frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 23 September 2025
DOI 10.3389/fsufs.2025.1501090

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Zhengzhou University, China
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Indira Gandhi Krishi Vishwavidyalaya, India

*CORRESPONDENCE
ShiChao Zhang
✉ lintualchao@126.com

RECEIVED 24 September 2024
ACCEPTED 27 August 2025
PUBLISHED 23 September 2025

CITATION
Zhang S, Zhang X, Zhang X and Lu Z (2025) Measuring and achieving moderate-scale operation of new agricultural business entities in hilly and mountainous areas: an empirical study on citrus, pepper, and grain farming in Chongqing's Jiangjin Modern Agricultural Park, China.
Front. Sustain. Food Syst. 9:1501090.
doi: 10.3389/fsufs.2025.1501090

Measuring and achieving moderate-scale operation of new agricultural business entities in hilly and mountainous areas: an empirical study on citrus, pepper, and grain farming in Chongqing's Jiangjin Modern Agricultural Park, China

ShiChao Zhang[1,2]*, Xiang Zhang[1], XuanYun Zhang[1] and ZhangYe Lu[1]

[1]Chongqing Key Laboratory of Surface Process and Ecological Restoration in the Three Gorges Reservoir Area, Chongqing Normal University, Chongqing, China, [2]Chongqing Field Observation and Research Station of Surface Ecological Process in the Three Gorges Reservoir Area, Chongqing, China

Moderate-scale agricultural operations are central to improving the quality and efficiency of modern regional agriculture and advancing agricultural modernization. It is particularly crucial for addressing persistent challenges, such as land fragmentation, low mechanization efficiency, and population aging, in hilly and mountainous areas. This study estimates the moderate operating scale for new agricultural business entities (NABEs) across various crop types and investigates strategies to achieve such scale. Drawing on data from 277 NABEs engaged in citrus, pepper, and grain farming in Chongqing's Jiangjin Modern Agricultural Park, we employ a translog production function to determine moderate-scale thresholds and a structural equation model (SEM) to examine both internal and external pathways toward achieving these thresholds. The findings show that the average moderate scale per labor for citrus, pepper, and grain farming is 2.55 hm^2, 2.67 hm^2, and 1.72 hm^2, respectively. Among the three, 13.33% of pepper-farming NABEs (16 households) reach the moderate scale, which has the highest share, while only 2.04% of grain-farming NABEs (one household) do so, representing the lowest share. Most NABEs operate either below or above the moderate scale. For NABEs exceeding the moderate scale, internal pathways are key (improving effective labor, adjusting business models, and investing in fixed assets and liquidity). For those below, external pathways matter (expanding their farming scale under suitable conditions). Specifically, citrus-farming NABEs should prioritize villages with higher per capita arable land and improved land conditions, while pepper- and grain-farming NABEs should focus on areas with higher per capita income and proximity to residential settlements. This study offers practical guidance for NABEs of different crops in hilly and mountainous areas to achieve moderate-scale operations through appropriate pathways, contributing to sustainable and efficient agricultural development in these regions.

KEYWORDS

land management, hilly and mountainous areas, new agricultural business entities, moderate-scale operations, internal and external pathways

1 Introduction

China's agriculture has long been dominated by smallholder farming, with fragmented, small-scale operations particularly common in hilly and mountainous areas, where topographical constraints intensify the challenges of scaling up. As a critical strategy in advancing agricultural modernization, moderate-scale agricultural operations integrate farmland consolidation, innovative management models, and optimized resource allocation (Gai et al., 2022; Gailhard and Bojnec, 2015). This approach promotes rural industrial restructuring, revitalizes agricultural land, and facilitates the transfer of surplus labor. Within China's rural revitalization framework, it serves as a critical mechanism to integrate smallholders into modern agricultural systems by fostering new agricultural business entities (NABEs), particularly through scaled operations (Guo and Yao, 2021; Zhang et al., 2023; Yang, 2022). Most NABEs, which have evolved, differentiated, and upgraded from smallholder farmers, encompass professional households, family farms, farmers' cooperatives, and agricultural industrialization leading enterprises. Compared with traditional smallholders, NABEs demonstrate stronger management capabilities and are more suited to large-scale farmland management, enabling more efficient resource use (Zhang et al., 2024). However, identifying effective strategies for NABEs to implement moderate-scale operations with Chinese characteristics remains challenging, particularly in the hilly and mountainous areas of Southwest China. For these entities, topographical barriers, such as steep slopes and scattered plots, are major obstacles to scaling up (Bailey et al., 2017; Xu et al., 2024). These conditions limit mechanization and the adoption of agricultural technology, leading to increased production costs, low operational efficiency, and reduced economic returns. This, in turn, weakens farmers' motivation to continue agricultural production (Ding et al., 2021; Zhang et al., 2023). Furthermore, labor-related issues further exacerbate these challenges (Gkiza and Nastis, 2017). Rapid urbanization has led to large-scale rural labor migration, leaving elderly individuals and women as the primary agricultural workforce. This demographic imbalance restricts technological progress and reduces productivity, hindering high-quality agricultural development (He, 2021; Zhang et al., 2023). These interconnected barriers highlight the urgent need to determine the optimal scale threshold for NABEs and to explore practical pathways for achieving it.

Currently, most studies on moderate-scale operations have focused on traditional smallholders (Guan, 2018; Guo and Yao, 2021). Additionally, a debate over whether agriculture exhibits scale effects is ongoing. Some argue that no statistically significant correlation exists between operational scale and per-unit yield, even suggesting that larger scales may reduce land productivity (Gao and Shi, 2021). Others contend that small-scale farming has long constrained agricultural productivity and per capita output, thereby hindering factor allocation efficiency, total factor productivity, and the development of modern agriculture (Haque, 2022). However, larger scales do not necessarily equate to higher efficiency, as the key lies in achieving a moderate scale (Guan, 2018; Cheng et al., 2023; Kiliç Topuz et al., 2025). Furthermore, no consensus exists on the quantitative threshold for a moderate scale. Scholars emphasize that defining this threshold requires multi-dimensional criteria for optimality, including economic, social, and ecological benefits, as well as the integration of land productivity, labor efficiency, and resource utilization (Guiomar et al., 2018; Luo et al., 2025). Most domestic studies on moderate-scale agricultural operations focus on government-oriented perspectives, emphasizing policy support for NABEs and related development pathways. For instance, García-Barrios et al. (2011) conducted qualitative analyses of supportive policies, including multiple pathways for scaling operations. Li et al. (2021) further highlighted policy-driven measures such as regulating land transfer, promoting agricultural technology, establishing policy guarantees, and refining government strategies as essential to advancing NABEs' moderate-scale operations. Beyond policy frameworks, Liu (2020) and Su et al. (2023) emphasized operational-level strategies such as refining farm management, promoting farmer specialization, upgrading agricultural technologies, and implementing farmland trusteeship as key to achieving moderate scale. Meanwhile, Wang et al. (2016) explored the "Internet + agriculture" model, noting that its associated mechanisms can also facilitate NABEs' development. However, existing studies have rarely explored both internal and external pathways for NABEs to achieve moderate-scale operations. As noted by Zhang et al. (2023), the internal pathways involve adjusting, optimizing, and improving the allocation of agricultural production factors, while external pathways depend on factors such as natural geography, socioeconomic conditions, and local government support. Lei et al. (2023) further revealed that agricultural factor misallocation hinders agricultural production efficiency, underscoring the criticality of addressing factor allocation in internal pathways for achieving high-quality moderate-scale operations. This study addresses this gap by focusing specifically on the integration of internal and external pathways, a dimension that has been largely overlooked in the literature.

The modern agricultural park in Jiangjin District, Chongqing, Southwest China, serves as a national modern agricultural demonstration zone and a model for moderate-scale agricultural operations in hilly and mountainous areas. Based on a survey of 277 NABEs engaged in citrus, pepper, and grain farming in Jiangjin Modern Agricultural Park, Chongqing, this study focuses on two core objectives. First, it employs a translog production function to calculate the moderate-scale thresholds for these three types of crop-farming NABEs. Second, it applies a structural equation model (SEM) to analyze the internal and external pathways through which NABEs achieve moderate-scale operations. Together, these efforts aim to provide targeted insights for NABEs in hilly and mountainous areas to achieve moderate-scale operations by coordinating internal and external strategies.

2 Materials and methods

2.1 Study area

The study was conducted in the hilly and mountainous areas of Chongqing's Jiangjin Modern Agricultural Park, located in Southwest China (105 °57′20″-106 °15′20″E, 28 °50′10″-29

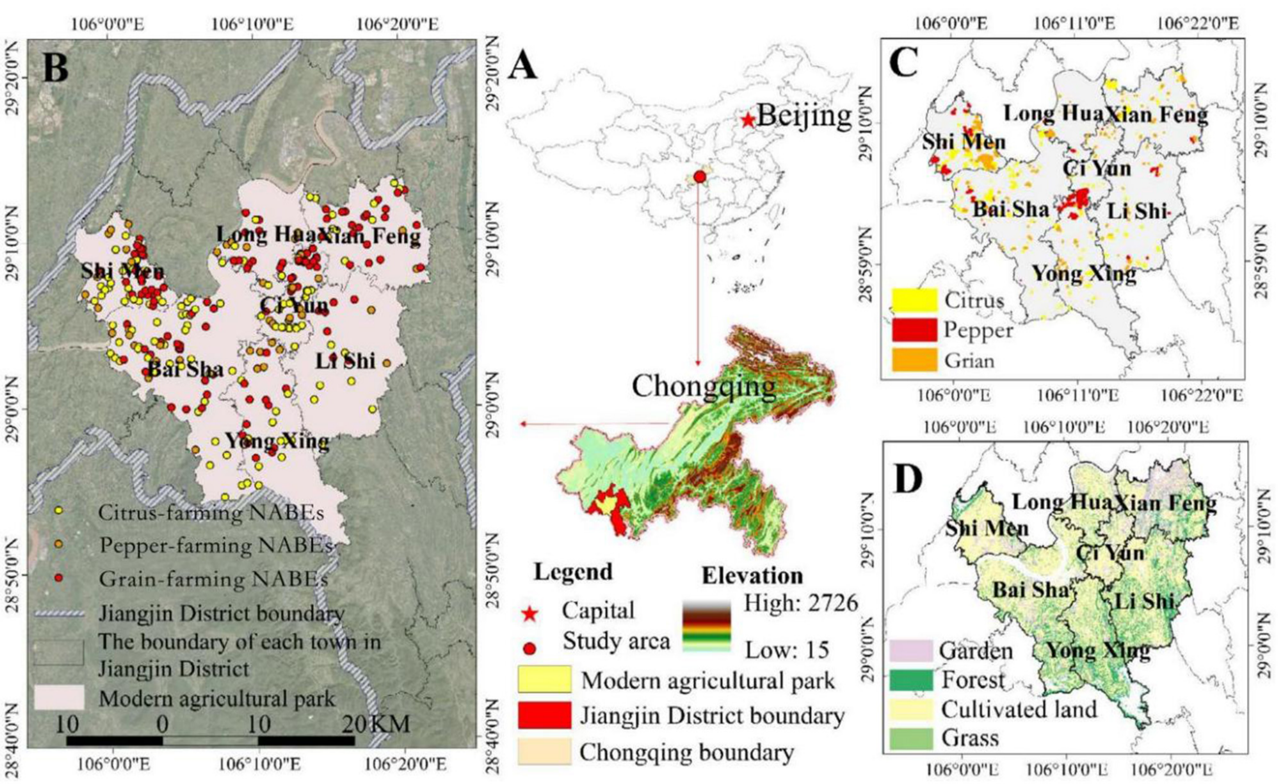

FIGURE 1
Study area. **(A)** Location and elevation (map verification number: GS (2022) NO. 1873), **(B)** distribution of NABEs, **(C)** the spatial distribution of crop farming of NABEs, and **(D)** land use types in 2023.

°18′20″N) (Figure 1). The park comprises seven towns: Ciyun, Longhua, Xianfeng, Lishi, Yongxing, Baisha, and Shimen, which encompass 68 administrative villages in total. Predominantly hilly and mountainous, it covers a total area of 90.55 hm^2, with elevations ranging from 163 m to 1,135 m. In 2023, the total output value of crop farming, forestry, animal husbandry, and fishery in the seven towns reached 8.23 billion yuan, accounting for 41.23% of the corresponding total in Jiangjin District. The average per capita disposable income of rural permanent residents stood at 42,364.21 yuan, 520.28 yuan higher than the district's overall average. The sown area of crops was 54,296.4 hm^2, accounting for 36.04% of the district's total. Boasting advanced agricultural practices, well-developed infrastructure, and convenient transportation, the study area holds a distinct advantage in developing peri-urban agriculture, serving as a major supplier of agricultural products to Chongqing's main urban area. The park prioritizes fostering diverse NABEs to boost high-quality citrus, pepper, and grain industries. It advances agricultural development through industrialized concepts, guides its activities by market forces, and leverages industrial and commercial capital to accelerate progress. Its ultimate goal is to establish a comprehensive agricultural demonstration park that integrates recycling, digitalization, industrialization, and ecological preservation, serving as a model and pilot for comprehensive agricultural development.

2.2 Data source

The data in this study include natural, socioeconomic, and land use data of the modern agricultural park in Jiangjin District, Chongqing, as well as survey data of NABEs within this park. Digital elevation model (DEM) data with a 12.5-m resolution were obtained from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn). Administrative boundary and land use data were provided by the Jiangjin District Planning and Natural Resources Bureau of Chongqing. Socioeconomic data were mainly extracted from the 2023 Statistical Yearbook of Jiangjin District (published by the Jiangjin District People's Government). Survey data on NABEs were collected through field research in 68 administrative villages from July to August 2023. The process involved interviews, questionnaires, and farmland investigations. Interviews with town and village cadres about village-level NABEs, rural industrial development, and land use patterns guided the selection of representative specialized households, family farms, cooperatives, and agricultural enterprises from each village. In total, 290 such representative households (all operating as NABEs) were then surveyed using questionnaires, supplemented by on-site surveys of their cultivated land. Of these, 277 valid responses were obtained: 108 were from citrus-farming NABEs, 120 from pepper-farming NABEs, and 49 from grain-farming NABEs.

The questionnaire captured key variables related to moderate-scale operations. These included operational information, such as resource endowments (land, labor, capital, mechanization, and technology), industrial development status (crop types, industrial chain extension, and market connectivity), land transfer details (scale, duration, mode, and costs), and input-output metrics (factor input structure, operational benefits, and cost composition). It also covered decision-making information such as operator attributes (age, educational background, gender, and professional skills), perceptions of moderate-scale operation (judgments about rationality and expected benefits), willingness to expand (inclination and demands of scaling up), and constraints on expansion (land transfer barriers, financing difficulties, and technical bottlenecks). These variables supported the study objectives by (1) enabling the use of the translog production function to measure moderate scale for different crop types; (2) identifying key factors influencing the realization of moderate-scale operation; and (3) supporting SEM analysis of pathways through which NABEs can achieve moderate-scale operation.

2.3 Theoretical framework

Studies have shown that newly established enterprises can adopt multiple strategies to achieve notable success (Mei and Ma, 2022), which are divided into external and internal pathways. To optimize the allocation of agricultural production factors and achieve moderate-scale operation, NABEs may adopt an internal pathway, which involves the scientific and rational optimization of their agricultural production factor inputs (Lei et al., 2023; Luo et al., 2023). Alternatively, the external pathways focus on utilizing external drivers to drive these NABEs toward moderate-scale operation, a process shaped by the external environment, natural geography, socioeconomic factors, and government support (Zhang et al., 2023). Achieving moderate-scale operation requires the synergistic integration of both internal and external pathways. However, we recognize that the environmental demands and agricultural production factor inputs vary significantly among NABEs based on the specific crops they cultivate, so a nuanced analysis is imperative. Accordingly, entities that have not yet achieved moderate-scale operation can be divided into two groups: those operating below scale and those operating above scale. Thus, we examine the pathways through which these two distinct types of NABEs are realized. Figure 2 presents the theoretical framework that underpins this analysis.

2.4 Methods

2.4.1 Measurement methods for the moderate-scale operations of NABEs

Operating scale and output level: an input-output model for NABEs based on the translog production function. The translog production function is suitable for analyzing factor substitution elasticity and economies of scale. Drawing on previous studies (Li et al., 2015; Lu et al., 2018), this study constructs the following model to estimate and compare agricultural productivity among NABEs, as it flexibly captures factor interactions.

$$\begin{aligned}\ln Y_i =\ & \alpha_0 + \alpha_1 \ln X_{i1} + \alpha_2 \ln X_{i2} + \alpha_3 \ln X_{i3} + \alpha_4 \ln X_{i4} \\ & + \frac{1}{2}\alpha_5 \ln X_{i1} \ln X_{i1} + \frac{1}{2}\alpha_6 \ln X_{i2} \ln X_{i2} + \frac{1}{2}\alpha_7 \ln X_{i3} \ln X_{i3} \\ & + \frac{1}{2}\alpha_8 \ln X_{i4} \ln X_{i4} + \alpha_9 \ln X_{i1} \ln X_{i2} + \alpha_{10} \ln X_{i1} \ln X_{i3} \\ & + \alpha_{11} \ln X_{i1} \ln X_{i4} + \alpha_{12} \ln X_{i2} \ln X_{i3} + \alpha_{13} \ln X_{i2} \ln X_{i4} \\ & + \alpha_{14} \ln X_{i3} \ln X_{i4} - U_i \end{aligned} \quad (1)$$

In Equation 1, Y_i is the agricultural income of NABEs; X_{i1} is the operating area (hm^2) of NABEs; X_{i2} is the effective labor quantity of NABEs; X_{i3} is the fixed-asset investment (agricultural machinery and equipment investment, farmland leveling project investment, agricultural infrastructure construction investment) of NABEs; X_{i4} is the liquid capital input (land rent, production materials, and labor wage) of NABEs; α_0-α_{14} are the parameters to be estimated.

Given the structure of the translog production function, which requires accounting for cross-substitution elasticity between factors, the formula for calculating the input-output elasticity of each production factor is as follows:

$$\begin{aligned}\varepsilon A =\ & \alpha_1 + \alpha_5 \ln X_{i1} \ln X_{i1} + \alpha_9 \ln X_{i1} \ln X_{i2} + \alpha_{10} \ln X_{i1} \ln X_{i3} \\ & + \alpha_{11} \ln X_{i1} \ln X_{i4} \end{aligned} \quad (2)$$

$$\begin{aligned}\varepsilon L =\ & \alpha_2 + \alpha_6 \ln X_{i2} \ln X_{i2} + \alpha_9 \ln X_{i1} \ln X_{i2} + \alpha_{12} \ln X_{i2} \ln X_{i3} \\ & + \alpha_{13} \ln X_{i2} \ln X_{i4}\end{aligned}$$

$$\begin{aligned}\varepsilon G =\ & \alpha_3 + \alpha_7 \ln X_{i3} \ln X_{i3} + \alpha_{10} \ln X_{i1} \ln X_{i3} + \alpha_{12} \ln X_{i2} \ln X_{i3} \\ & + \alpha_{14} \ln X_{i3} \ln X_{i4}\end{aligned}$$

$$\begin{aligned}\varepsilon I =\ & \alpha_4 + \alpha_8 \ln X_{i4} \ln X_{i4} + \alpha_{11} \ln X_{i1} \ln X_{i4} + \alpha_{13} \ln X_{i2} \ln X_{i4} \\ & + \alpha_{14} \ln X_{i3} \ln X_{i4}\end{aligned}$$

In Equation 2, εA, εL, εG, and εI are the elasticity coefficients of land, labor, fixed assets, and liquid capital, respectively; other variables remain consistent with those above.

Based on the results of Equations 1 and 2, the equation for calculating the optimal labor-averaged land operation scale under profit maximization is derived using the multivariate function extreme value method and is presented as follows:

$$MaxA = \frac{\varepsilon A^* w}{\varepsilon L^* n} \quad (3)$$

In Equation 3, $MaxA$ refers to the optimal labor-per-capita land moderation size, w and n denote the agricultural labor wage and land rent, respectively.

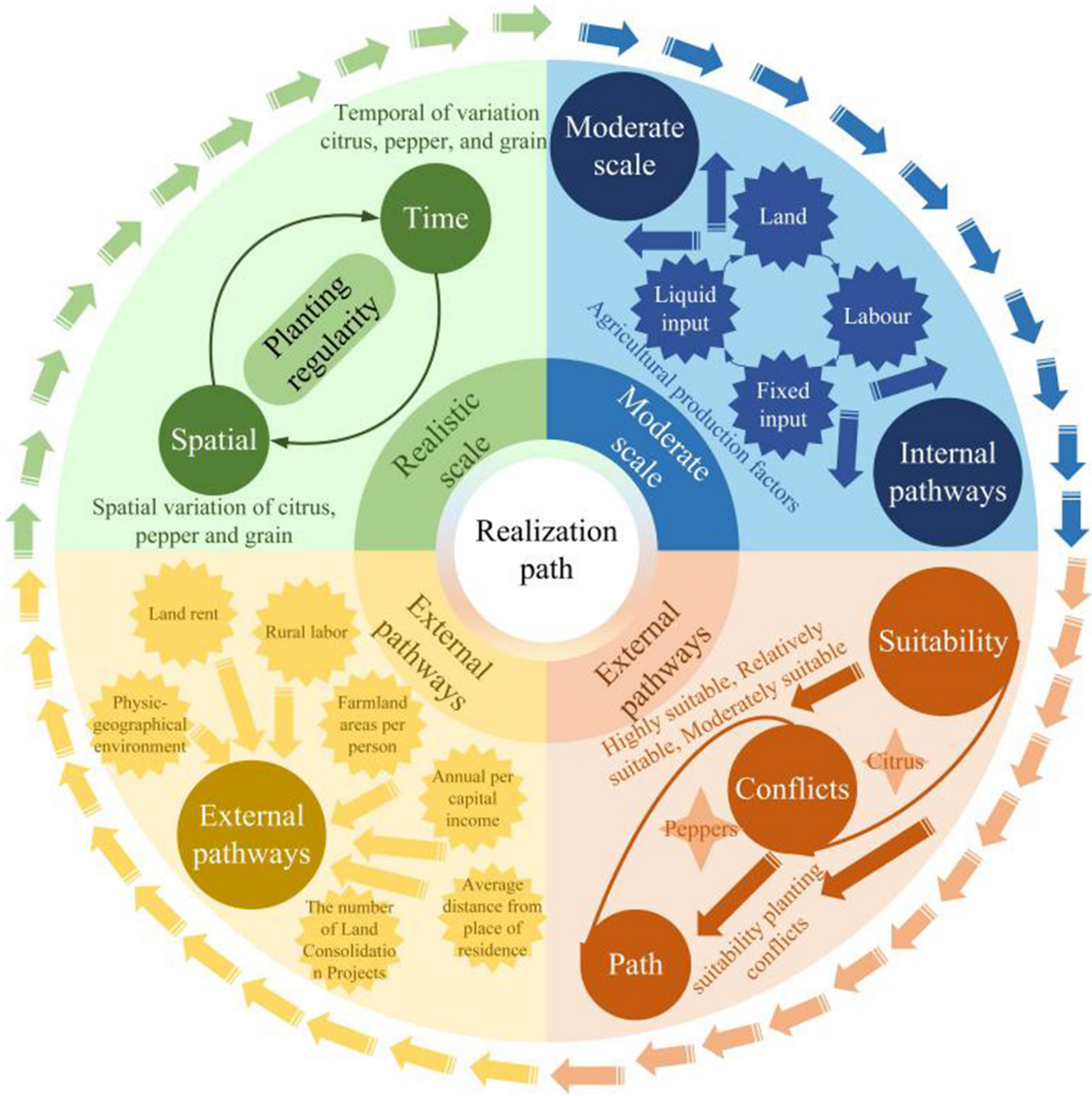

FIGURE 2
Theoretical framework.

2.4.2 The structural equation model of internal and external pathways

To address the complexity of multifactor causation in the moderate-scale operation of NABEs in hilly and mountainous areas, structural equation model (SEM) is adopted for its unique advantages (Herlambang et al., 2021). Unlike traditional methods such as regression analysis, which struggle to disentangle interdependent effects between observable and unobservable factors, such as how operational efficiency is shaped jointly by labor quality (observable) and policy support perception (unobservable), SEM enables the simultaneous estimation of direct, indirect, and mediating effects (Brandmaier et al., 2013; Wang et al., 2021). This capability is critical because the moderate-scale operation of NABEs depends on interrelated mechanisms in which internal factor allocation (land, labor, and other inputs) and external environmental constraints (such as slope limitations) exert reciprocal influences. For instance, land input efficiency is mediated by soil quality, a latent variable with only partially observable indicators, something that traditional methods cannot capture. The choice of SEM in this study is justified by its strong alignment with the research questions and design. The core objective is to reveal how these interrelated mechanisms shape the pathways through which NABEs achieve moderate-scale operation. Unlike simpler path analysis, SEM integrates both measurable variables and latent constructs, ensuring that the full complexity of scaling processes in these regions is represented.

The internal pathways focus on NABEs' endogenous capacity to optimize scale by adjusting agricultural production factors. Key factors include land, the foundational input determining yield and productivity in fragmented hilly and mountainous terrain (Lei et al., 2023; Luo et al., 2023); labor, a dynamic element whose efficiency is influenced by education, skills, and gender composition

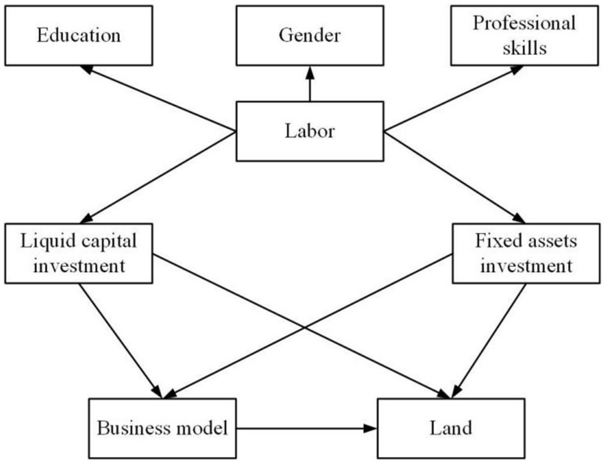

FIGURE 3
Structural equation model of internal pathways for NABEs to achieve moderate-scale operation. The key path of internal pathways in the SEM framework. (1) Education, gender, and professional skills → labor: the characteristics of the labor force—including education level, gender composition, and professional skills—directly influence the overall effectiveness of labor input; (2) labor → liquid capital investment and fixed-asset investment: labor further affects investment decisions, with more skilled and educated labor enabling more efficient allocation of both liquid capital and fixed assets in agricultural production; (3) liquid capital investment and fixed-asset investment → business model and land: investments in capital shape the choice of business model and the utilization of land resources, influencing land use strategies; (4) business model → land: the business model directly affects land allocation and utilization, which in turn determines whether NABEs can achieve moderate-scale operation; and (5) all arrows indicate hypothesized causal relationships within the SEM framework, reflecting both direct and indirect effects of agricultural production factors and resource allocation on NABEs' achievement of moderate-scale operation.

TABLE 1 Evaluation indicator system for external pathways of NABEs to achieve moderate-scale operation.

Indicator	Indicator meaning
Elevation	The average altitude of the administrative village. As the altitude increases, the temperature becomes lower, making crops (such as citrus, pepper, and grain) grown in the village more susceptible to frost damage, which may affect their yield and quality.
Slope	The average slope of land. Different crops have varying slope requirements. Generally, the greater the slope, the more challenging cultivation and production become.
Effective soil layer thickness	The average effective soil layer thickness of cultivated land. Soil fertility and crop yields both increase with the thickness of the effective soil layer.
Soil organic matter	The average soil organic matter of land. Soil fertility and crop yields both increase with the amount of organic matter present.
Farmland area per capita	Per capita land area of the administrative village. It is easier for NABEs to transfer land and thus achieve moderate-scale operation in villages with higher per capita farmland area.
Land rent	The economic compensation paid by NABEs to small farmers or village collectives for obtaining the right to operate rural land within a specified period. It is less advantageous for NABEs to transfer more land and thus achieve moderate-scale operation in villages with higher land rent per unit area.
Rural labor force	The composition of the administrative village's labor force. It is easier for NABEs to hire low-cost laborers and thereby achieve moderate-scale operation in villages with a more abundant labor force.
Annual per capita income	The annual per capita income of farmers in the administrative village. The village's economic development is positively correlated with farmers' average annual per capita income, which in turn promotes land transfer.
The number of land consolidation projects	The number of land consolidation projects implemented in the administrative village. With stable funding support, the greater the number of land consolidation projects, the more significantly farmland quality improves. This facilitates land transfer by NABEs and thereby promotes the realization of moderate-scale operations.
Average distance from rural settlements to farmland	The average distance from farmers' residential settlements to their contracted farmland is a key spatial indicator affecting land transfer. The closer this average distance, the more conducive it is for NABEs to transfer more land, thereby promoting the realization of moderate-scale operations.
The number of households above or below moderate scale	The number of NABEs within administrative villages that operate at a scale above or below the moderate level.

(Blien and Hirschenauer, 2020); capital, subdivided into liquid and fixed assets that enhance labor capacity and production efficiency (Luo et al., 2023); and business model, represented by six types (NABEs plus traditional farmers and farming bases, NABEs plus traditional farmers, NABEs plus farming bases, NABEs plus NABEs and farming bases, NABEs plus NABEs and traditional farmers, and solo operation) that differentiate operational efficiency.

These five indicators, namely land, labor, capital (subdivided into liquid and fixed assets), and business model, form the internal pathways of SEM, examining how NABEs, whether below or above moderate scale, optimize agricultural resource allocation to achieve moderate-scale operation. Accordingly, the SEM for the internal pathways of citrus-, pepper-, and grain-farming NABEs was constructed to explore how NABEs of different scales combine factor input to achieve moderate-scale operation. The final model is shown in Figure 3.

The external pathway emphasize the influence of broader physicogeographical and socioeconomic environments at the village scale, along with support from local government departments (Zhang et al., 2023). Favorable natural conditions and high agricultural productivity shape the viability of large-scale crop cultivation by NABEs. Key physicogeographical variables, including elevation, slope, effective soil layer thickness, and soil organic matter, exert significant impacts on crop yields (Mo et al., 2019). Socioeconomic factors such as per capita arable land area, land rental rates, the size of the rural labor force, farmers' annual per capita income, and the average distance from rural settlements to farmland also determine the suitability of large-scale crop cultivation by NABEs within a given administrative village (Zhang et al., 2023). Local government interventions, such as land consolidation projects, affect land quality and the feasibility of moderate-scale operations, particularly in hilly and mountainous areas. Based on these factors, 11 indicators were employed to construct the SEM for the external pathways of

NABEs: elevation, slope, effective soil layer thickness, soil organic matter, per capita farmland area, land rent, rural labor force, annual per capita income, the number of land consolidation projects, average distance from rural settlements to farmland, and the number of households above or below moderate scale. Indicator definitions are detailed in Table 1. The SEM evaluates how NABEs achieve moderate-scale operation through external pathways (Figure 4).

By integrating both internal and external pathways within the SEM framework, this study comprehensively examines how NABEs optimize internal agricultural production factors and how external environmental and socioeconomic contexts shape their moderate-scale processes. This dual-path analytical approach provides a holistic understanding of the mechanisms driving the moderate-scale operation of NABEs, ensuring that both endogenous adjustments and exogenous influences are captured and interpreted within a unified analytical framework.

2.4.3 The suitability analysis of agricultural land

Moderate-scale operation requires careful consideration of both the farmland location and the current environmental conditions (Zhang et al., 2023). Accordingly, a detailed assessment of the operation scale capacity of garden land, forest land, grassland, and agricultural land was conducted, incorporating both plot size and rural settlement distribution. The evaluation indicator system is shown in Table 2. Terrain, soil, and other plot-level elements were found to significantly impact crop cultivation. Topographic elements are among the key considerations in crop cultivation (Mo et al., 2019; Wu et al., 2022). Slope determines daily sunshine exposure and also influences drainage and irrigation. Altitude shapes climate conditions, with temperature decreasing as altitude rises (Catalano et al., 2023). Soil variables—including their physical and chemical properties as well as environmental conditions—exert a significant impact on the quality and growth of crop plantations (Zhang, 2020). Their detailed scores are presented in Tables 3–5.

For NABEs, village-scale conditions for large-scale operation should be fully considered. Relevant studies have demonstrated that, while concentrated and contiguous land is not a stand-alone factor in agricultural output, it can generally influence how different production factors are allocated and function in agricultural production (Heinrichs et al., 2021; Hu and He, 2014). More densely concentrated and contiguous farmland exhibits a more uniform distribution of production factors, significantly enhancing land utilization efficiency. Relevant studies note that the size of the labor force significantly impacts the growth rate

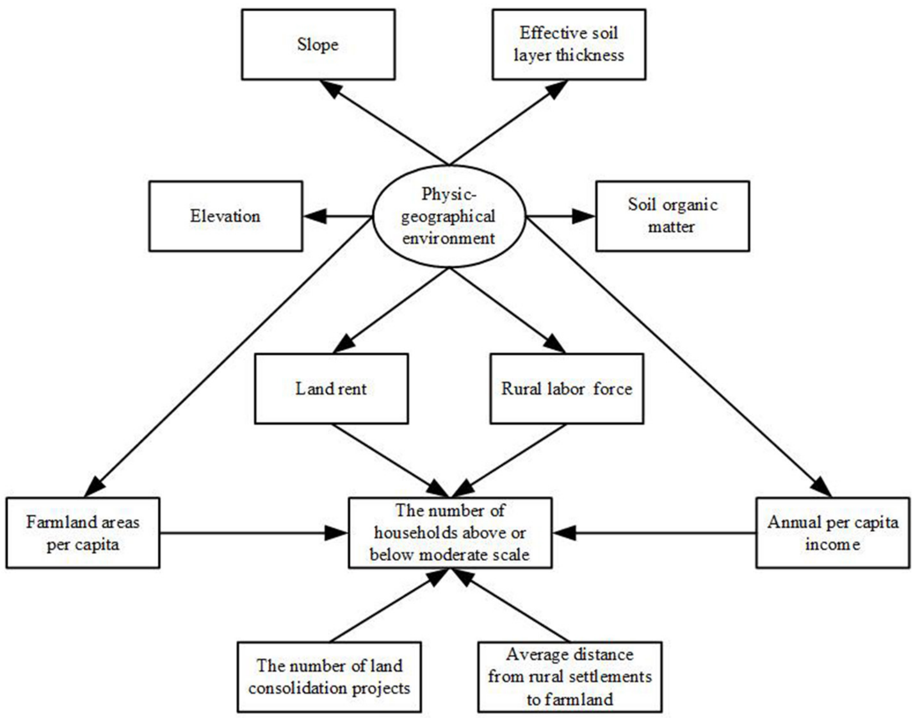

FIGURE 4
Structural equation model of external pathways for NABEs to achieve moderate-scale operation. The key paths of external pathways in the SEM framework. (1). Physicogeographical environment → land rent and rural labor: the physicogeographical environment—encompassing slope, soil thickness, elevation, and organic matter content—exerts a direct influence on land rent and rural labor dynamics; (2) farmland area per person and annual per capita income → the number of land consolidation projects: these economic and scale-related indicators drive the implementation of land consolidation projects, as larger operational scales and higher profitability are more likely to incentivize such interventions; and (3) the number of land consolidation projects and average distance from rural settlements to farmland → the number of households above or below moderate scale: the number of land consolidation projects and the average distance from rural settlements to farmland jointly influence whether NABEs achieve moderate-scale operation. Land consolidation reorganizes land structure, and distance affects management efficiency. Collectively, they shape the realization of moderate-scale operation.

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TABLE 2 Evaluation indicator system for agricultural land suitability.

Scale level	Factor	Indicator	Indicator meaning
Plot scale	Topographic factor	Slope x1	The slope gradient of the plot
		Elevation x2	The altitude of the plot
		Slope aspect x3	The slope aspect of the plot
	Soil factor	Effective soil layer thickness x4	Thicker effective soil layers typically enhance soil fertility, improve crop stress resistance, and reduce the difficulty of mechanized farming, thereby supporting higher crop yields.
		Soil organic matter x5	Soil organic matter refers to the total carbon-containing organic substances per unit mass of soil, including plant and animal residues, microbial biomass, and microbially transformed organic compounds.
		Soil pH x6	Indicating whether soil is too alkaline or too acidic for healthy crop growth, as well as the strength of the soil's acid-base reaction.
		Soil texture x7	Soil texture (custom classification for this study): 1 = loam, 2 = clay, 3 = sand
	Farming facilitation factor	Plot area x8	Large-scale operations are more suited to larger plots.
		Dimensionality index x9	The patch's shape is described by a square index; a higher value indicates a more intricate patch shape, which is more unfavorable to large-scale agricultural operations.
		Geometric shape index x10	The patch's shape is described by its roundness index; a higher roundness index indicates a more intricate planar shape, making it less advantageous for large-scale agricultural operations.
		Scale advantage index x11	Scale advantage index evaluates the adaptability of landscape patterns to large-scale agricultural operations; a higher index value indicates more favorable conditions for such operations.
		Cultivation radius x12	Cultivation radius is determined by measuring the distance between agricultural land and the nearest residential area.
		Distance from main road x13	The closer an agricultural plot is to the main road, the more advantageous it is for the transportation of agricultural products.
Village scale	Management factor	Aggregation index x14	It reflects the aggregation and dispersion state of patches. Values range from −1 to 1: −1 indicates complete dispersion, 0 indicates random distribution, and 1 indicates full aggregation. A higher aggregation index value is more conducive to large-scale agricultural operations.
		Connectivity index x15	The connectivity of patches is characterized by analyzing the functional connections between them. A patch structure that effectively integrates landscape components results in a higher ratio of functional connection sites. A more favorable connectivity index indicates greater suitability for large—scale agricultural operations.
		Fragmentation index x16	Fragmentation index quantifies the fragmentation degree of patches in a region, which is an important part of patch distribution complexity. A lower fragmentation index indicates more favorable conditions for large-scale agricultural operations.
		Polymerization index x17	Polymerization index quantifies the degree of aggregation and connectivity among patches in a region. A higher polymerization index indicates more favorable conditions for large-scale operations.
		Water supply guarantee rate x18	Water is an indispensable factor for the growth and development of planted crops.
		Rural labor force x19	The larger the local labor force in the administrative village, the greater the opportunities for NABEs to hire sufficient skilled workers. This, in turn, will help facilitate the expansion of larger-scale operations.
		Land rent x20	The extent to which NABEs can benefit from centralizing land transfers for large-scale agricultural operations is primarily determined by the average land transfer rent in the administrative village. Lower land rents enhance the advantages of such large-scale operations.
	Location factor	Farmers'markets x21	Large-scale operations and convenience of agricultural product sales of NABEs are positively correlated with proximity to farmers' markets.
		External transportation accessibility x22	The closer the administrative village is to the high-speed intersection, the easier it is for NABEs to transport agricultural products to other locations for sale. Additionally, villages with higher transportation accessibility tend to have a higher land transfer rate, which further facilitates NABEs in renting more land.

TABLE 3 The classification criteria and scores of evaluation indicators for citrus.

Factor	Indicator	Quantitative score				
		100	80	60	40	20
Topographic factor	Slope	6–15	15–25	25–35	<6	≥35
	Elevation	150–400	400–500	>500	–	–
	Aspect	Sunny slope	Semi-sunny slope	–	Semi-shady slope	Shady slope
Soil factor	Effective soil layer thickness	≥100	–	40–100	–	<40
	Soil organic matter	≥20	–	10–20	–	<10
	Soil pH	6–6.5	5.5–6	5–5.5	6.5–7.5	<5 or ≥7.5
	Soil texture	Loam	–	Sand	–	Clay

TABLE 4 The classification criteria and scores of evaluation indicators for pepper.

Factor	Indicator	Quantitative score				
		100	80	60	40	20
Topographic factor	Slope	<6	6–15	15–20	20–35	>35
	Elevation	300–400	400–500	500–600	<300	>600
	Aspect	Sunny slope	Semi-sunny slope	–	Semi-shady slope	Shady slope
Soil factor	Effective soil layer thickness	>100	–	40–100	–	<40
	Soil organic matter	>20	–	10–20	–	<10
	Soil pH	6.5–7	7–7.5	7.5–8	<6.5	>8
	Soil texture	Loam	–	Sand	–	Clay

TABLE 5 The classification criteria and scores of evaluation indicators for grain.

Factor	Indicator	Quantitative score				
		100	80	60	40	20
Topographic factor	Slope	<2	2–6	6–15	15–25	>25
	Elevation	<300	300–500	500–750	750–1,000	1,000–1,500
	Status of terraces	1	2	3	4	–
Soil factor	Effective soil layer thickness	>100	70–100	60–70	40–60	<40
	Soil organic matter	>3%	2–3%	1–2%	0.6–1%	<0.6%
	Soil pH	6–7	5.5–6 or 7.0–7.5	5.0–5.5 or 7.5–8.0	<5.0 or >8.0	–
	Soil texture	Loam	—	Sand	—	Clay

of NABEs. When the labor supply is sufficient, NABEs are more inclined to engage in large-scale operations (Blien and Hirschenauer, 2020). Furthermore, lower land rents facilitate NABEs' participation in a land transfer for large-scale operations. In the cultivation process of citrus and pepper, transportation losses constitute a critical issue. Specifically, the circulation process from harvest to final sale to consumers results in significant transportation losses (Hu and Zhong, 2012; Qiao, 2018). Therefore, it is essential to reduce the weight, shorten transit times, and minimize transportation losses. In light of this, we identified nine indicators for evaluation across two dimensions: management factors and location factors. These indicators include the concentration and contiguity of village farmland, labor and land rent conditions, the influence of farmers' markets, and the accessibility of external transportation. Drawing on the five factors and 22 indicators (detailed in the Table 2 below), we evaluated the operational conditions of garden land, forest land, grassland, and agricultural land at two scales: plot scale and village scale. Conversely, food crops prioritize land transfer and terrace conditions over slope orientation and proximity to external transportation. This is because most primary food producers in rural China, particularly in the southwest, either sell their produce locally or retain it for self-consumption. As a result, in contrast to citrus and pepper, we identified two indicators for grain: land transfer rate and terrace conditions.

2.4.3.1 Projection pursuit model

The projection pursuit model is a novel statistical technique for handling multi-factor, high-dimensional, and non-linear data. Using this model, high-dimensional data is projected into a low-dimensional space, where the properties of the high-dimensional data structure are examined. It has been widely applied to urban ecological assessment and the evaluation of resource carrying capacity. The precise calculation stages are as follows (Liu and Tang, 2022; Zhou et al., 2022):

2.4.3.1.1 Normalization of original data.

Setting the sample set to $x^*(i,j)|i = 1 \sim n, j = 1 \sim p$, among them, the $x^*(i,j)$ means raw data for the jth evaluation indicator of the i-th NABEs. n is the number of NABEs, and p is the number of evaluation indicators. The original data of the evaluation indicator can be standardized by the range method:

The more and better indicator can be expressed as follows:

$$x(i,j) = \frac{[x^*(i,j) - x_{\min}(j)]}{[x_{\max}(j) - x_{\min}(j)]} \tag{4}$$

The less and better indicator can be expressed as follows:

$$x(i,j) = \frac{\left[x_{\max}\left(j\right) - x^*\left(i,j\right)\right]}{\left[x_{\max}\left(j\right) - x_{\min}\left(j\right)\right]} \tag{5}$$

In Equations 4 and 5, $x_{\max}\left(j\right)$, $x_{\min}\left(j\right)$ are the maximum and minimum values of the raw data of the evaluation indicator. $x\left(i,j\right)$ is a standardized value for evaluation indicators. $x\left(i,j\right)$ is normalized value (in the range of 0 to 1).

2.4.3.1.2 Establishment of the projection objective function.

In Equation 6, $a = \left\{a\left(1\right), a\left(2\right), \ldots, a\left(p\right)\right\}$ is the unit projection direction vector, and the one-dimensional projection value of sample i in this direction is as follows:

$$Z\left(i\right) = \sum_{j=1}^{p} a\left(j\right) x\left(i,j\right) \;\; \left(i = 1 \sim n\right) \tag{6}$$

Then, $Z\left(i\right)$ is classified based on a one-dimensional scatter diagram, which requires local projection points to remain as dense as possible, which would be better to gather into one cluster, and projection points between clusters should spread out as far as possible. So the objective function can be defined as the product between the distance and density of the category, that is Equation 7:

$$Q\left(a\right) = S_z D_z \tag{7}$$

where S_z and D_z are the standard deviation and local density of the projected value $Z\left(i\right)$, respectively, namely:

$$S_z = \sqrt{\frac{\sum_{i=1}^{n} \left(Z\left(i\right) - E\left(z\right)\right)^2}{\left(n-1\right)}} \tag{8}$$

$$D_z = \sum_{i=1}^{n} \sum_{j=1}^{p} \left(R - r\left(i,j\right)\right) u\left(R - r\left(i,j\right)\right) \tag{9}$$

In Equations 8 and 9, $E\left(z\right)$ is the sequence $\{Z\left(i\right) | i = 1 \sim n|\}$ average. R is the window radius of local density. The distance $r\left(i,j\right) = \left|Z\left(i\right) - Z\left(j\right)\right|$, $u\left(R - r\left(i,j\right)\right)$ is the unit step. This step is assumed to be 1 when $R \geq r\left(i,j\right)$, otherwise, it is assumed to be 0.

2.4.3.1.3 Optimization of projection direction.

Once the sample set is determined, the change of projection direction vector a determines the change of projection objective function $Q\left(a\right)$. Specifically, different projection direction vectors correspond to different data structure features, and the one that best reflects the structural features of high-dimensional data is considered the optimal projection direction vector. From Equations 10 and 11 and by imposing constraint conditions, the maximized projection objective function was solved, and the direction vector of the nearest projection was calculated (Liu and Li, 2022); the corresponding formula is presented as follows:

Objective function maximization:

$$\max Q\left(a\right) = S_z D_z \tag{10}$$

Constraint condition:

$$\sum_{j=1}^{p} a^2\left(j\right) = 1 \tag{11}$$

This is $\left\{a_j = \middle| j = 1 \sim p\right\}$ as optimization variables, a complex non-linear optimization problem, and it is difficult to use conventional optimization methods. The accelerated genetic algorithm is adopted to solve the optimal problem in the paper.

3 Results

3.1 The realistic scale and moderate scale of NABEs

Substituting these coefficient estimates (Table 6) into Equation 2, we calculated the output elasticities of various factors and returns to scale coefficients for citrus-, pepper-, and grain-farming NABEs (Table 7). Among these factors, land exhibits the highest output elasticity across all three crops, indicating that it is the primary driver of productivity. The output elasticity of labor is positive but small because the planting industry is labor-intensive and constrained by the challenges of mechanized operations in hilly and mountainous areas. As a result, NABEs must employ more labor force, yet the majority consists of elderly laborers, which reduces the size of the effective labor force. It is evident that NABEs should prioritize increasing inputs, such as farmland leveling projects and the construction of agricultural infrastructure, since merely expanding the operating area will not be sufficient to increase operational profits.

The output elasticity of fixed assets is positive, whereas that of liquid capital is negative. The returns-to-scale coefficients differ

TABLE 6 Estimation results of the translog production function for input-output analysis of NABEs.

Parameter	Citrus-farming NABEs		Pepper-farming NABEs		Grain-farming NABEs	
	Coefficient	T-value	Coefficient	T-value	Coefficient	T-value
α_0	0.818***	6.229	2.849***	10.273	3.165***	4.501
α_1	0.609***	2.692	0.775***	3.252	0.952**	2.245
α_2	0.290**	2.069	0.615**	2.509	−0.161	−0.773
α_3	0.167***	3.402	−0.108	−0.644	0.189	0.261
α_4	0.245	1.293	−0.371	−1.671	0.158	0.283
α_5	0.452**	2.218	−0.416***	−2.952	−0.811***	−7.579
α_6	−0.259*	−1.854	−0.648***	−6.439	0.142*	1.692
α_7	0.050**	2.586	−0.318***	−3.936	0.196	0.530
α_8	−0.253**	−2.589	−0.130	−1.011	0.930***	4.300
α_9	−0.144	−0.946	0.342***	3.681	0.014	0.214
α_{10}	−0.008	−0.175	0.293***	4.190	0.377**	2.156
α_{11}	−0.075	−0.867	−0.022	−0.315	0.140	1.131
α_{12}	−0.023	−0.497	−0.181	−1.621	−0.011	−0.108
α_{13}	0.125	1.023	0.190	1.555	−0.042	−0.463
α_{14}	−0.021	−0.740	0.085	0.799	−0.746***	−2.831

*, **, and*** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

TABLE 7 Output elasticities of various factors and returns to scale coefficient for NABEs.

Independent variables	Citrus-farming NABEs	Pepper-farming NABEs	Grain-farming NABEs
εA	0.803	0.584	0.439
εL	0.157	0.202	0.173
εG	0.187	0.179	0.081
εI	−0.443	0.244	0.153
Returns to scale coefficient	0.704	1.209	0.847
Moderate scale per labor (hm^2/person)	2.55	2.67	1.72

εA, εL, εG, and εI are the elasticity coefficients of land, labor, fixed assets, and liquid capital, respectively.

across crop-farming NABEs. Citrus and grain both have coefficients below 1 (0.704 and 0.847, respectively), indicating diminishing returns to scale. In contrast, pepper has a coefficient of 1.209, reflecting increasing returns to scale. Accordingly, the moderate-scale thresholds per labor are 2.55 hm^2 for citrus, 2.67 hm^2 for pepper, and 1.72 hm^2 for grain. Pepper-farming NABEs, therefore, have the largest moderate-scale operation, followed by citrus and then grain.

In general, the number of NABEs operating above or below the moderate scale is greater than the number operating at the moderate scale (Figure 5). For citrus-farming NABEs, 51.85% are below, 38.89% above, and only 9.26% at the moderate scale. For pepper-farming NABEs, 62.50% are below, 24.17% above, and 13.33% at the moderate scale. For grain-farming NABEs, only 2.04% are at the moderate scale, while 38.78% are below and 59.18% are above. These figures indicate that most NABEs operate either below or above the moderate scale, while relatively few operate at the optimal scale. However, many have the potential to reach it through appropriate land expansion.

Figure 6 shows the spatial distribution of NABEs by operation scale. The distribution of citrus-farming NABEs operating at the moderate scale is decentralized, although most are located in Baisha. Citrus-farming NABEs operating below the moderate scale are concentrated in the west and north of Baisha and the southwest of Longhua, while those operating above the moderate scale are mainly in the eastern and northwestern parts of Baisha. The distribution of pepper-farming NABEs at the moderate scale is highly centralized, with most located in Baisha. Compared with citrus-farming NABEs, those below the moderate scale are more dispersed, spanning Shimen, Ciyun, Baisha, and Yongxing, with concentrations in the southwestern part of Shimen and Ciyun. Pepper-farming NABEs operating above the moderate scale are relatively centralized, mainly in the northwestern part of Baisha and the northeastern part of Ciyun. The distribution of grain-farming NABEs at the moderate scale is highly centralized, with most located in Lishi. Those operating below the moderate scale are concentrated in the southern part of Lishi, while those above the moderate scale are relatively concentrated in the northwestern part of Baisha, the central part of Ciyun, and the western and southern parts of Xianfeng.

The natural and economic conditions of the 68 villages vary considerably (Figure 7). Most villages have favorable natural conditions for farming, with an average elevation of 278.89 m, a slope of 11.13°, a soil organic matter content of 12.75 g/kg, and an

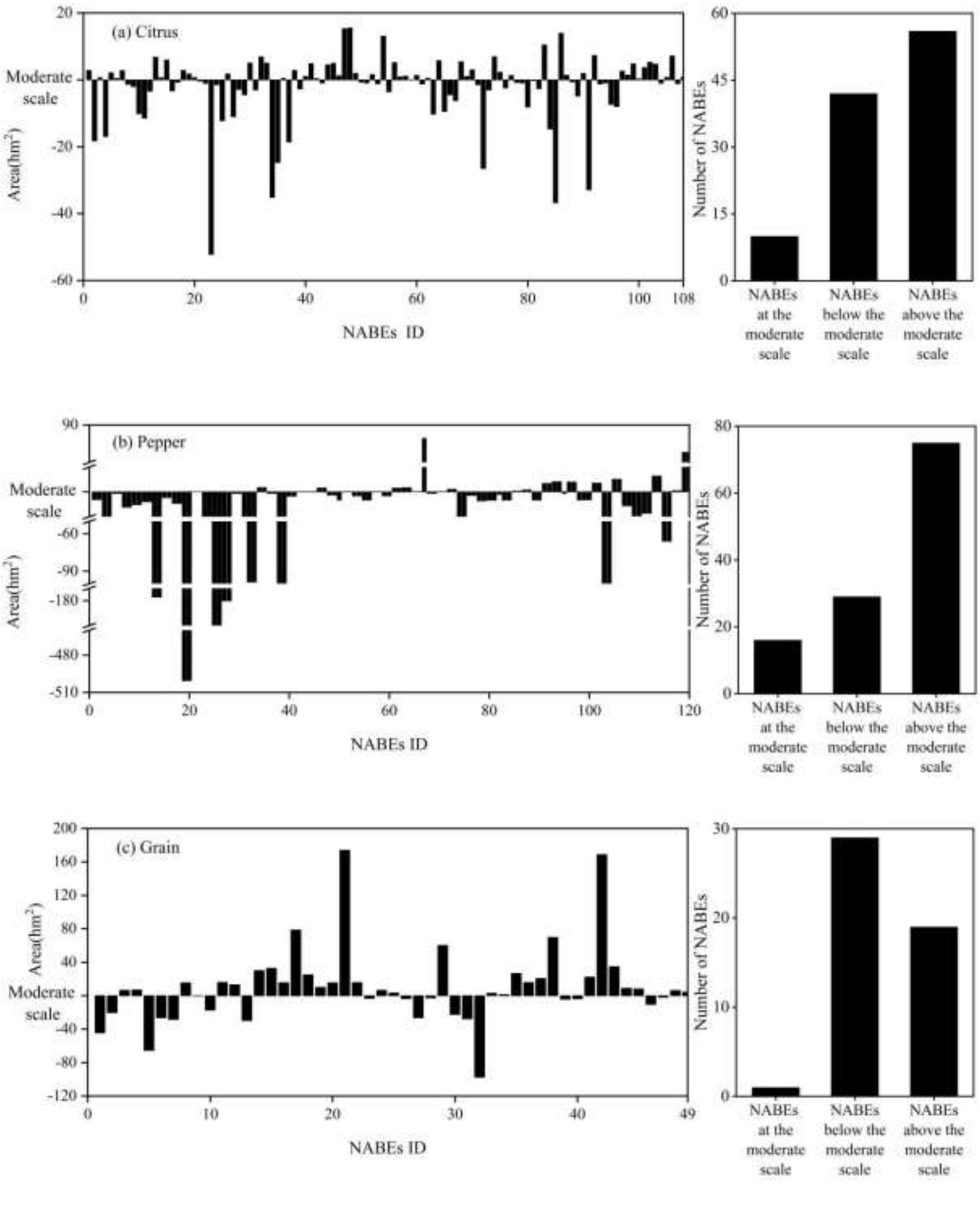

FIGURE 5
The moderate scale of NABEs by different crop farming types: **(A)** Citrus-farming NABEs, **(B)** Pepper-farming NABEs, and **(C)** Grain-farming NABEs.

effective soil layer thickness of 64.39 cm. Socioeconomic conditions are also favorable, with average annual household income standing at 112.27 yuan, an average rural labor force of 1,586.83 people, per capita cultivated land of 1.19 hm^2, an average land rent of 564.14 yuan, and an average distance from rural settlements to farmland of 747.56 m. Local government support is evident, with an average of 1.48 land consolidation projects per village. These conditions allow NABEs to identify suitable villages for moderate-scale operation.

3.2 The internal pathways of NABEs

For NABEs below or above moderate scale, internal pathways can facilitate the achievement of moderate-scale operations, with a more pronounced effect for those above moderate scale. As shown in Table 8, the model fit indices of the internal pathways SEM for citrus-, pepper-, and grain-farming NABEs across different scale types all fall within the acceptable range. These results indicate a good model fit and reliable estimation. After finalizing the path

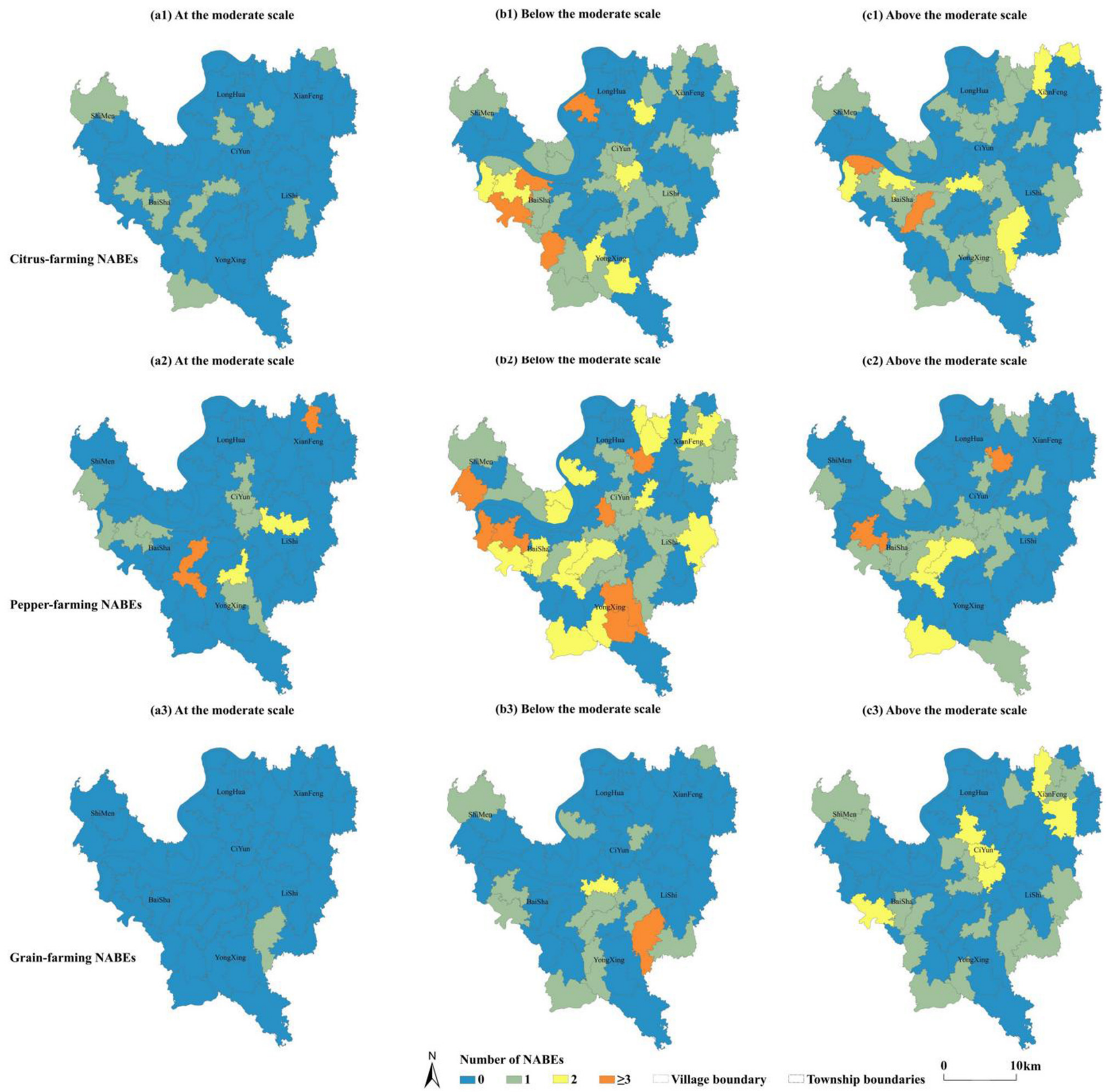

FIGURE 6
Spatial distribution of citrus-, pepper-, and grain-farming NABEs by operation scale.

models, path coefficients were calculated, and both direct and indirect effects of each pathway were analyzed. Table 9 presents the coefficient estimation results of the internal pathways SEM. Based on measurements of the direct, indirect, and total effects of internal pathways, the optimal internal pathways for citrus-, pepper-, and grain-farming NABEs were identified.

There are significant differences in the internal pathways through which citrus-, pepper-, and grain-farming NABEs achieve moderate scale (Figure 8). For citrus-farming NABEs operating below the moderate scale, the strongest internal influence is the combined effect of labor, fixed-asset investment, and land (total effect = 0.272). These NABEs should increase the availability of skilled labor, hire additional labor, and boost fixed-asset investment to expand land and thereby achieve moderate-scale operation. Conversely, citrus-farming NABEs operating above the moderate scale are most influenced by labor, business model, and land (total effect = 0.06). These NABEs need to reduce excessive labor, since overstaffing increases liquid capital investment and thus reduces production efficiency, and adjust their business models by optimizing organizational structures such as "entity + farmer + base," "entity + farmer," or "entity + base" to achieve moderate-scale operation. For pepper-farming NABEs below the moderate scale, the main internal drivers are labor, fixed-asset investment, and land (total effect = 0.049). These

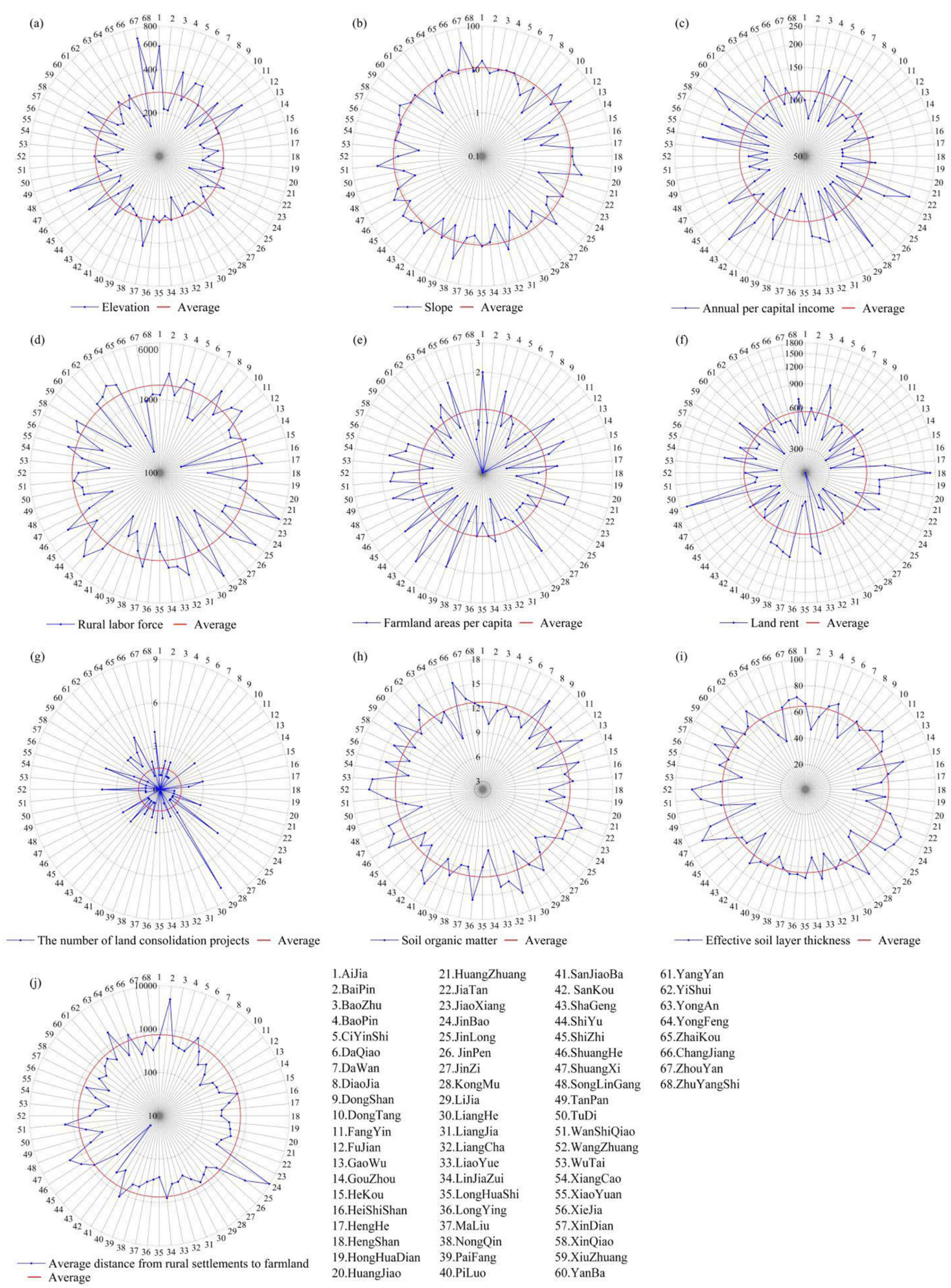

FIGURE 7
Characteristic indicators of 68 villages: **(a)** elevation, **(b)** slope, **(c)** annual per capita income, **(d)** rural labor force, **(e)** farmland areas per capita, **(f)** land rent, **(g)** the number of land consolidation projects, **(h)** soil organic matter, **(i)** effective soil layer thickness, and **(j)** average distance from rural settlements to farmland.

TABLE 8 The model fit indices for structural equation model of internal pathways of NABEs.

Types of NABEs		χ^2/df	CFI	GFI	TLI	NFI	RMSEA
Citrus-farming NABEs	Below the moderate scale	2.894	0.982	0.993	0.987	0.993	0.028
	Above the moderate scale	1.951	0.992	0.998	0.978	0.997	0.027
Pepper-farming NABEs	Below the moderate scale	1.631	0.993	0.998	0.989	0.995	0.029
	Above the moderate scale	2.930	0.992	0.998	0.991	0.999	0.034
Grain-farming NABEs	Below the moderate scale	1.142	0.992	0.999	0.993	0.999	0.045
	Above the moderate scale	2.450	0.993	0.998	0.990	0.999	0.031

χ^2/df, CFI, GFI, TLI, NFI, and Standardized Root Mean Square Residual (SRMR) are model fit indices for SEM. χ^2/df reflects the model's overall fit, with lower values indicating better fit ($1 < \chi^2/df < 3$). CFI and TLI assess incremental model fit compared to a null model (for CFI: 0.90–0.95 indicates acceptable fit; >0.95 indicates excellent fit; for TLI: 0.90–0.95 indicates acceptable fit; >0.95 indicates excellent fit). GFI and NFI evaluate overall model fit to the data and comparative fit, respectively (for GFI: <0.8 indicates poor fit; >0.9 indicates acceptable fit; for NFI: <0.8 indicates poor fit; >0.9 indicates acceptable fit). RMSEA estimates the approximation error per degree of freedom: <0.05 indicates excellent fit; 0.05–0.08 indicates acceptable fit; >0.10 indicates poor fit.

TABLE 9 Coefficient estimation results of the structural equation model of internal pathways of NABEs.

Indicator	Citrus-farming NABEs		Pepper-farming NABEs		Grain-farming NABEs	
	Below	Above	Below	Above	Below	Above
Fixed-asset investment<–Labor	3.287***	−0.133	0.498***	2.83***	9.325***	28.054***
Liquid capital investment<–Fixed-asset investment	0.244***	0.102***	0.491***	0.625***	0.276***	0.327***
Liquid capital investment<–Labor	−0.546***	−0.05*	0.348***	−0.194***	−0.046	−4.96***
Business model<–Labor	0.04***	−0.056***	0.011***	−0.01**	0.004	0.055***
Business model<–Fixed-asset investment	0.007***	0.002	0.003***	−0.006*	0.009***	0
Business model<–Liquid capital investment	−0.03***	0.02	−0.001	0.019***	−0.038***	0.001
Land<–Labor	2.562***	3.24***	0.507***	3.353***	0.021**	0.611***
Land<–Fixed-assets investment	0.083***	0.028***	0.099***	−0.137***	0.037***	0.014***
Land<–Business model	0.253*	−1.076***	−0.227	1.697***	−0.728***	1.306***
Land<–Liquid capital investment	−0.234***	0.08	0.249***	−0.026	−0.017*	0.069***
Gender<–Labor	−0.019***	0.005	−0.002***	−0.004**	−0.001	0.04***
Education<–Labor	−0.003	−0.016***	−0.002*	−0.002	0.019***	−0.009
Professional skills<–Labor	0.01**	0.017***	0.001	0.003**	0.006***	−0.024***

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

NABEs should enhance labor quality and productivity, increase fixed-asset investment, and accelerate infrastructure development to expand their land area. Pepper-farming NABEs operating above the moderate scale show a slightly negative internal effect from labor, liquid capital investment, and land (total effect = −0.003). To improve efficiency, these NABEs should reduce labor input and liquid capital investment and moderately scale down their land area. For grain-farming NABEs below the moderate scale, labor, fixed-asset investment, and land exert the strongest internal influence (total effect = 0.345). These NABEs should recruit better-educated laborers with agricultural expertise, increase labor input, and raise fixed-asset investment to expand their farmland. Grain-farming NABEs operating above the moderate scale also experience a strong internal effect from labor, fixed assets, and land (total effect = 0.39). However, to optimize their operational scale, they should reduce labor input and scale back both liquid capital and fixed-asset investment. Overall, achieving moderate-scale operation among citrus-, pepper-, and grain-farming NABEs primarily depends on improving labor quality, refining business models, managing fixed and liquid capital investments, and optimizing land use. NABEs below the moderate scale share a common pathway that emphasizes increasing fixed-asset investment. By contrast, those operating above the moderate scale require crop-specific internal adjustments: citrus-farming NABEs should focus on business model optimization, pepper-farming NABEs on reducing current asset investment, and grain-farming NABEs on decreasing fixed-asset investment to sustain moderate-scale operations.

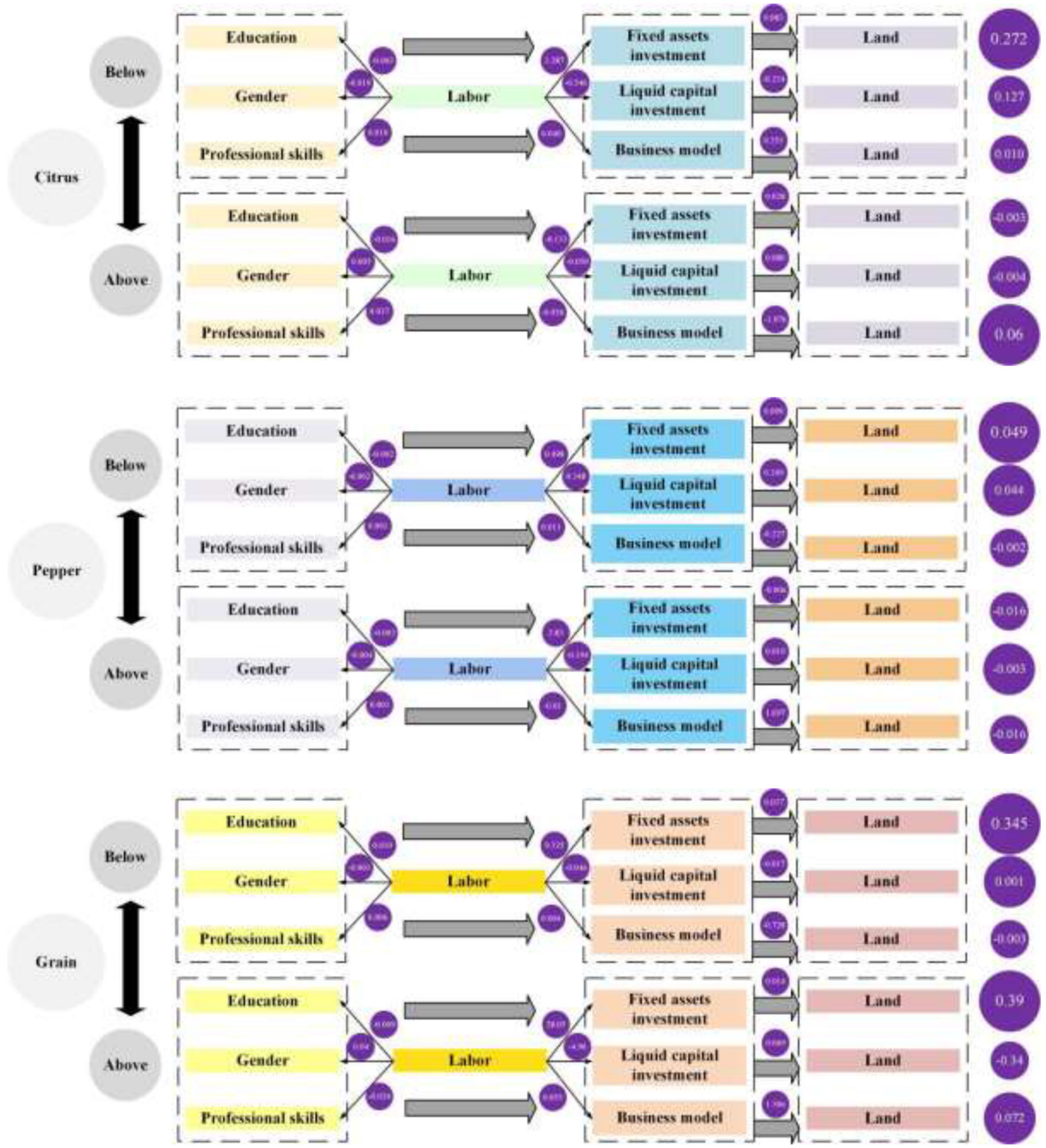

FIGURE 8
Internal pathways of citrus-, pepper-, and grain-farming NABEs.

3.3 The external pathways of NABEs

The land suitability requirements for planting vary significantly among different crop types (Figure 9). For citrus, the elevation of garden land, the cultivation radius of forest land, and elevation exert a significant impact on its cultivation. For pepper, key influencing factors include the effective soil layer thickness of garden land, land rent, cultivation radius of forest land, and effective soil layer thickness of grassland. For grain, soil pH, topsoil texture, and cultivation radius of cultivated land are the primary determinants of its planting suitability. Clearly, the influence of land type on crop suitability differs markedly across species. The results of planting suitability evaluations for different land types—based on crops' specific land requirements—are shown in

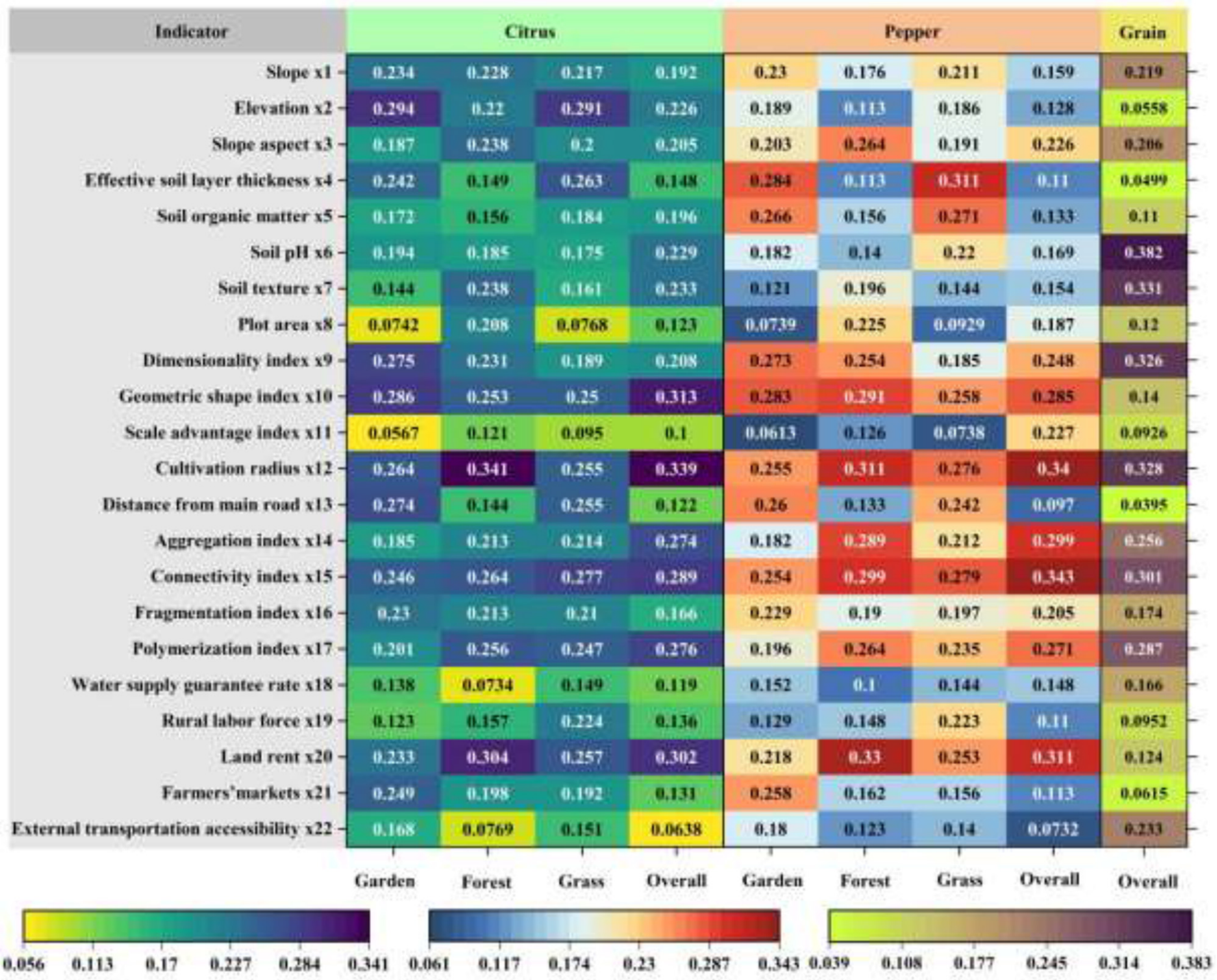

FIGURE 9
Direction vectors of land suitability factors for citrus, pepper, and grain planting.

Figure 10, which also illustrates the spatial distribution of different land types. Using the natural breakpoint method, land suitability is classified into five categories: highly suitable, relatively suitable, moderately suitable, marginally suitable, and unsuitable. Notably, there is a significant conflict in land suitability between citrus and pepper cultivation. Specifically, a substantial area of land is suitable for both crops, and the spatial distribution of such land is presented in Figure 11.

Based on the evaluation results and the delineation of planting conflict plots, external pathways for citrus-, pepper-, and grain-farming NABEs were identified. These pathways vary significantly across the three crop-farming NABE types, as illustrated in Figure 12. For citrus- and pepper-farming NABEs, three distinct paths are identified: the first path is highly and relatively suitable land, the second path is moderately and marginally suitable land, and the third path is land with cultivation conflicts. For grain-farming NABEs, the three paths are defined as highly and relatively suitable cultivated land, moderately and marginally suitable land, and unsuitable land. For citrus-farming NABEs, large-scale operations are concentrated in Xianfeng and northern Lishi (highly suitable garden land), central Baisha (moderately suitable), and Longhua (conflict land with peppers). When reserve resources such as forest and grassland are included, suitability broadens to most of Longhua and Xianfeng, with moderately suitable areas in southeastern Baisha and northern Yongxing, and conflict areas in central Shimen and Xianfeng. For pepper-farming NABEs, the primary suitable areas are Ciyun (highly suitable), southern Baisha and Yongxing (moderately suitable), and Longhua (conflict land). Reserve resources expand suitable zones to Longhua and Xianfeng, with moderately suitable areas in central Baisha and Yongxing, and conflicts in central Shimen and Xianfeng. For grain-farming NABEs, the highly suitable zone spans a broad northern area, with moderately suitable regions distributed in southern Baisha and from central to southern Lishi. Less suitable land is concentrated in southern Yongxing and southern Lishi.

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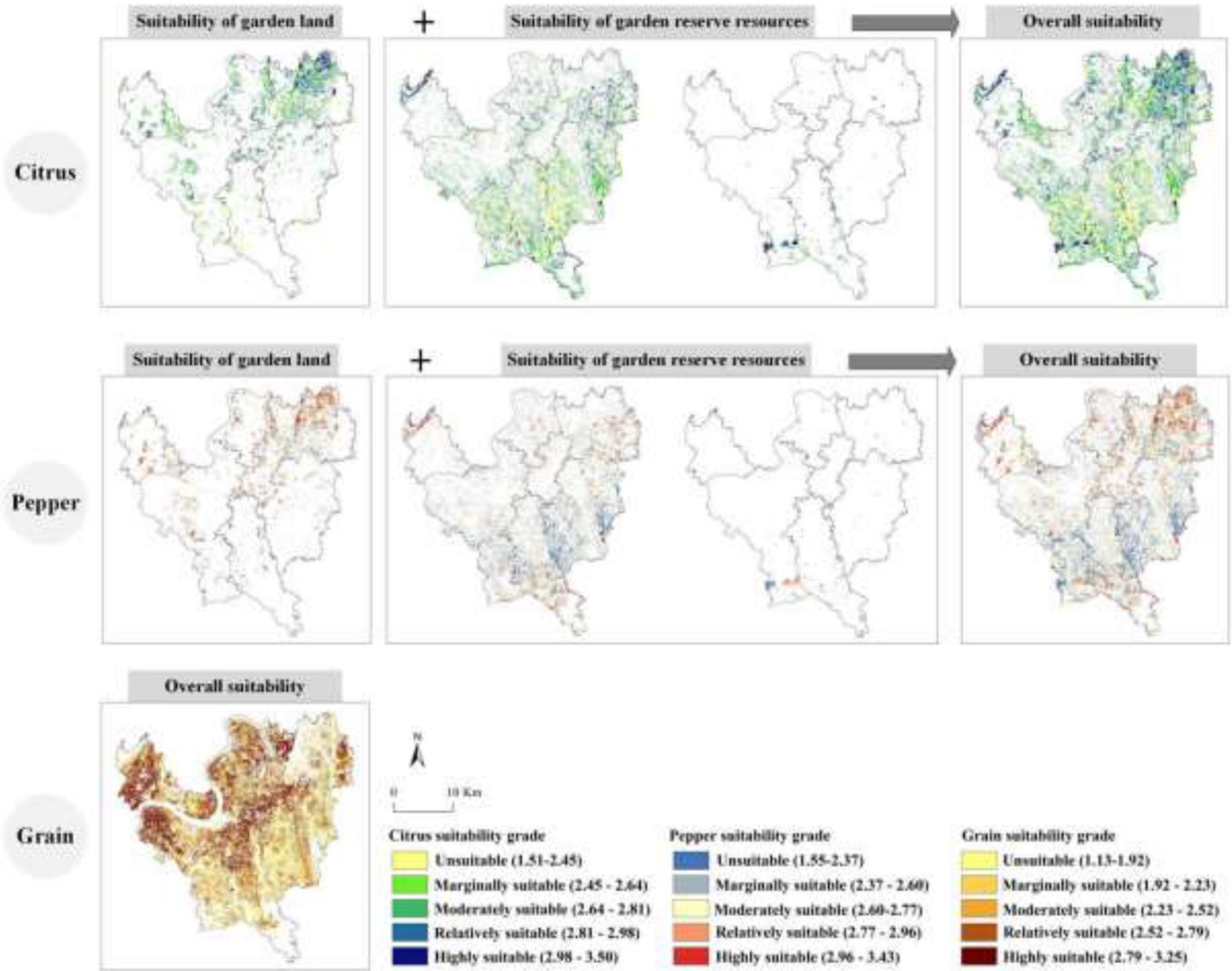

FIGURE 10
Evaluation results of land suitability for planting citrus, pepper, and grain.

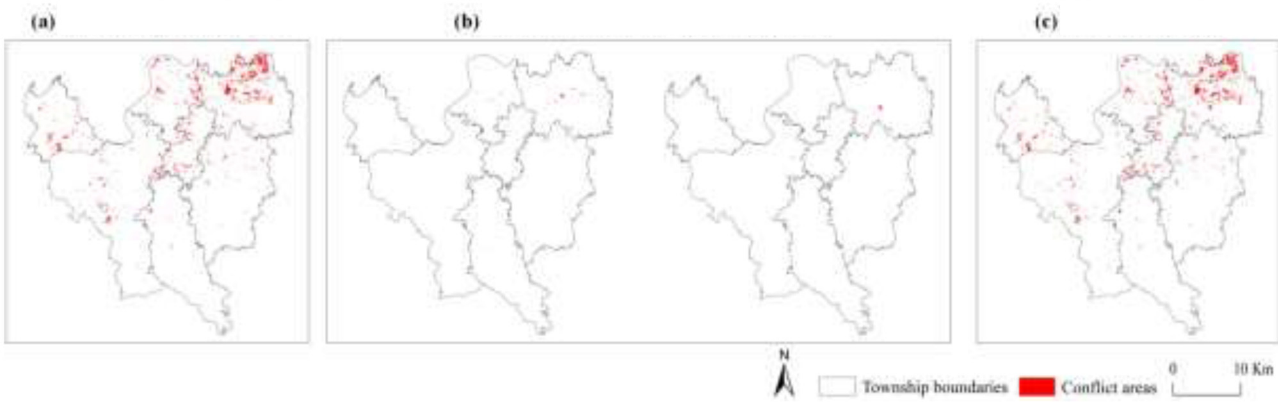

FIGURE 11
Land conflict areas of suitable planting for citrus and pepper. **(A)** Suitability of garden land **(B)** Suitability of garden reserve resources **(C)** Overall suitability.

As shown in Table 10, the model fit indices of the external pathways SEM for citrus-, pepper-, and grain-farming NABEs across different scale types all fall within the acceptable range. Specifically, all models exhibit Chi-square/degree of freedom ratios (χ^2/df) below 3, with Comparative Fit Index (CFI), Goodness of Fit Index (GFI), Tucker-Lewis Index (TLI), and Normed Fit Index

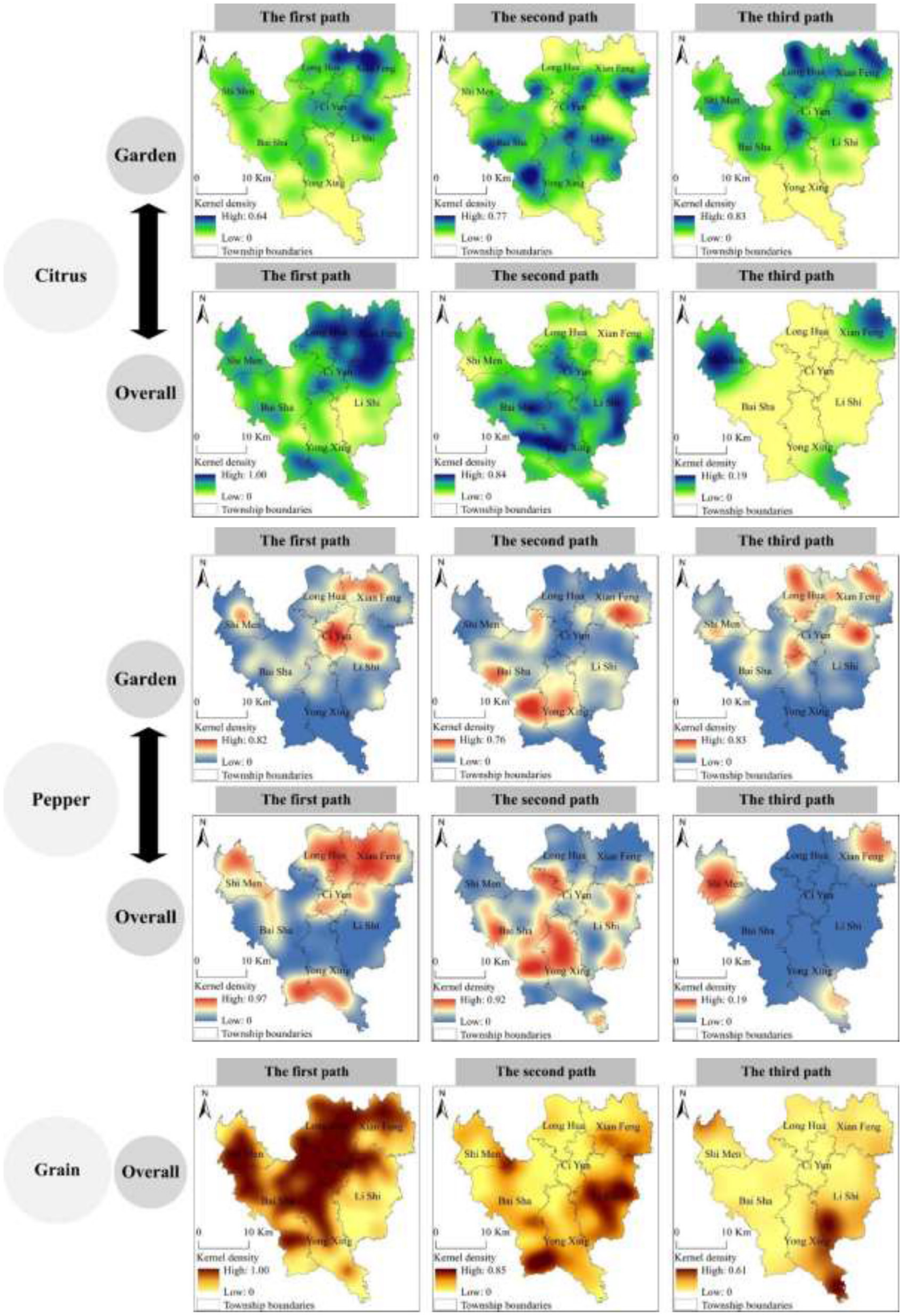

FIGURE 12
Multiple pathways of citrus-, pepper-, and grain-farming NABEs to achieve moderate-scale operation.

(NFI) values exceeding their respective thresholds and RMSEA values well below the maximum limit—collectively indicating a satisfactory model fit. Thus, the SEM developed in this study yields robust estimation results. Following the determination of final path models, path coefficients were calculated, and the direct and indirect effects of each pathway were decomposed. Table 11

TABLE 10 The model fit indices for the SEM of external pathways of NABEs.

Types of NABEs		χ^2/df	CFI	GFI	TLI	NFI	RMSA
Citrus-farming NABEs	Below the moderate scale	2.928	0.986	0.995	0.991	0.986	0.033
	Above the moderate scale	2.869	0.982	0.989	0.994	0.966	0.029
Pepper-farming NABEs	Below the moderate scale	2.930	0.987	0.992	0.986	0.976	0.034
	Above the moderate scale	2.948	0.984	0.993	0.988	0.981	0.035
Grain-farming NABEs	Below the moderate scale	2.167	0.988	0.996	0.992	0.987	0.046
	Above the moderate scale	2.022	0.991	0.996	0.993	0.987	0.039

presents the coefficient estimation results of the SEM. Based on measurements of the direct, indirect, and total effects of external pathways, the optimal external pathways for citrus-, pepper-, and grain-farming NABEs were identified.

There are significant differences in the external pathways through which citrus-, pepper-, and grain- farming NABEs achieve moderate scale (Figure 13). For citrus-farming NABEs operating below the moderate scale, the strongest external influence includes the physical-geographical environment, per capita farmland area, number of land consolidation projects, and the number of households below moderate scale (total effect = 0.000005). These NABEs should prioritize villages with favorable natural conditions for citrus, higher per capita land, and active government-led land improvement projects. Conversely, citrus-farming NABEs above the moderate scale are most influenced by the physical environment, land rent, and the number of households above the moderate scale (total effect = 0.394). These NABEs should select areas with low land rent and partial government remediation, reduce their operational land area, and maximize benefits at lower costs. For pepper-farming NABEs below the moderate scale, the dominant external factors include the physical environment, annual per capita income, distance from rural residential settlements to land plots, and the number of households below the moderate scale (total effect = 0.0002). These NABEs should focus on suitable environments for pepper cultivation, choose villages with higher farmer incomes, and prefer lands close to residential settlements, as peppers are high-value local specialties that encourage planting. For those above the moderate scale, the main external factors are the physical environment, land rent, and the number of households above the moderate scale (total effect = 0.192). Accordingly, selecting low-rent, improved land and moderately reducing land area are recommended for efficient scaling. Grain-farming NABEs below the moderate scale are most influenced by the physical environment, farmer income, distance to residence, and households below the moderate scale (total effect = 0.00015). These NABEs should choose villages with higher per capita income and close proximity to residential settlements to support moderate-scale operations, as grains are staple crops. Grain-farming NABEs above the moderate scale show similar external effects (total effect = 0.00015) and should either relocate to villages with greater per capita land and government land improvements or moderately reduce land area in their current locations. Overall, citrus-, pepper-, and grain-farming NABEs achieve moderate scale externally by selecting villages with favorable natural conditions, adequate per capita land, and active government land improvement. Entities below the moderate scale focus on enhancing external environments by selecting better villages and higher-quality land. By contrast, NABEs above the moderate scale tend to select locations with lower land rent and partial land improvements to balance scale and cost efficiency. Notably, citrus-farming NABEs below the moderate scale prioritize villages with larger per capita farmland and strong government support, while pepper- and grain-farming NABEs emphasize villages with higher farmer income and proximity to residential settlements.

4 Discussion

International agricultural farm sizes vary significantly across countries: medium and large family farms predominate in the United States, Canada, and Argentina (averaging over 300 ha); small- and medium-sized family farms dominate in France (under 80 ha); and small-scale farms prevail in China, Japan, and the Netherlands (under 2 ha) (Lin, 2017; Zhao et al., 2019; Luo et al., 2022). Given these disparities, defining "moderate-scale operation" in agriculture requires complex, multi-dimensional consideration across different systems. Key factors include cross-country differences in land endowments, economic development, agricultural technologies, mechanization rates, and policies, all of which shape how "moderate scale" is conceptualized (Eastwood et al., 2010; Li et al., 2015; Zhao et al., 2019; Zhang, 2018). Additionally, the moderate scale varies by crop type, including food crops, fruits and vegetables, and cash crops (Song et al., 2016; Zovincová, 2024). This observation is further substantiated by the empirical evidence from our study, which confirms the existence of significant variations in moderate-scale thresholds across pepper, citrus, and grain. Based on an average of 7.76 effective laborers per NABE household (Zhang et al., 2023), the moderate scale of NABEs was calculated as 13.35–20.72 hm^2, derived by multiplying the per-labor moderate scale (1.72–2.67 hm^2) by this labor number. Recent studies on farm size and scale operation across different contexts provide useful comparisons with our findings. Zhou et al. (2023) identified the appropriate management scale for paddy fields in Jiaxing to be 10-30 hm^2, which aligns closely with our grain scale estimates (1.72 hm^2 per laborer, equivalent to 13.25 hm^2 per household). Fan et al. (2018) indicated that crop type had little influence on the moderate scale but a substantial impact on net income; their study suggested that the moderate scale for economic and grain crops among traditional small farmers in hilly areas was 1.62 hm^2 and 1.64 hm^2 per household, respectively, based on maximizing per-labor income. Similarly, Liu (2024) indicated

TABLE 11 Coefficient estimation results of the SEM of external pathways of NABEs.

Indicator	Citrus-farming NABEs		Pepper-farming NABEs		Grain-farming NABEs	
	Below	Above	Below	Above	Below	Above
Annual per capita income<−Physic-geographical environment	0.01	0.164	0.174	0.169	0.151	0.151
Annual per capita income<−Average distance from rural settlements to farmland	−0.004***	−0.004***	−0.004***	−0.004***	−0.004***	−0.004***
Farmland areas per capita<−Physic-geographical environment	−0.007***	−0.007***	−0.007***	−0.007***	−0.007***	−0.007***
The number of land consolidation projects<−Average distance from rural settlements to farmland	0.001	0.001	0.001	0.001	0.001	0.001
Rural labor force<−Physic-geographical environment	−12.63***	−9.936	−12.891***	−12.986***	−5.886	−5.886
The number of land consolidation projects<−Farmland areas per capita	0.007	−0.023	−0.013	−0.015	−0.033	−0.033
Rural labor force<−Annual per capita income	6.003***	5.14***	5.125***	5.106***	5.017	5.017***
Rural labor force<−Average distance from rural settlements to farmland	0.056**	0.042	0.043*	0.043	0.043	0.043*
Land rent<−Physic-geographical environment	−8.593***	−8.996***	−8.698***	−8.779***	−8.489***	−8.489***
Land rent<−Rural labor force	−0.014*	−0.019**	−0.022**	−0.021**	−0.015*	−0.015*
Land rent<−Farmland areas per capita	105.11***	80.29***	79.174***	78.913***	78.198***	78.198***
Land rent<−The number of land consolidation projects	−21.43***	−21.17***	−19.823***	−21.72***	−28.77***	−28.768***
Elevation<−Physic-geographical environment	0.126	−0.018	0.033	0.011	−0.308	−0.308
Slope<−Physic-geographical environment	−0.042	0.118**	0.116***	0.102***	0.087***	0.087***
Effective soil layer thickness<−Physic-geographical environment	1.000	1.000	1.000	1.000	1.000	1.000
The number of households above or below moderate scale<−Physic-geographical environment	−0.012***	−0.004	−0.008	0.004	0.013***	0.003
The number of households above or below moderate scale<−The number of land consolidation projects	−0.108***	−0.16***	−0.034	−0.065***	−0.046***	0.027*
The number of households above or below moderate scale<−Land rent	0.001	0.001	0.001***	0.001**	0.001	0.001
The number of households above or below moderate scale<−Rural labor force	0.001***	0.001***	0.001***	0.001***	0.001***	0.001**
The number of households above or below moderate scale<−Annual per capita income	0.004***	0.001	−0.007***	−0.003***	−0.002***	0.001**
The number of households above or below moderate scale<−Average distance from rural settlements to farmland	0.001***	0.001	0.001***	0.001***	0.001***	0.001***
The number of households above or below moderate scale<−Farmland areas per capita	0.789***	−0.151**	0.408***	−0.078	0.384***	0.133**
Effective soil layer thickness<−Physic-geographical environment	0.664*	0.179***	0.163***	0.165***	0.163***	0.163***

*, **, and*** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

that under profit-maximizing conditions, the average moderate scale was 0.38 hm^2 per household in the Beibu Gulf Economic Zone of Guangxi, China. These results are significantly lower than our estimates. This discrepancy likely reflects that NABEs acquire additional land through transfers and hire more labor. Compared with traditional small farmers, NABEs, supported by more efficient resource allocation and stronger management capacities suitable for large-scale production, tend to have larger optimal moderate scales. As Ma et al. (2023) revealed efficiency differences among NABEs, finding that family farms had the highest average cross-efficiency values, with optimal operating scales of 600-667 hm^2 in Northeast China. Luo et al. (2025) determined that the optimal for wheat-maize systems in the North China Plain was 35–55 hm^2 per household, associated with lower Greenhouse Gases (GHG) emissions and higher net profits. Their emphasis on low-emission agronomic practices (such as optimized fertilization) aligns with our advocacy for crop-specific internal adjustments. These figures are much larger than our estimates, reflecting regional differences

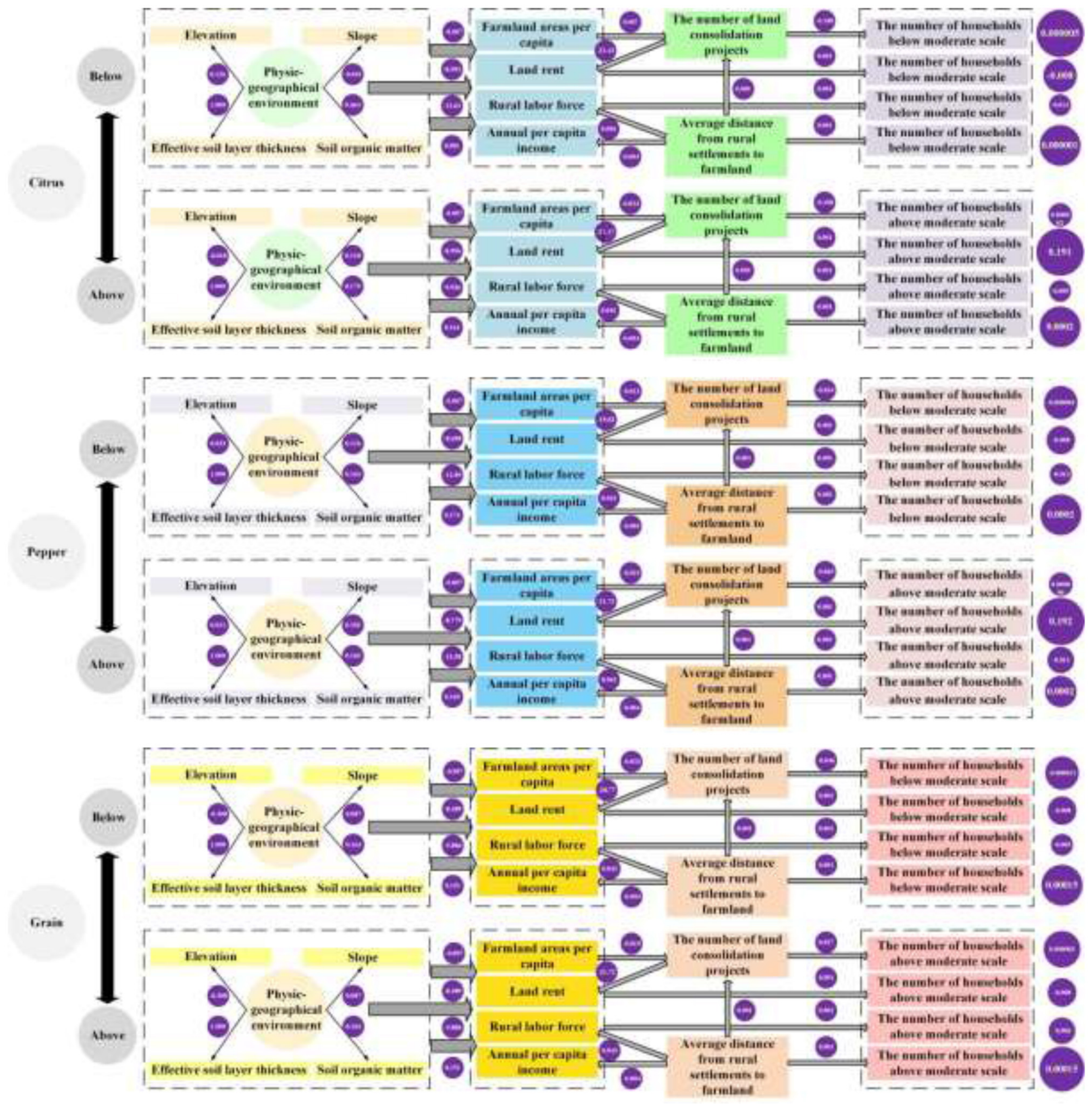

FIGURE 13
External pathways of citrus-, pepper-, and grain-farming NABEs.

in land endowments: flat plains enable larger scales, whereas hilly terrain constrains optimal size because of fragmented plots and mechanization limits. Additionally, Kiliç Topuz et al. (2025) identified the average hazelnut farm size in Türkiye as 2.5 hm^2, partly due to better access to extension services. This aligns with our citrus and pepper estimates, as hazelnut, citrus, and pepper share labor-intensive characteristics that rely heavily on manual cultivation. Meanwhile, Jänicke et al. (2024) found that medium- and large-sized farms in Germany ranged from 50 to 7,000 hm^2, underscoring how flat terrain enables larger scales and how farm size generally increased with field size across most federal states and crop types. These disparities stem from crop-specific land suitability requirements.

In the hilly and mountainous areas of Southwest China, the criteria for land selection by NABEs vary depending on the crops they grow. Over the years, the locations of citrus- and pepper-farming NABEs have often been inconsistent with the land suitability evaluation conducted in this study. Conversely, the locations of grain-farming NABEs align with it, as they are all situated on highly suitable land. For cash crops such as citrus and pepper, while suitable growing environments are essential, not all land in China meets the conditions required for their cultivation.

More importantly, China implements a strict land management system, which explicitly stipulates that cash crops, such as citrus and pepper, may only be grown on non-arable lands such as orchard land, with a strict prohibition on occupying arable land. By contrast, grain, which is essential to national food security, is given the highest cultivation priority, and high-quality arable land must be reserved for grain production. This principle is central to China's land use policy, making suitable arable land an indispensable foundation for grain cultivation. This policy-driven land use differentiation directly affects NABEs' ability to expand: grain-farming NABEs face limited access to high-quality arable land due to its scarcity in fragmented hilly areas, while citrus- and pepper-farming NABEs are restricted from using arable land, confirming their expansion to non-arable land or land transferred from smallholders (Yang, 2022). This, in turn, enhances agricultural productivity and supports the stable growth of smallholders' income (Xiong et al., 2023). Relevant studies indicate that the proportion of "moderately suitable" and "suitable" orchard land is significantly positively correlated with annual yield (Catalano et al., 2023; Wu et al., 2022), highlighting land suitability as a key factor influencing crop yield (Zhang et al., 2023). Grain farming shows the lowest attainment rate due to its strict dependence on high-quality, contiguous land. This aligns with our observation that grain-farming NABEs are exclusively clustered in areas classified as "high suitability," a scarce resource in fragmented hilly regions (Zhang, 2020). However, pepper demonstrates stronger adaptability to varied terrain, enabling pepper-farming NABEs to achieve the highest rate of moderate-scale operation.

NABEs have effectively overcome the constraints of fragmented smallholder farming through land transfer, large-scale management, and technological integration, thereby promoting the transformation of agriculture from fragmentation to moderate-scale operations (Zhang et al., 2023). However, their strategies vary depending on their current operational scale relative to the moderate-scale threshold and are further tailored to the characteristics of the crops they cultivate. For grain-farming NABEs, strategies include improving land consolidation to increase the contiguity of high-quality arable land. For citrus- and pepper-farming NABEs, optimizing cooperative land transfers to utilize suitable non-arable land is essential. Notably, the strategy of jointly developing diversified and mixed operations is still being implemented by NABEs (Zhao, 2020). Therefore, efforts should focus on achieving a moderate scale through a combination of internal and external pathways. Insights from cross-regional studies further validate the need for scale-specific optimization. Zhang et al. (2025) revealed a U-shaped relationship between farm scale and unit cost of corn farmers in China. Their finding that excessive scale leads to rising cost because of managerial bottlenecks directly supports our observation that NABEs exceeding the moderate scale must prioritize internal optimization, such as labor training and fixed-asset investment. However, their focus on plain regions with greater mechanization potential contrasts with our context, where resource allocation and crop-land matching are more critical for internal adjustments. Internally, for NABEs above moderate scale, optimization efforts must align with crop-specific scale sensitivities. Pepper-farming NABEs benefit most from replicating their successful integrated models (e.g., "NABEs + smallholders + production base") to stabilize efficiency, as their adaptability to moderate land quality reduces the risk of over-scaling (Meng et al., 2019; Li and Yu, 2020). Citrus-farming NABEs require stricter factor allocation, prioritizing labor training for slope management and capital investment in soil conservation practices such as cover cropping to mitigate terrain-induced inefficiencies (Mo et al., 2019). Grain-farming NABEs, despite rarely exceeding their scale threshold, should focus on precision input management strategies such as fertilizer optimization to prevent productivity losses. Existing studies also suggest that green, high-quality, and high-efficiency initiatives can support such internal adjustments by avoiding blind expansion and enhancing yield, quality, and standardization of planting systems, thereby improving overall productivity (Liu et al., 2020).

Externally, for NABEs below moderate scale, external strategies must prioritize crop-land matching. Cross-country and domestic comparisons further reinforce the importance of context-specific external support. In southern Ghana, Horlu et al. (2023) found that farm size was influenced positively by input expenditures, household sizes, crop type, farm credits, and subsidies, whereas labor scarcity hindered scale expansion. They recommend providing farm credits and subsidies, among other interventions, to sustain farm sizes. This highlights the role of external support in scaling, which resonates with our finding below that external pathways, such as land rent subsidies, are essential for NABEs at the moderate scale. However, in Ghana, smallholders often trade off food consumption to maintain farm inputs, a dynamic less evident in our study, where NABEs, as relatively larger operators, may have stronger resource buffers. Additionally, Hu et al. (2024) demonstrated that land consolidation, combining land tenure adjustment with engineering construction, significantly expanded plot scale (average plot area increased by 12.0%), reduced the number of plots by 28.8%, and promoted contiguous cultivation in China's Yangshan County. This aligns with our emphasis on land consolidation as a critical external pathway for NABEs below the moderate scale. However, their policy-driven focus on reducing fragmentation contrasts with our study's hilly terrain, where contiguous land is scarce and crop-specific land suitability, such as citrus on non-arable land, plays a more decisive role. Citrus-farming NABEs should focus on villages with larger per capita orchard land, aligning with their restricted planting zones, and should participate in government-led land consolidation projects. These efforts are consistent with national initiatives to establish agricultural production protection zones and advantageous areas for specialty agricultural products, which are developed based on local natural endowments (Wang et al., 2018). Pepper-farming NABEs, which are adaptable to diverse land types, benefit from proximity to residential areas, as this facilitates labor recruitment for frequent harvests. Grain-farming NABEs, which rely on high-quality land, should be prioritized in land consolidation efforts to improve the contiguity of their limited plots. This is particularly important as traditional smallholders face significant barriers to scaling. Therefore, government supervision of land transfer cooperation and support for the adoption of advanced equipment are essential for encouraging smallholders to participate in NABEs (Xu et al., 2021). Similarly, Su et al. (2023) stated that socialized farmland operation is the essence of farmland scale management. Realizing farmland scale management through farmland trusteeship entails meeting the requirements of socialized farmland use, management, and output. However, such trusteeship relies on strong rural collective action. Zheng et al. (2025) argued that land trusteeship entities and large-scale grain producers have competed for resources, particularly scarce and immovable land, leading to higher land transfer rent. This, in turn, has reduced both the number of local large-scale grain producers and the area of their operations. These perspectives align with our findings on external pathways, such as government-led land consolidation; however, whether the service operation scale characterized by outsourcing can fully replace the land operation scale driven by land transfer remains uncertain and warrants further study.

Notably, the interaction between internal and external pathways was further highlighted by Cheng et al. (2023), who found that farmland scale and agricultural eco-efficiency follow an inverted U-shape in China, with service outsourcing flattening this curve by reducing scale-related inefficiencies. This parallels our finding that internal optimization, such as business model adjustment, works for over-scale NABEs, while external strategies, such as land transfer, help NABEs below moderate scale expand. Such reliance on combined internal and external support aligns with global patterns, where agricultural scaling-up in developed countries relies heavily on land policies and technological support. For instance, in the United States, a country with abundant land resources, the expansion of family farm sizes was facilitated by direct subsidies and tax incentives that promoted land concentration in large-scale farms. At the same time, increased mechanization significantly raised the returns of large-scale farms compared to small- and medium-sized farms (MacDonald et al., 2013). By contrast, in resource-constrained countries such as Japan, South Korea, and the Netherlands, agricultural scaling-up was achieved not simply by expanding farm areas but through organizational restructuring, industrial chain integration, land consolidation, land transfer, targeted policy, and subsidy empowerment (Lin, 2017; Zhao et al., 2019; Luo et al., 2023). Our findings carry implications beyond Chongqing. In other mountainous regions of China, such as Sichuan and Guizhou, prioritizing crop-land matching, such as allocating grain cultivation to flat arable land and cash crops to sloped areas, and strengthening support for NABEs could accelerate the transition toward moderate-scale operations. For policymakers, it is therefore crucial to formulate both differentiated subsidy policies and measures that optimize the spatial layout of grain and oil crops. For NABEs above the moderate-scale threshold that depend on internal optimization, subsidies should enhance internal capacity by funding labor training, encouraging business model innovation, and supporting investments in machinery and storage facilities. For NABEs below the moderate-scale threshold, policies should instead enable scale expansion by providing subsidies for land rent and agricultural credit, directly assisting operators in scaling up through land transfer. In addition, policies should promote a gradual spatial replacement strategy, shifting arable farming to lower-lying areas while encouraging fruit and forest cultivation in mountainous regions.

Despite its widespread application in estimating the optimal scale of agricultural operations, the translog production function used in this study has several important limitations. While the model itself does not explicitly assume Hicks-neutral technical change, it fails to incorporate technological progress and its heterogeneous impacts across production factors, crops, or terrains. In practice, technological progress, such as mechanization (partially captured in fixed assets) or crop-specific cultivation techniques, often produces biased effects. For instance, labor-saving machinery disproportionately influences the substitution between labor and land, varying significantly by context. In hilly and mountainous areas, for example, complex terrain constrains the effectiveness of mechanization. Yet, the current specification does not account for how terrain shapes the substitution effect between machinery and labor, which may lead to biased estimates of scale elasticity. This omission limits the model's capacity to reflect how technical constraints in mountainous and hilly areas influence NABEs' scale thresholds. Crops also show distinct technical sensitivities. Pepper cultivation depends heavily on labor-intensive methods, whereas citrus requires specialized soil and water conservation technologies. Because the translog production function does not incorporate crop-specific technical variables or their interactions with factor inputs, such as the effect of labor quality on pepper cultivation, it risks obscuring crop-level technical requirements and misinterpreting moderate-scale thresholds. Future studies could improve the model by integrating technological variables, such as crop-specific coefficients or terrain-technology interactions, to refine moderate-scale estimations. Another limitation is its reliance on cross-sectional household survey data, which provides only a static snapshot of NABEs' operations at one point in time. This design restricts the model's capacity to capture changes in operational scale pathways, potentially biasing conclusions about stability and long-term effectiveness. Additionally, some NABEs engage in multi-cropping, such as pepper farms that also cultivate grain, where the allocation of labor and capital, as well as efficiency dynamics, is shaped by interactions between co-cultivated crops. To focus on crop-specific scale dynamics, this study classified NABEs into citrus, pepper, or grain-farming types according to their dominant crop, defined as the one occupying over 90% of the total planting area. Although this strict threshold helps isolate the influence of the core crop on scale decisions, it oversimplifies the complexity of multi-cropping systems. By reducing diverse planting practices to a single dominant crop, the data may obscure actual patterns of factor use, such as labor shared between crops, which can bias estimates of crop-specific moderate-scale thresholds. In addition, the representativeness of the data is limited by the sample: 277 NABEs drawn solely from Jiangjin Modern Agricultural Park, and restricted to citrus, pepper, and grain. These do not capture the full range of operational models or other crops in China's hilly areas. Moreover, because the findings are rooted in Chongqing's particular conditions, including fragmented landholdings, low mechanization, and municipal-level subsidies targeted to park-based NABEs, they may differ from results in China's plains or in international contexts with different land tenure systems,

10.3389/fsufs.2025.1501090

technologies, or subsidy frameworks. This regional boundedness reduces the generalizability of the estimated moderate-scale thresholds and limits their relevance to more complex agricultural systems. For crops with greater mechanization potential, such as wheat in northern China, or lower labor intensity, such as oil palm in Southeast Asia, optimal scales are likely to exceed our estimates. Similarly, the identified strategies of internal optimization vs. external expansion may not apply in areas with more active land markets or stronger technological support. Future research should therefore integrate panel data to capture long-term adjustments in scale, expand to multi-regional and multi-crop samples, and incorporate institutional moderators, such as land tenure arrangements and subsidy intensity, to enhance generalizability.

5 Conclusion

Our findings reveal significant variations in moderate-scale thresholds and achievement rates across crops: 2.55 hm^2 for citrus, 2.67 hm^2 for pepper, and 1.72 hm^2 for grain, with attainment rates of 13.33% for pepper, approximately 8% for citrus, and 2.04% for grain. This variation is closely linked to the land suitability of different crops: grain farming requires high-quality land, whereas citrus and pepper farming have lower land quality demands, which influences how easily NABEs can achieve moderate scales. Moreover, for NABEs operating above the moderate scale, internal pathways should be prioritized: enhancing labor quality, adjusting business models, and increasing investment in assets and liquidity. For those operating below this scale, external pathways are critical, given that land suitability for citrus, pepper, and grain is generally high, albeit with spatial conflicts—particularly between citrus and grain. To achieve scale expansion, these NABEs should focus on expanding into suitable areas: citrus-farming NABEs should prioritize villages with higher per capita arable land and improved land conditions, while pepper- and g rain-farming NABEs should target areas with higher per capita income and proximity to residential settlements. These findings contribute to existing research by quantifying crop-specific moderate operating scales for NABEs in hilly and mountainous areas and by clarifying contextually tailored strategies: differentiating internal pathways (for above-scale entities) and external pathways (for below-scale ones) based on crop-specific land suitability and operational realities, thereby providing targeted solutions for similar regions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

SZ: Writing – original draft, Writing – review & editing. XiZ: Writing – original draft, Writing – review & editing. XuZ: Writing – original draft, Writing – review & editing. ZL: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was supported by the National Natural Science Foundation of China (no. 41971244), the Ministry of Education Humanities and Social Sciences Research in Western and Border Areas Project (no. 24XJCZH022), and the Natural Science Foundation of Chongqing Municipal Science and Technology Commission (no. CSTB2025NSCQ-GPX1025).

Acknowledgments

We would like to thank Editage (www.editage.cn) for English language editing during the preparation and revision stages of this manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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