and mobility improvement factors. Before defining the mobility improvement factor, it is critical to establish a clear boundary and degree of restriction for the limiting factors, categorizing them sequentially as the primary and secondary limiting factors. The level of restriction is contingent upon the extent to which it impedes the transformation of barren grassland into arable land. This study innovates by employing a factor score code combination, superseding the traditional factor code combination commonly used by scholars. The factor with the lowest score is designated as the upper limit factor, with subsequent factors being analogously identified as the common limit factor and the lower limit factor [25, 26]. When the factor score is 50 or less, it will have a significant restriction on the development of barren grassland that are suitable for cultivation [27, 28], and the project has to be implemented for transformation. For example, when the thickness of the soil layer is 0–30 cm, the score is 10, and it is necessary to combine the soil source conditions to increase the guest soil or carry out deep plowing. This article identifies factors with scores of 50 and below as high limiting factors [27]. Under the excellent conditions of soil thickness more exceptional than 150 cm, shallow groundwater depth, and surface texture of medium soil, there is no limit to the development and utilization, and the score is 90–100 points. A score of 100 does not mean that there is no limit, but the applicable threshold is low, so this factor is defined as a minor limit factor. The element with a score of 60–80 is set as a common limiting factor. Depending on the characteristics of different regions, high and medium limiting factors are selected as improved areas for improvement of mobility. Expand to other land types or areas, and then adjust the corresponding scores and elements according to the actual situation.

2.5. Project Type Selection

2.5.1. Engineering Type Combination Preparation Method

When selecting types of development projects, it is essential to consider both the project's intrinsic qualities and the regional characteristics, encompassing environmental and economic factors. Concurrently, emphasis should be placed on regional ecological environmental security, as well as economic and technical viability. Preference should be given to the utilization of proven technologies, while the introduction of new technologies ought to be approached with prudence.

A combination of engineering types refers to a collection of different engineering types, with numeric codes representing different engineering types. It is propounded that mobility enhancement initiatives should incorporate a "no need" selection, a feature absent in stationary improvement projects. The degree of engineering type transformation will be affected by the input level, so it is necessary to distinguish different input levels. The letter M (Medium level) represents the general input level, which refers to the current input level of barren grassland development in the region. The letter H (High level) represents the high input level, which refers to the development process and the total input level of further improving the general quality level of cultivated land in the future. In this paper, the input level that can now meet the acceptance criteria [29] is set as the general input level (M), and the input level of future technological development and overall improvement of cultivated land quality is high-level input (H). This paper takes the general input level as an example. The engineering type is divided into a mobile improvement project and a fixed improvement project. The mobility improvement project is indicated by "A", and the fixed improvement project is meant by "B". The preparation method is "input level + mobility improvement engineering and engineering code + fixed improvement engineering and engineering code". For example, a development project adopts the engineering type numbered "2" in the mobility improvement project, and the engineering type numbered "4" in the fixed improvement project. Both are implemented under the general input level, and the code is "MA2B4". The order of sub-projects is the same as the order of engineering in the project type quick lookup table. The final engineering combination type is represented according to the code combination of the selected project, such as "MA332B11". If two or more sub-projects appear, they are represented by "( )", such as "MA3(13)2B11", which can simplify complex systems.

2.5.2. Project Type Analysis

The engineering suitability characteristic analysis involves examining and computing the most appropriate engineering type through a simplified selection process. This method minimizes the impact of economic factors by adhering to the applicable technical scope prescribed by the relevant regulations and standards, thereby determining the engineering category [30].

In mountainous areas, the factors enhancing joint mobility primarily include slope gradient, soil depth, and topsoil texture. The static factors contributing to this improvement are chiefly the conditions of drainage, irrigation systems, and road infrastructure. Through investigation and synthesis of typical project planning and design, project budget, engineering effect evaluation, and other data, the sub-project types, project suitability scope, project implementation level effects, etc., the soil improvement, irrigation drainage, road construction, and slope-changing ladders are clarified. Barren grassland development projects in mountainous areas can be generally divided into several project types as follows, such as soil improvement projects (including soil thickening projects, topsoil quality improvement projects, etc.), irrigation and drainage projects (mainly irrigation projects, drainage projects), road engineering and slope modification. The ladder project comprises four critical components, with each major issue being further segmented into various smaller segments according to distinct objectives and characteristics [31].

Soil improvement engineering may be further selected based on multiple dimensions including soil layer thickness, profile configuration, topsoil texture, organic matter content, and bedrock outcrop degree. The effective soil layer thickening engineering employs methodologies such as soil replacement, deep loosening, or blasting techniques, contingent upon the bedrock type beneath the effective soil layer, its friability, as well as external conditions encompassing soil source availability and transportation distance. During soil replacement and deep loosening processes, soil texture modifications inevitably occur, necessitating the concurrent implementation of topsoil texture enhancement engineering with layer thickening operations. Bedrock outcrop elimination primarily utilizes blasting and selective removal techniques. Technologies for organic matter enhancement predominantly involve organic fertilizer application, straw returning, and green manure cultivation.

Slope-to-Terrace Conversion Engineering refers to the practice of transforming sloped land into terraced fields. The selection of terrace types must integrate regional slope gradients and soil layer thickness characteristics, with primary classifications including horizontal terraces, interval-slope terraces, slope-style terraces, and reverse-slope terraces. Terrace construction involves the strategic selection of embankment types, predominantly categorized as earth embankments, stone embankments, and biological embankments. This process necessitates a holistic evaluation of soil and water conservation requirements, slope stability, and local material availability to optimize the advantages of distinct embankment configurations. For instance, stone embankments exhibit superior stability and enhanced water-soil retention performance, yet their economic feasibility diminishes in regions with limited stone resources. Conversely, earth embankments, while inherently less stable, can achieve comparable water and nutrient retention when integrated with biological embankments. This integrated approach underscores the importance of adaptive design aligned with localized geotechnical and ecological conditions.

Irrigation Engineering Water sources for irrigation systems primarily consist of surface water and groundwater. Corresponding to these divergent water sources, distinct water abstraction methodologies are employed, categorized into diversion systems, well-pump systems, and storage-based systems. Implementation requires a holistic analysis of regional water resource supply-demand dynamics, coupled with contextual factors (e.g., development objectives, policy frameworks, and technological capacities) to determine optimal water source selection and abstraction strategies. Drainage Engineering is jointly governed by topographic conditions and available hydraulic infrastructure. Drainage methodologies are broadly classified into natural drainage and pumped drainage. Pumped drainage is preferentially applied in areas prone to waterlogging, while natural drainage is utilized in other contexts to align with environmental and economic feasibility.

Road engineering in agricultural contexts comprises field roads and production roads. Field roads, serving as connectors between residential areas and cultivated lands, facilitate farmer mobility and agricultural machinery transportation. In mountainous terrains where terraced fields dominate, road design must be adapted to slope gradients. Field roads are primarily classified into newly constructed field roads and rehabilitated field roads, with construction materials predominantly including cement concrete and gravel. Production roads, functioning as inter-plot connectors to support farming operations, typically employ earth or gravel as surface materials. Material selection is contingent upon regional availability and the engineering characteristics of local resources.

3. Results

3.1. Development of Limiting Factors and Combination

3.1.1. Limiting Factors

According to the characteristics of the natural conditions of the study area, after field investigation and expert discussion, 8 indicators including soil thickness, rock outcrop, topsoil texture, organic matter content, slope, irrigation conditions (water source conditions), drainage conditions (water collection conditions), and road conditions were selected. According to the characteristics, it is divided into mobility improvement factors and fixed improvement factors, and the factor score standards are formulated (**Table 2**). Because barren grassland has no irrigation and drainage facilities before development, the water source conditions and water collection conditions characterized barren grassland [32].

Table 2. Types of influence factors and score criteria.

Limit Factor Type	Mobility Improvement Factor					Fixed Improvement Factor		
Factor Score	**Soil Thickness (cm)**	**Rock Outcrop (%)**	**Topsoil Texture**	**Organic Matter Content(%)**	**Terrain Slope (o)**	**Water Source Condition**	**Drain Condition**	**Road Conditions (Distance from Barren Grassland) (m)**
100	≥150	≤2	Middle soil, heavy soil		≤2	Fully satisfied	Excellent	0–100
90	100–150	2–10			2–5			
80			Light soil, clay	≥2.0		Basic satisfaction	Good	
70	60–100	10–25		1.5–2.0	5–8			100–200
60			Sandy soil	1.0–1.5		Generally satisfied	General	
50			Sand		8–15			
40	30–60	≥25		0.6–1.0				200–500
30			Gravel soil		15–25			
20				<0.6		Shortage	Bad	
10	<30							>500

Note: Water source conditions—I. Fully satisfied: Groundwater depth is 0–100 m; surface water is abundant; 0–500 m from a surface water source; there is no mining limit for groundwater or surface water. II. Basic satisfaction: Groundwater depth is 100–200 m; there is certain surface water; 500–1000 m from surface water source; there is no limit to groundwater or surface water exploitation. III. Overall satisfaction: Groundwater depth is more than 200 m; surface water is relatively small and 1000–2000 m away from a surface water source; groundwater or surface water has mining restrictions. IV. Shortage: Groundwater depth of more than 200 m; no surface water or more than 2000 m; groundwater or surface water has mining restrictions.
Drainage conditions—I. Excellent: Do not cause flooding all year round do not accumulate water, only need simple improvement. II. Good: seasonal flood or seasonal water supply, can be enhanced by flood control and drainage measures. III. General: Floods or long-term water accumulation all year round, need to be improved by more complicated flood control and drainage measures. IV. Wrong: frequent flood threats or prolonged flooding, poor drainage conditions, and difficulty in improvement.

3.1.2. Development of Limiting Factors Combination

Eight critical factors were identified to evaluate the barren grassland within the sampling area of this study: soil thickness, rock outcrop, topsoil texture, organic matter content, topographic slope, water source conditions, drainage conditions, and road conditions. Among them, water source conditions, drainage conditions and road conditions are three fixed improvement factors. The distribution of factors in barren grassland in the study sampling area is shown in **Figure 4**.

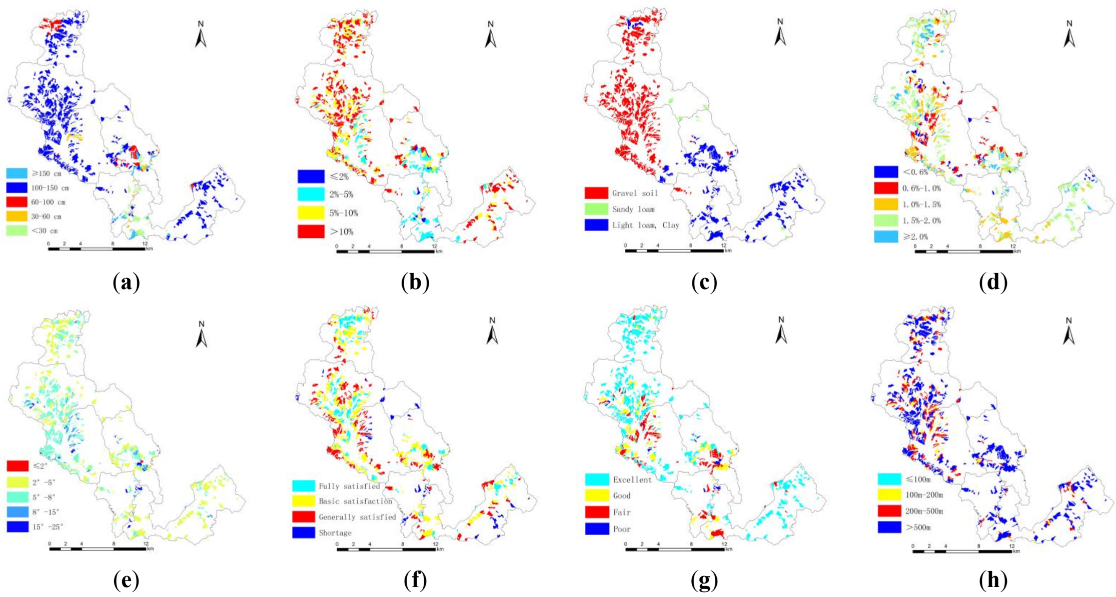

Figure 4. Distribution of the limiting factors of the sample area: (**a**) soil thickness; (**b**) rock outcrop; (**c**)topsoil texture; (**d**) soil organic matter content; (**e**) slope; (**f**) water source condition; (**g**) drainage condition; and (**h**) road conditions.

Combined with the distribution of factor scores and the characteristics of the study area, the high-limit areas of soil mobility improvement factors, such as soil thickness, rock outcrop, topsoil texture, and organic matter content, were used as the critical areas for factor improvement. The slope is a major limiting factor for barren grassland development, and it also affects regional ecological security to a large extent. Accordingly, zones with high and medium slope limitations are targeted as crucial areas for slope amelioration. The manuscript describes how elements promoting mobility and static improvement factors are synthesized according to the sequence delineated in the factor table, culminating in a composite framework of environmental improvement factors (**Table 3** and **Figure 5**). According to the sequence and score of eight indexes of "soil layer thickness, rock outcrop, topsoil texture, organic matter content, terrain slope, water source condition, drain condition and road conditions", the status of limiting factors in the development of a certain plot is represented.

Table 3. Types of limiting factors improvement.

Figure Spot Number	Factor Combination Type	Mobility Improvement Factor	Fixed Improvement Factor	Factor Improvement Area
1	143638+4	Soil thickness + rock outcrop + topsoil texture + slope	Irrigation + drainage + road	Soil thickness + rock outcrop + topsoil texture + slope + irrigation + drainage + road
2	143468+7	Soil thickness + rock outcrop + topsoil texture + organic matter + slope	Irrigation + drainage + road	Soil thickness + rock outcrop + topsoil texture + organic matter + slope + irrigation + drainage + road
3	173656+4	Soil thickness + soil thickness + slope	Irrigation + drainage + road	Soil thickness + soil thickness + slope + irrigation + drainage + road
…	…	…	…	…
1442	17379+27	Soil thickness + topsoil texture	Irrigation + drainage + road	Soil thickness + topsoil texture + irrigation + drainage + road
1443	146432+4	Soil thickness + rock outcrop + organic matter + slope	Irrigation + drainage + road	Soil thickness + rock outcrop + organic matter + slope + irrigation + drainage + road

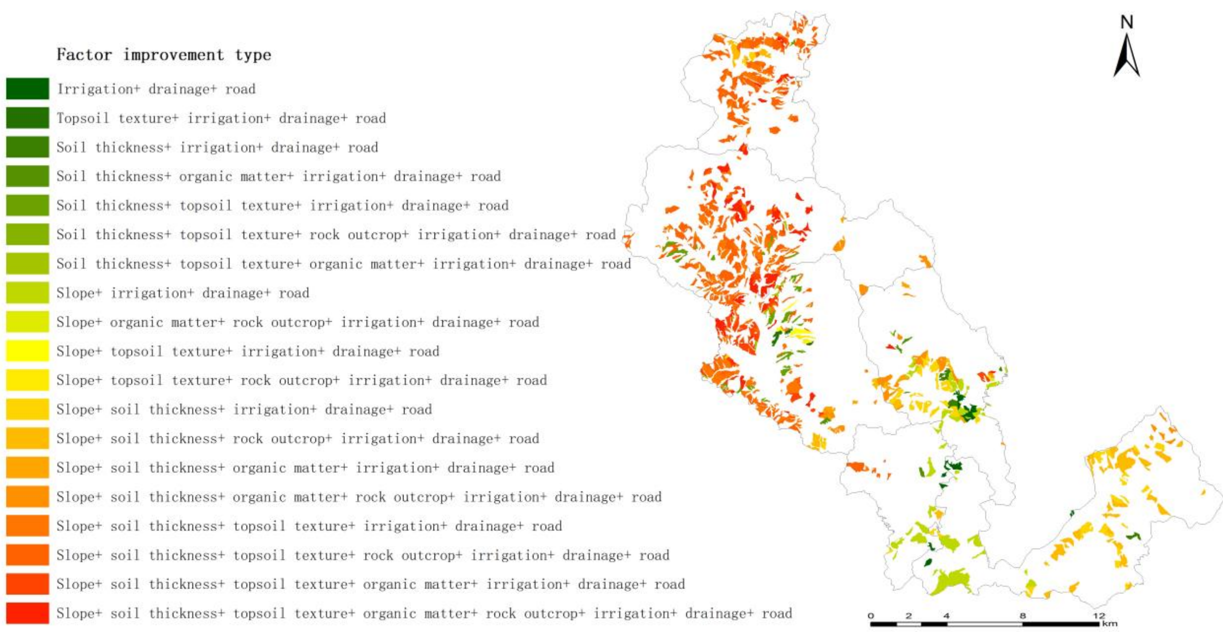

Figure 5. Factor improvement type distribution.

The factor combination type table serves multiple purposes: it facilitates a comprehensive review of the status of barren grassland elements within the region, streamlines the naming of types and identification of improvement factors, and narrows the scope for selecting relevant engineering approaches. This focused approach consequently provides guidance for defining subsequent choices in engineering selection and combination strategies. Among the research factors for improving the mobility of the sample area, the slope area improved the largest area, which was 4943.02 hm^2, accounting for 97.41% of the area of the study area, followed by the thickness of the soil layer, and the proportion was as high as 84.56%. Combining the eight limiting factors, the combination of factors was obtained, and there were 19 improved areas in the study area.

Among them, “slope + soil thickness + topsoil texture + rock outcrop + irrigation conditions + drainage conditions + road conditions” has the largest area of improvement, which is 1280.32 hm^2. The smallest area is the improvement zone of “soil thickness + topsoil texture + rock outcrop + irrigation conditions + drainage conditions + road conditions”, which is 4.05 hm^2. It can be seen from the figure that the northern and southern regions of the study area are relatively complex, and the soil thickness and rock outcrop are the main types of mobility improvement. In contrast, the central region is characterized by a relatively thick soil layer, where the primary mobility improvement factors are mainly topsoil texture and slope. These factors are widely distributed across the study area and represent the most significant constraints within the region.

3.2. Project Type Combination

This study meticulously analyzes the characteristics of barren grassland development types, obtaining and meticulously mapping the applicable scopes, conditions, sub-types, and transformation degrees of various engineering types. These insights are cohesively compiled into an intuitive quick-reference guide for development engineering typologies. For the scope of application and the type of project, the project content can be expanded or reduced according to the difference between different regions and different projects.

In order to guide the small-scale precision development, this study subdivided the four engineering types into the following 11 project types, that is, soil thickening project, rock outcrop finishing project, topsoil texture engineering, organic matter improvement, terrace type, type of field ridge, irrigation water intake project, drainage engineering, field road engineering, production road engineering and road shape (**Table 4**). The scope, selection, and degree of reconstruction of barren grassland development projects in Tang County will be sorted out and summarized, and a quick look-up table for the formation of engineering types will be prepared. There are numerous types of engineering in the study area, and the kinds of engineering types are diverse. Through the engineering type quick check table (which can be expanded or reduced), it is convenient to find the engineering types suitable for different regional characteristics and guide the precise development of the area.

Table 4. Engineering type quick reference table.

Project Type	Engineering Property	Project Property Scope	Subproject Type	Code
Soil thickening project	A	Limestone area, soil source distance <3 km, soil layer thickness <50 cm	Guest soil	1
		In the gneiss area, the soil source distance is >3 km, and the soil layer thickness is 30 < X < 50 cm.	Deep pine	2
		Soil thickness < 30, slope <15°	Full explosion + deep pine	3
		Soil thickness < 30, slope 15° < X < 15°	Slope blasting + deep pine	4
		Soil thickness > 50 cm	No need	5
Rock outcrop finishing project	A	Limestone area, rock outcrop >10%, slope <25	Blasting + culling	1
		In the gneiss area, the rock outcrop is >10%	Deep pine + picking	2
		Rock outcrop <10%	No need	3
Topsoil texture engineering	A	The topsoil texture is gravel soil or sand and the soil source distance is <3 km.	Guest soil	1
		In the gneiss area, the topsoil texture is gravel soil or sand, and the soil source distance is >3 km.	Deep plowing + gravel removal	2
		The topsoil texture is gravel soil or sands, and it is impossible to use mechanical soil and guest soil.	Biochemical improvement of organic fertilizer/soil structure improver	3
		Topsoil texture is non-gravel soil and sand	No need	4

Table 4. *Cont.*

Project Type	Engineering Property	Project Property Scope	Subproject Type	Code
Organic improvement	A	Ecological matter content X < 0.6%	Mainly organic fertilizer, supplemented by straw returning and planting green manure	1
		Organic matter content 0.6% < X < 1.0%	Mainly organic fertilizer, supplemented by straw returning and planting green manure	
		Organic matter content >1.0%	No need	2
Terrace type	A	Slope < 10°, final soil thickness >50 cm	Horizontal terrace	1
		Slope < 15°, final soil thickness >30 cm	Sloping terrace	2
		Slope 15° < X < 25°	Slope terrace	3
		Slope < 5°	No need	4
Type of field ridge	A	Gneiss and loess areas, horizontal terraces and sloping terraces	Ridge	1
		Slope terrace	Ridge + biometric	2
		Limestone area	Stone ridge	3
		Gneiss and loess areas, soily sandy loam	Ridge + stone ridge	4
		Do not build terraces	No need	5
Irrigation engineering	B	Within 800 m from Tanghe	Water diversion project	1
		Groundwater depth < 20 m away from 800 m away from Tang River	Big well project	2
		800 m away from the Tang River, the groundwater depth is 20 m < X < 200 m	Well engineering	3
		Groundwater depth >200 m away from Tang River 800 m	Water storage project	4
Drainage works	B	Slope > 10°, poor water collection capacity	Concrete trench self-discharge	1
		Limestone area, poor water collection capacity	Block gravel self-discharge	2
		Gneiss and loess areas, poor water collection capacity	Ditch self-discharge	3
		Large catchment area in low-lying areas	Ditch/stone ditch	4
Field type	B	Barren grassland are far from the original field road and are not connected	New study	1
		Barren grassland are close to each other and connected to the original field road	Renovation	2
Production road material	B	Gneiss, loess area	Plain soil	1
		Limestone	Sandstone	2
Road shape	B	Slope < 3°	Flat road	1
		Slope 3° < X < 10°	Slanted	2
		Slope > 10°	Zigzag, S shape	3

For effective macro-scale planning and layout, it is imperative to delineate the main project types within a region. To facilitate macro-directional guidance and practical application, this study builds upon pre-existing engineering classifications. Taking into account the primary limiting features of the study area and the potential effects on newly cultivated land, we have selected and amalgamated five key types: terraced fields, soil layer thickening, topsoil texturing, irrigation techniques, and drainage systems (**Table 5**).

Table 5. Project type code table.

Terrace Type	Engineering Attribute A					Engineering Property B			
	Code	Soil Thickening Project	Code	Topsoil Texture Engineering	Code	Irrigation Engineering	Code	Drainage Method	Code
Horizontal terrace	1	Guest soil	1	Guest soil	1	Water diversion project	1	Concrete self-discharge	1
Sloping terrace	2	Blasting + deep pine	2	Deep plowing	2	Well irrigation project	2	Ditch self-discharge	2
Slope terrace	3	No need	3	No need	3			other	3
No need	4								

The study sample area contains a total of 62 types of engineering types, with a total area of more than 100 hm^2 for a single type and 14 combinations. Firstly, the total area is 3994.40 hm^2, accounting for 78.71% of the barren grassland area in the plot area, of which the largest area is "MA232B11" is 547.04 hm^2 which accounting for 10.78% of the total grassland area; secondly, the combined "MA332B11" area is 444.69 hm^2 which accounting for 8.76% of the total area. The combined area and distribution of the 14 major engineering types are shown in **Figure 6**.

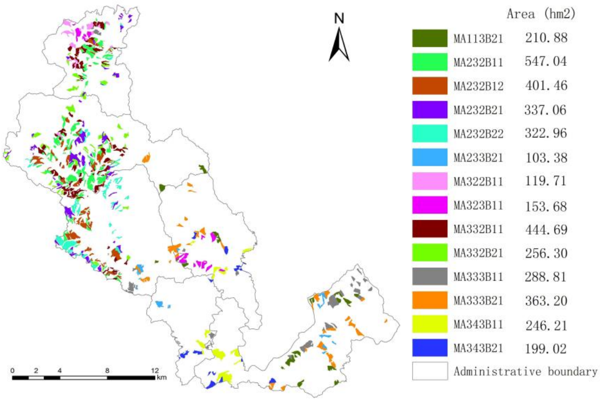

Figure 6. Engineering type combination distribution.

4. Discussion

The goals of land development are diverse[33]. While pursuing economic benefits, attention should also be paid to viewing the entire development project as a complete whole, considering the development and use value of land from multiple aspects. In specific development work, not only should quantity be considered, but also quality and ecological aspects should be ensured[34]. In the future development, we can first test different regions and different lands, analyze the effects of different land development projects, and formulate targeted and operational programs according to the characteristics of different regions[35].

Innovation in land science and technology centers on the technological advancement of land engineering. By conducting research to identify land development limiting factors and to inform engineering selection, it directly aligns with the strategic approaches toward land science and technology innovation. This focus is crucial for the reinforcement of ecological civilization construction[4]. The undulating terrains of low hills are abundant with barren grassland resources; these regions also exhibit a notable aggregation of poverty. Illustratively, within China's Hebei Province, 25 poverty-stricken counties are nestled in the Yanshan-Taihang mountainous zone. The agricultural land reclaimed from barren grasslands in these modestly mountainous districts holds the potential to generate substantial local profits, thereby aiding in poverty alleviation and furthering rural revitalization efforts[36, 37].

Generally, research on land development, both domestically and internationally, predominantly concentrates on its interplay with agriculture, rural growth, infrastructure, and other production-related conditions. Substantial work has been conducted on models of land development and consolidation as well as the assessment of their attendant benefits[38–40]. With the development, while considering economic factors, land development progressively amalgamates the principles of ecological environmental protection. This integration has introduced new objectives and requirements for the advancement of land development strategies[35, 41]. This study strives to enhance capital efficiency and minimize environmental disruption and damage wrought by land development projects, while aligning such endeavors with local circumstances. Many studies concentrate on enhancing a specific factor without integrating it into a comprehensive land development engineering system aimed at improving arable land quality in multiple aspects. The absence of systematic technical selection and integration tailored to regional land constraints poses significant technological barriers in the design of practical land development projects. Traditional engineering matching primarily relies on experience, often with insufficient preliminary planning, leading to challenges in achieving optimal land development and utilization outcomes in subsequent stages[3, 7, 8, 28]. This study presents a comprehensive analysis for project selection by establishing an index evaluation system and assessing engineering suitability. The selection of indicators and engineering categories is specifically tailored to the attributes and engineering features of the mountainous area terrain, providing a foundation for the future construction of an engineering combination system. This approach, along with its methodologies and conceptual framework, holds the potential for application to other types of land.This study presents a comprehensive analysis for project selection by establishing an index evaluation system and assessing engineering suitability. The selection of indicators and engineering categories is specifically tailored to the attributes and engineering features of the mountainous area terrain, providing a foundation for the future construction of an engineering combination system. This approach, along with its methodologies and conceptual framework, holds the potential for application to other types of land. The "engineering type combination method" incorporates the concept of factor combination into the selection of engineering types, based on the investigation and analysis of engineering characteristics and resource conditions. This approach facilitates the rapid and straightforward establishment of a grassland development engineering combination system, offering valuable insights for engineering design and implementation. This paper delineates explicit criteria and foundational protocols for preliminary activities and operational phases, encompassing special land development planning, project selection, engineering design, and budget estimation. Nevertheless, further research pathways remain to be explored, offering direction for future investigations.

In recent years, with the development and widespread application of modern high-tech technologies such as "3S" technology, rapid progress has been made in land development, gradually shifting from a singular approach to a comprehensive development encompassing "quantity, quality, and ecology". To achieve scientific and rational development and utilization of barren grassland, it is imperative to conduct a thorough investigation of the characteristics of barren grassland, provide suitable development directions based on this, match appropriate engineering types, improve the pertinence of engineering technology, avoid ineffective land disturbance and engineering investment, and form a development theory and work technology system suitable for the actual situation of the region, and avoid ecological risks from project planning[10, 22, 34, 39]. This has gradually become particularly important.

While this study has contributed to the precision alignment of agricultural land development engineering, certain limitations persist, and multiple research directions warrant further investigation.

1. In the application of factor combinations, it is possible to simplify complex problems, consequently reducing repetitive tasks. As the number of factors grows, the variety of combinations also increases. Thus, there remains a plethora of aspects to be investigated. Future research should focus on extracting key combinations, discerning the inherent relationships among them, and devising novel methods and expressions for these combinations.In addition, the relationship between different limiting factors should be more thoroughly explored, which can provide a good support for the promotion and application of research framework and results and simulation prediction.
2. This study focuses on project selection yet acknowledges a gap in evaluating post-implementation effects. Considering a constant limiting factor, diverse projects may yield different outcomes, thereby necessitating on-the-spot investigation and thorough inquiry into particular land development endeavors. Advancing land project development stands as a critical technological subject for future research.
3. This paper focuses on the theoretical exploration of engineering matching utilizing survey data and system engineering methodologies, without incorporating practical validation. Future work should seek to implement these findings in case study scenarios and integrate benefit analysis into case studies to substantiate the value and efficacy of the results.

5. Conclusions

Focusing on the targeted development of agricultural land and using barren grasslands as the subject, this study establishes a methodology for identifying limiting factors in land development and constructing a combination system for barren grassland development projects. It offers a simplified approach for classifying these limiting factors and selecting and combining development projects. A case study of barren grassland in Tang County was carried out.

- Based on the investigation of barren grassland, this paper devised a selection protocol for limiting factors and synthesized the primary constraints to barren grassland development. It elucidates the shared and distinctive factors of barren grassland, categorizing them into static and dynamic improvement factors. Drawing on the fundamental precepts of the analogy method, a typology of restrictive factor combinations has been established, leading to the formation of a classification scheme for improvement factors.

- According to the combination of limiting factors, this study proposes selection principles and criteria for determining the engineering type. Upon establishing a specified input level, an engineering type is discerned. Subsequently, a tailored combination for the chosen engineering type is developed, accompanied by the creation of a quick-reference chart and a coding system for expedited verification.
- In Tang County, a typical sample area was selected to analyze barren grassland. We pinpointed factors that could enhance the mobility of the terrain, including soil thickness, slope, rock exposure, topsoil texture, and soil organic matter content. Other factors, such as irrigation, drainage, and accessibility via roads, were considered as constant ameliorative parameters, culminating in 19 derived areas of improvement factors. To facilitate precise land development strategies, we organized a comprehensive quick-reference guide for the selection and conversion processes pertinent to barren grassland development projects in Tang County. This groundwork yielded 14 principal combination types, integrating crucial aspects such as choice of terracing methods, soil amendment projects, topsoil management, irrigation techniques, and drainage implementations.

Author Contributions

Conceptualization, Z.C. and Y.Z.; methodology, Z.C. and X.Z.; software, B.S.; validation, Y.C., B.S.; formal analysis, X.Z.; investigation, Z.C., Y.Z. and X.Z.; resources, Y.C.; data curation, Z.C. and Y.C.; writing—original draft preparation, Z.C.; writing—review and editing, X.Z.; visualization, B.S.; supervision, Y.C.; project administration, Z.C.; funding acquisition, Z.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

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Conflicts of Interest

The authors declare no conflict of interest.

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