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Moderate operation scales of agricultural land under the greenhouse and open-field production modes based on DEA model in mountainous areas of southwest China

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ABSTRACT

The identification of the moderate scale of agricultural land was recognized as one of the key measures promoting sustainable agriculture development. However, due to the research gap in mountainous areas, new agricultural business entities (NABE) in these areas usually either refer to the plain area or simply pursue large scale, resulting in low production efficiency and even posing a threat to their sustainable survival. In this study, the Data Envelopment Analysis (DEA) model and Tobit regression model tools were employed to quantitatively reveal the moderate scale and key driving factors of agricultural land under the scale operation modes of greenhouse and open-field types. It was based on 154 NABE questionnaires in the mountainous areas around the Sichuan Basin in China, where NABEs are flourishing. The findings show an approximately "inverted U-shaped" curve relationship between NABE's production efficiency and their planting scale. The primary reason for the failure of NABE to achieve an overall high level of production efficiency is scale inefficiency. The optimal scale intervals for the greenhouse and open-field types of scale operation modes are 3.0–4.3 ha and 3.3–5.0 ha, respectively. Business entities' age, land circulation scale, land rent, and agricultural insurance are common factors that influence the scale efficiencies of both the greenhouse and open-field types. Accordingly, policy interventions regarding the guidance of moderate-scale operation of agricultural land are proposed for achieving the dual goal of cultivating NABE and implementing the Rural Revitalization Strategy in mountainous areas of China. While contributing to the knowledge on scale efficiency of agricultural land, this research also enlightens the practice of policy-making targeted to the sustainable development of agricultural industry led by NABE worldwide.

1. Introduction

Agriculture investment has been proved as an effective strategy for eradicating poverty, inequality and hunger [1], and shows great potential in biodiversity maintenance and rural environmental protection [2,3]. Based on this knowledge, agriculture has grown into a fundamental and pillar industry in many countries, especially in some developing countries where the sector shares a large part of the

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population [4]. Consequently, there is a continuous debate regarding what type or scale of agriculture should be promoted for better achieving the above mentioned functions [3,5]. For some scholars, smallholder farming or family farms are recommended as optimal types with the fact that they contribute a large share of the world's food production and that most food consumed in Africa and Asia is produced by local smallholders [6]. In contrast, some other scholars maintain that agricultural production typically follows Pareto's law that a small number of large and medium-sized farms undertake a majority of agricultural production functions [7]. The worldwide agricultural census data also verified that large and medium-sized farms operate about 75 % of the world's agricultural land, while small farms (less than 2 ha) only operate about 12 % of the world's agricultural land [5]. In China, despite that agricultural land are traditionally dominated by smallholders [8], it is verified that with a 1 % increase in farm size is associated with a 1 % increase in agricultural labor productivity, a 0.3 % and 0.5 % decrease in agricultural chemicals input and only leads to a statistically insignificant 0.02 % decrease in crop yields [9]. Actually, the average farm sizes increased in most countries worldwide during the past decades, especially in some middle to upper income countries and nearly all of the high income countries [5,10].

However, as far as the operation scale of agricultural land is concerned, bigger is not always better. Many studies indicate that there is an "inverted U-shaped" curve relationship between agricultural business entities' scale and their production efficiency [11,12]. The identification of the moderate scale of agricultural land was recognized as one of the key solutions for promoting sustainable agriculture development [13,14]. Our literature review shows that existing related studies mostly concentrate on plain areas [13,15,16], and mainly taking single food crops or cash crops planted on family farms as research objects [13,15]. The research methods involved mainly include the data envelopment analysis (DEA) model [14], the production function [17], the input-output model [18], and the threshold model [19]. As seen from research conclusions, the determination results of moderate scale vary greatly with the specific regions and types of agricultural business entities and the specific variety of crops [19,20].

Mountainous and hilly areas are characterized by a high level of agricultural land fragmentation and more diversified crop types, making factors influencing the benefits of scale operation are especially complex there. Although a few studies have attempted to explore the phenomenon of moderate scale operation of agricultural land in mountainous areas [20,21], they have not yet received adequate attention when compared to plain areas. As a result, agricultural entities in mountainous areas usually refer to plain areas when determining their operation scale, and blindly pursue large scale without a thorough consideration of production efficiency. Both aspects have led to many agricultural entities in mountainous and hilly areas are exposed to serious challenges threatening their sustainable survival [22,23].

Scaled agricultural land are operated by many kinds of large and medium-sized agricultural business entities, including family farms, agricultural enterprises, and specialized cooperatives [23]. These entities are classified as new agricultural business entities (NABE) for distinguishing them from traditional smallholders. Generally, NABE has the distinctive ability of realizing economies of scale through large-scale operation, management innovation, and efficiency improvement [23,24]. Besides, many studies have demonstrated that NABE plays a significant driving role in promoting regional agriculture development, rural socio-economic stability, and farmers' income increase [25,26]. The nurture of NABE has been recognized as an effective strategy for many countries where NABE are leading the sustainable development of agriculture and rural socioeconomy [9]. How to identify the moderate scale of NABE and their influencing factors becomes a prerequisite for the nurture of NABE, especially for mountainous and hilly areas where the related research gaps are much larger than plain areas.

As a mountainous country, about two thirds of China's land area are occupied by mountains. In the past decades, the implementation of a succession of rural strategies in China, such as coordinated urban-rural development, new rural construction, land circulation, and poverty alleviation, has broken the traditional agricultural production pattern of smallholders' absolute dominance [9]. Instead, NABE are now leading China's new pattern of scale operation and standardized agricultural production [27,28]. The "No. 1 Central Document" for 2022 also proposes to foster the high-quality development of NABE in order to provide strong support for boosting rural revitalization and accelerating agricultural modernization. However, China's agricultural industry still faces bottlenecks such as low industrialization level, weak competitiveness, and improper operation scale [9,29], and a number of new issues have emerged, such as the short-term growth of agricultural industry and the false prosperity of agricultural business entities [22]. Consequently, the scale operation of agricultural land, as well as the cultivation and development of NABE are becoming an inevitable trend for the purposes of resolving the puzzle of "who is going to do farm work" and accomplishing the multiple goals of the rural revitalization strategy [30].

Despite of the high level of land fragmentation and diversified crop types, scale operation modes of agricultural land in mountainous and hilly areas can be simplified as greenhouse and open-field types based on the distinctive management methods. Taking a typical area in the mountainous areas around the Sichuan Basin in China as study area, this study uses the DEA model to explore the moderate scale of agricultural land operated by NABE under the different operation modes of greenhouse and open-field types. It also analyzes the key driving factors influencing the scale efficiency of NABE from multiple dimensions of individual characteristics of NABE and their production and operation characteristics, aiming to provide policy guidance for the development of NABE in mountainous areas. As compared to the existing literature, this study mainly contributes to differentiate the scale-operated agricultural land in mountainous areas as the greenhouse and open-field types according to their different production modes, and distinguished their moderate scales and influencing factors.

Section 2 details our data sources and methodological approach, including the theory of DEA model and Tobit regression model, as well as the screened indicators used in the two models. In Section 3 and Section 4 we present and discuss our results with the differentiated greenhouse and open-field production modes of agricultural land. Finally, Section 5 outlines the main conclusions.

2. Data and methods

2.1. Overview of the study area

This study takes two typical mountainous areas around the Sichuan Basin in China as the study area (Fig. 1). One of the typical area, Nanjiang County, located at the northeastern margin of the Sichuan Basin, is under the jurisdiction of Bazhong City, Sichuan Province, with a total area of 3389.5 km^2. The primary geomorphic type of the county is mountains and hills, and the terrain is high in the north and low in the south (370–2507 m). The county has a subtropical monsoon humid climate, with annual precipitation of 1200 mm, an annual average temperature of 16.2 °C, and a frost-free period of 259 d. Some specialties including plums, tea and walnuts are popularly planted here, and mainly under the scale operation mode of open-field type. At the end of 2020, there were 31 townships (towns), 309 villages, and about 460,000 people under the county's jurisdiction. The country's population density was 137.96 people/ km^2, and its agricultural population accounted for 62.05 % of its total population. In 2020, Nanjiang County had a GDP of 13.982 billion yuan and a per capita disposable income of 14,387 yuan for farmers [31].

Another typical area, the Anning River Basin, located at the southwestern margin of the Sichuan Basin, is under the jurisdiction of Liangshan Yi Autonomous Prefecture, Sichuan Province. It mainly covers Mianning County, Xide County, Dechang County, and Xichang City, with a total area of 11,150 km^2. The basin has a subtropical monsoon humid climate, with abundant sunlight, annual precipitation of 1079 mm, an annual average temperature of 17.2 °C, and a frost-free period of 270 d. Some special fruits and vegetables including grapes, strawberries and tomatoes are popularly planted here, and mainly under the scale operation mode of greenhouse type. At the end of 2020, the basin had a total population of about 1,734,800 and a population density of 147.07 people/ km^2. The agricultural population comprised 50.19 % of its total population. In 2020, the basin had a GDP of about 80.482 billion yuan, and farmers had a per capita disposable income of 18,473 yuan [32].

2.2. Data sources

The data were mainly derived from the questionnaire interviews of NABE in the study area from October to November 2021. The interviewees were selected using stratified random sampling. Firstly, two typical townships (towns) were selected from each county based on the development status of the agricultural industry in various townships (towns) of each typical county. Then 20–30 NABE were randomly selected from each sampled township (town) for semi-structured questionnaire interviews. The questionnaire mainly investigated basic information, cost-benefits, land circulation, future development expectations, and other required information about NABE. Data were collected via face-to-face interviews with NABE entities, and this process took about 1.5–2 h. Valid questionnaires (n = 154) had an effective rate of 96.25 %. Field surveys have shown that scale operation of agricultural land in mountainous and hilly areas can be categorized as greenhouse and open-field types. The obtained 154 valid questionnaires include 54 greenhouse type questionnaires and 100 open-field type questionnaires.

2.3. Model methods

2.3.1. DEA model

(1) The basic principles of DEA model

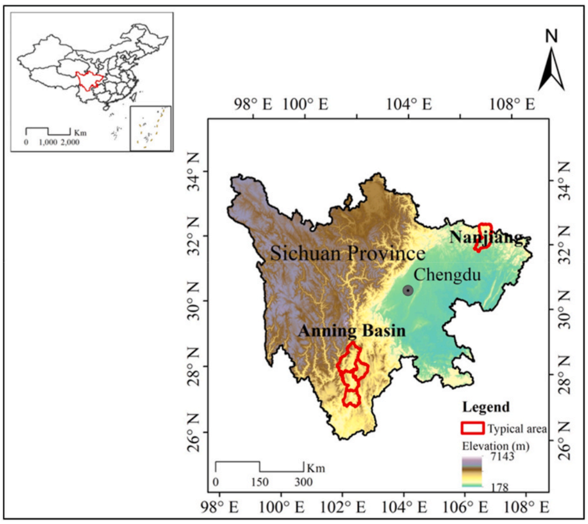

Fig. 1. Location of the study areas.

The production efficiency of NABE can be seen as the maximum input-output ratio that can be achieved under certain production conditions [25]. DEA is a common tool for efficiency evaluation, and is widely used in the fields of operations research, management science, and mathematical economics [33]. According to the principle of DEA models, the efficiency status can be judged by comparing the relative effectiveness between "decision-making units (DMUs)" with multiple inputs and outputs data. The essence is to judge whether a DMU is located at the production frontier [34]. The two most representative DEA models are the CCR model based on the constant returns to scale (CRS) assumption and the BCC model based on the variable returns to scale (VRS) assumption [35]. Where, the DEA-CCR model was named after its first proposers of Charnes, Cooper and Rhodes, and the DEA-BCC model was named after its first proposers of Banker, Charnes and Cooper [36]. In addition, DEA models can be further classified into input-oriented and output-oriented models. Compared with the CCR model, which can only measure comprehensive technical efficiency, the BCC model can decompose the obtained technical efficiency into pure technical efficiency and scale efficiency [36]. The pure technical efficiency refers to improving the production efficiency through technical means under the same resource conditions. However, the super-efficiency DEA–SE model presented by Andersen et al. deletes the constraints with an output/input ratio of ≤ 1 to ensure consistency with traditional DEA evaluation in the case of invalid DMUs. In the presence of valid DMUs, multiple valid DMUs can be ranked to screen out the optimal DMU [37]. Considering that agricultural business entities can only control inputs but cannot regulate outputs in production, this study employs an input-oriented DEA–BCC model based on the premise of VRS [35]. The function form is as equation (1):

$$\min[\theta - \varepsilon(e^t s^- + e^t s^+)]$$

$$s.t.\begin{cases} \sum_{i=1}^{n} \lambda_i x_i + s^- = \theta x_0 \\ \sum_{i=1}^{n} \lambda_i y_i - s^+ = y_0 \\ \sum_{i=1}^{n} \lambda_i = 1 \end{cases} \tag{1}$$

$$\lambda_i \geq 0; i = 1, 2, \ldots, n; s^- \geq 0, s^+ \geq 0$$

where x_i and y_i denote input and output indicators, respectively; x_0 and y_0 denote the original input and output indicators of DMUs, respectively; n denotes the number of DMUs; ε denotes the non-Archimedean infinitesimal; λ_i denotes the coefficient of DMUs; e^t denotes the single-row vector; s^- and s^+ denote the slack variables of input and output, respectively; θ ($0 \leq \theta \leq 1$) denotes the production efficiency of DMUs, i.e., comprehensive technical efficiency (which is valid when $\theta = 1$ and invalid when $\theta < 1$).

While the results of the BCC model may have multiple valid DMUs, the super-efficiency DEA–SE model can screen out the optimal DMU by comparison of the efficiency of valid DMUs and thus make up for the defects of the BCC model [35]. Therefore, the DEA–SE model was further used for efficiency analysis and ranking. The functional form is as equation (2):

$$\min[\theta - \varepsilon(e^t s^- + e^t s^+)]$$

$$s.t.\begin{cases} \sum_{\substack{i=1 \\ i \neq i_0}}^{n} \lambda_i x_i + s^- = \theta x_0 \\ \sum_{\substack{i=1 \\ i \neq i_0}}^{n} \lambda_i y_i - s^+ = y_0 \end{cases} \tag{2}$$

$$\lambda_i \geq 0; i = 1, 2, \ldots, n; s^- \geq 0, s^+ \geq 0,$$

where θ denotes the super-efficiency value of DMUs; i_0 denotes the DMU under evaluation. The meanings of other variables are the same as those in equation (1). The DEA–SE model has been improved, in that DMU i_0 is compared with the linear combination of all the other DMUs in evaluation, and that the linear combination of the inputs and outputs of all the other DMUs is used to represent the input and output of DMU i_0, thus leaving out DMU i_0 [35]. The constraints with an efficiency indicator of < 1 are deleted in the calculation, so that the efficiency value θ obtained can break through the threshold of 1, that is, serve as the super-efficiency value.

(2) DEA model indicators

Screened input and output indicators are needed when using the DEA model. Most studies take land, capital (such as fertilizers and seeds costs), and labor as input indicators [14], and select agricultural operating income and agricultural production value (crop yield or output value) as output indicators [38,39]. Since DMUs may differ greatly due to the varied input-output values of different crops

[39], some indicators reflecting the total quantity were screened as the input-output indicators in this study (Table 1).

Specifically, some capital input variables including land rent, agrochemicals cost, labor cost, and the depreciation cost of fixed assets, such as plastic greenhouses and agricultural machinery were screened as input indicators [14]. Hereby, land input refers to the total land area operated by NABE, including their self-owned land and transferred land [43]. The depreciation cost of fixed assets is calculated from the total price of agricultural materials and their service life. Labor input refers to the total amount of labor consumed in the whole process of production and operation, including family labor and hired labor [21].

In terms of output indicators, the indicator of total yield refers to the total yield of crops harvested by NABE during one year. It can directly reflect NABEs' scale and operating results [43]. The indicator of total net profit refers to the net profit obtained by NABEs through production and operation during one year, which can directly reflect NABEs' economic benefits and operating capacity [38].

(3) The implementation steps of DEA model

Firstly, before using the DEA model, it is necessary to subject indicators to the homogeneity test, ensuring that output values increase with input values [14]. This study analyzes the correlation of various input and output indicators based on Pearson correlation coefficients by using the SPSS 23.0 software. Secondly, since the land operation scale of the study area spans a large scope, and is shown as hundreds of discrete scale values, it is needed to utilize a clustering method for producing several intervals with continuous scale values, which are called DMUs in the DEA model. Since the hierarchical clustering method can cluster samples with high correlation or similarity into a small category or cluster samples with low correlation or similarity into a large category, it was used for producing several DMUs in this study (Table 2). Thirdly, the DEA–BCC model was applied to analyze multiple valid DMUs by using the DEAP 2.1 software. Finally, the super-efficiency DEA–SE model was applied to identify the optimal DMU by using the EMS software.

2.3.2. Tobit regression model

(1) The basic principle of Tobit regression model

Considering that the scale efficiency values calculated by the DEA–BCC model range from 0 to 1 with censored distribution, the Tobit regression model should be applied to analyze the factors influencing the moderate scale of NABE [14]. The basic principle of this model is as equation (3):

$$y_{it} = \begin{cases} \beta^T x_{it} + \varepsilon_{it}, \beta^T x_{it} + \varepsilon_{it} > 0 \\ 0, otherwise \end{cases} \tag{3}$$

$$i = 1, 2, \ldots, n$$

where y_{it} denotes the explained variable; x_{it} denotes the explanatory variable; β^T denotes the vector of the regression coefficient of the explanatory variable; $\varepsilon\varepsilon_{it}$ denotes the stochastic error term. Tobit regression analysis is performed using STATA16.0 software.

(2) Tobit model indicators

Agricultural production efficiency may be affected by multiple factors, including business entities' individual characteristics (such as age and education level), agricultural material inputs (such as pesticides, fertilizers, and machinery), and socialized services (such as technical training, financial credit, and brand certification) [44,45]. For exploring the factors influencing the scale operation efficiency

Table 1
Descriptive statistics of the input-output indicators of NABE.

Variable category	Variable name	Unit	Reference	Scale operation mode of greenhouse type (n = 54)	Scale operation mode of open-field type (n = 100)
Capital input	Seedling cost	Yuan[a]	([14,21, 38])	939.55 ± 1017.22	227.57 ± 228.15
	Fertilizer cost	Yuan[a]		2478.06 ± 1352.26	464.55 ± 224.33
	Pesticide cost	Yuan[a]		541.91 ± 607.97	155.41 ± 166.79
	Agricultural film cost	Yuan[a]		324.89 ± 485.23	61.19 ± 56.62
	Land rent	Yuan[a]		2334.72 ± 830.87	338.11 ± 216.78
	Labor cost	Yuan[a]		1300.20 ± 1360.78	441.38 ± 357.93
	Depreciation cost of fixed assets	Yuan[a]		1428.35 ± 1114.04	85.34 ± 110.14
Labor input	Family labor	Person	([14,40, 38])	3.19 ± 3.25	2.87 ± 1.76
	Hired labor	Person		39.83 ± 41.39	68.23 ± 90.94
Land input	Self-owned land area	ha	([14,41, 42])	0.27 ± 0.32	0.36 ± 0.90
	Transferred land area	ha		3.07 ± 3.43	5.19 ± 6.61
Output	Total yield	5000 kg	([14,38, 41])	19.77 ± 18.49	25.00 ± 28.73
	Total net profit	10,000 Yuan[a]		68.09 ± 65.99	41.93 ± 44.90

Note: [a] 1 USD ≈ 6.45 yuan (during the study period).

Table 2
Input-output values of each cluster of land operation scale.

Scale operation modes of agricultural land	DMU (Operation scale, ha)	Land input (ha)	Capital input (10,000 Yuan)	Labor input (person)	Total yield (5000 kg)	Total net profit (10,000 Yuan)
Greenhouse type	[0.27–1.33]	0.70 ± 0.27	9.53 ± 5.01	10.13 ± 3.42	4.65 ± 2.13	12.15 ± 6.38
	[1.33–3.00]	1.74 ± 0.40	24.19 ± 7.11	25.11 ± 4.64	11.89 ± 3.12	41.97 ± 15.55
	[3.00–4.33]	3.67 ± 0.31	52.74 ± 15.09	35.00 ± 9.46	23.82 ± 2.97	82.25 ± 14.57
	[4.33–7.33]	5.53 ± 0.82	77.18 ± 18.24	77.00 ± 25.98	31.66 ± 10.99	110.77 ± 27.35
	[7.33–10.00]	8.98 ± 0.84	123.56 ± 16.37	112.25 ± 24.81	48.02 ± 8.51	173.02 ± 80.61
	[10.00–14.00]	12.87 ± 1.36	177.33 ± 40.19	151.33 ± 0.58	68.87 ± 16.52	235.80 ± 88.53
Open-field type	[0.33–1.67]	0.88 ± 0.33	2.30 ± 1.36	12.58 ± 5.68	4.17 ± 2.44	7.08 ± 4.51
	[1.67–3.33]	2.40 ± 0.39	6.29 ± 1.61	28.64 ± 12.99	12.76 ± 3.15	20.41 ± 4.53
	[3.33–5.00]	4.10 ± 0.48	12.89 ± 9.67	45.53 ± 22.11	20.77 ± 7.18	37.77 ± 8.98
	[5.00–6.33]	5.52 ± 0.34	12.48 ± 4.43	57.78 ± 29.89	24.11 ± 7.94	38.29 ± 10.11
	[6.33–8.67]	7.19 ± 0.62	19.73 ± 4.07	88.22 ± 58.21	33.49 ± 13.33	58.59 ± 9.99
	[8.67–12.00]	10.23 ± 0.30	27.75 ± 6.39	149.75 ± 3.30	47.58 ± 11.20	77.15 ± 23.77
	[12.00–16.67]	14.27 ± 1.12	37.82 ± 3.41	191.00 ± 17.13	65.60 ± 9.96	105.37 ± 27.18
	[16.67–21.33]	20.00 ± 0.00	48.90 ± 0.00	303.00 ± 0.00	79.98 ± 0.00	127.05 ± 0.00
	[21.33–24.67]	22.93 ± 1.32	63.36 ± 5.15	275.50 ± 36.06	103.20 ± 5.94	157.46 ± 28.86
	[24.67–28.00]	26.42 ± 0.50	69.76 ± 1.70	380.75 ± 20.66	117.87 ± 5.23	183.08 ± 20.37

of NABE, the Tobit regression model was used in this study based on the screened two types of variables including NABEs' individual characteristics, and their production and operation characteristics (Table 3).

The screened indicators of NABEs' individual characteristics include their age, education level, and number of family labor. Some scholars believe that older business entities have richer experience, which is conducive to improving agricultural production efficiency [46]. Others counter that, compared with young people, older business entities are going downhill in terms of health status and learning ability, and thus compromising agricultural production efficiency [14]. On this basis, this study assumes that the effect of business entities' age on the scale operation efficiency of agricultural land is uncertain. Generally speaking, business entities with a higher education level can more easily master new knowledge and apply new technologies, thus facilitating agricultural production efficiency [47]. More family labor helps to reduce labor costs, however, in terms of working efficiency and the sense of responsibility, there may be differences between family labor and hired labor. Consequently, this study assumes that the effect of family labor quantity on scale efficiency is also uncertain.

Investments in land, fertilizers, pesticides, and fixed assets are bound to affect the production efficiency of NABE [16]. Influenced

Table 3
Descriptive statistics of factors influencing the scale efficiency of NABE (Mean ± Std.).

No.	Variable name	Model 1[a] (n = 54)	Model 2[b] (n = 100)	Expected direction
Individual characteristics				
X1	Household head age	48.83 ± 11.92	46.89 ± 9.79	+/−
X2	Household head education (1 = primary school and below; 2 = junior high school; 3 = senior high school; 4 = College degree or above)	3.98 ± 0.96	3.09 ± 1.32	+
X3	Number of family labor	5.13 ± 2.01	4.69 ± 2.91	+/−
Production and operation characteristics				
X4	Fertilizer cost (yuan/ha)	102.96 ± 40.87	58.05 ± 13.36	+
X5	Pesticide cost (yuan/ha)	23.09 ± 11.82	15.42 ± 9.00	+
X6	Proportion of transferred land (%)	91.10 ± 9.39	84.79 ± 16.64	+
X7	Land rent (Yuan/ha)	171.14 ± 26.69	22.20 ± 6.92	+
X8	Average depreciation cost of fixed assets (Yuan/ha)	152.04 ± 42.22	8.20 ± 4.53	+
X9	Annual technical training frequency (times)	5.74 ± 2.15	3.14 ± 2.37	+
X10	Agricultural product quality certification (0 = Uncertified; 1 = Organic certification; 2 = Green certification; 3 = Green and organic certification)	1.74 ± 0.97	1.36 ± 1.01	+
X11	Loan amount (10,000 Yuan)	13.78 ± 9.42	15.18 ± 6.18	+
X12	Agricultural insurance (0 = Not purchased; 1 = Purchased)	0.46 ± 0.50	0.37 ± 0.49	+

Note.
[a] Scale operation mode of agricultural land with the greenhouse type.
[b] Scale operation mode of agricutural land with the open-field type.

by land fragmentation endemic to mountainous and hilly areas, business entities acquire land management rights through land circulation and combine them with contiguous land consolidation to improve the efficiency of large-scale production [48]. Thus this study assumes that land rent has a positive impact on scale efficiency. Technical training is expected to positively affect scale efficiency by exposing business entities to more advanced agricultural production technologies. Besides, agricultural product certification helps to improve the popularity and thus the sales of agricultural products; agricultural loans are conducive to the expanded reproduction of business entities, and agricultural insurance may reduce the risks faced by business entities [49]. The above three indicators may all positively affect agricultural production efficiency.

This study was approved by the Ethics Committee of Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, with ethics approval reference No. 2016–17. We confirm that information consent was obtained from all participants for our study.

3. Results

3.1. Correlation analysis of input-output indicators

Results of the Pearson correlation analysis show that there is a significant positive correlation between the indicator of land input and the screened two output indicators for either the scale operation mode of the greenhouse or open-field types at the level of 1 %, with correlation coefficients of 0.974 and 0.952 (for greenhouse type) and of 0.973 and 0.970 (for open-field type), respectively (Table 4). Similarly, the indicator of capital input and labor input also manifest significant positive correlations with the screened two output indicators. The correlations between input and output indicators have all passed the 1 % significance level test, with positive correlation coefficients. This suggests that the indicators selected have passed the homogeneity test and can be used for the DEA model analysis.

3.2. Moderate scale results based on the DEA model

The average values of various DMU indicators are substituted into the DEA–BCC model to obtain each DMU's production efficiency (Table 5). In the results, the efficiency value of the DMU is closer to 1.000, means the closer to the production frontier, and thus denotes higher production efficiency. It can be seen that, with the expansion of planting scale, the comprehensive technical efficiency and scale efficiency of the greenhouse and open-field types both present a rise-fall trend. The efficient planting scales for the greenhouse type are 1.33–3.00 ha and 3.00–4.33 ha. Those for open-field types are 1.67–3.33 and 3.33–5.00 ha. Within the above scale intervals, the comprehensive technical efficiencies, pure technical efficiencies, and scale efficiencies of the greenhouse and a open-field type are all 1.000, meaning that they are in the CRS stage. The pure technical efficiency of the greenhouse type is uniformly 1.000, except in the interval of 4.33–7.33 ha. The scale efficiency of the greenhouse type reaches 1.000 in the intervals of 1.33–3.00 ha and 3.00–4.33 ha, but fails to do so in other intervals. Similarly, the pure technical efficiency of the open-field type is uniformly 1.000, except in the intervals of 8.67–12.00 ha (0.996) and 16.67–21.33 ha (0.956). The scale efficiency of the open-field type reaches 1.000 in the intervals of 1.67–3.33 ha and 3.33–5.00 ha, but fails to do so in other intervals. The above results indicate that, on the whole, the utilization of input resources by NABE in the study area is efficient and that technical efficiency of the study area is not low. The failure to reach an overall efficiency level is mainly caused by scale inefficiency, manifested by the overall low scale efficiency.

The efficient scale judged from Table 5 spans across a large scope and thus has a limited guiding significance for agricultural production practice. For this reason, the above two types of results are further ranked according to comprehensive technical efficiency based on the super-efficiency DEA–SE model to identify the optimal scale (Figs. 2 and 3). It is found that the super-efficiency values of inefficient scale intervals are consistent with the results of the DEA–BCC model, while the super-efficiency values of the four efficient scale intervals identified are greater than 1. The maximum super-efficiency value of the greenhouse type is 1.437, corresponding to the optimal scale of 3.00–4.33 ha. Whereas the maximum super-efficiency value of the open-field type is 1.164, corresponding to 3.33–5.00 ha. Within the above two scale intervals, all of the comprehensive technical efficiency, pure technical efficiency, and scale efficiency reach optimal.

Interestingly, the optimal scale interval of the greenhouse type (3.00–4.33 ha) is slightly smaller than that of the open-field type (3.33–5.00 ha). The possible reason is that the greenhouse type scale operation mode in this study is mainly located in the Anning River Basin. Endowed with excellent agricultural resources, the basin has attracted large amounts of external investments, resulting in a sharp increase in the local land circulation price (about 45000 yuan/ha on average). As a result, grapes and other high-price fruits and vegetables are largely planted in greenhouses for increasing the output value per unit area. Whereas the open-field type scale operation mode in this study area is mainly located in Nanjiang County and faces a low land circulation price (about 6000 yuan/mu on average).

Table 4
Correlation analysis of input-output indicators.

Scale operation mode	Indicator	Land input	Capital input	Labor input
Greenhouse type	Total yield	0.974**	0.937**	0.933**
	Total net profit	0.952**	0.948**	0.915**
Open-field type	Total yield	0.973**	0.943**	0.956**
	Total net profit	0.970**	0.960**	0.934**

Note: ** means that it is significant at the level of 5 %.

Table 5
Production efficiency under the BCC model.

Scale operation mode	DMU (Operation scale, ha)	Comprehensive technical efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
Greenhouse type	[0.27–1.33]	0.993	1.000	0.993	irs
	[1.33–3.00]	1.000	1.000	1.000	–
	[3.00–4.33]	1.000	1.000	1.000	–
	[4.33–7.33]	0.842	0.975	0.863	drs
	[7.33–10.00]	0.836	1.000	0.836	drs
	[10.00–14.00]	0.823	1.000	0.823	drs
	Average value	0.916	0.996	0.919	
Open-field type	[0.33–1.67]	0.947	1.000	0.947	irs
	[1.67–3.33]	1.000	1.000	1.000	–
	[3.33–5.00]	1.000	1.000	1.000	–
	[5.00–6.33]	0.953	1.000	0.953	drs
	[6.33–8.67]	0.939	1.000	0.939	drs
	[8.67–12.00]	0.878	0.996	0.882	drs
	[12.00–16.67]	0.865	1.000	0.865	drs
	[16.67–21.33]	0.807	0.956	0.844	drs
	[21.33–24.67]	0.846	1.000	0.846	drs
	[24.67–28.00]	0.839	1.000	0.839	drs
	Average value	0.907	0.995	0.839	

Note: irs, -, and drs denote increasing returns to scale, constant returns to scale, and decreasing returns to scale, respectively.

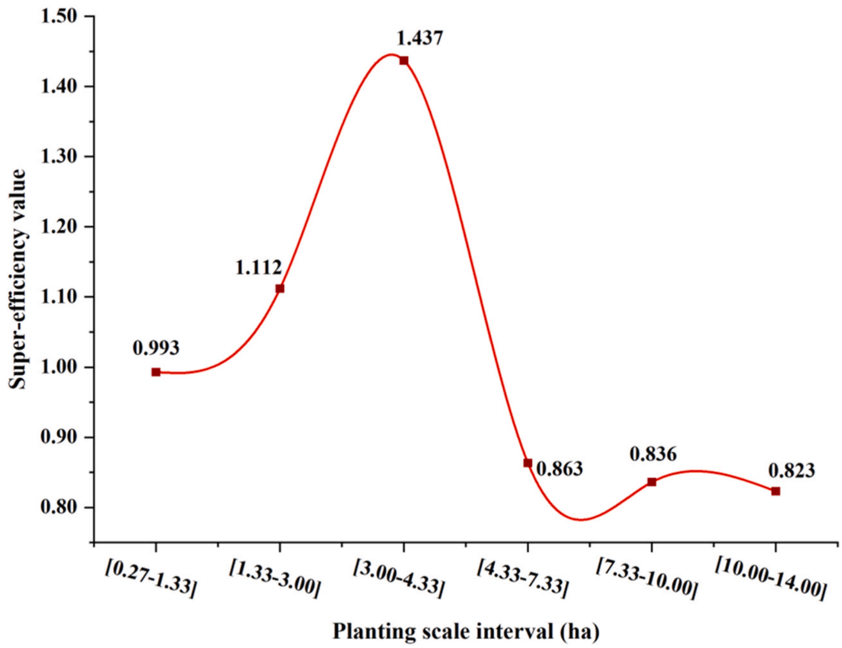

Fig. 2. Variation trend of super-efficiency under the greenhouse type scale operation mode.

Under this mode, genuine TCM materials (such as honeysuckle) and nut crops (such as walnut) are planted outdoors, with low output values per unit area.

3.3. Influencing factors of moderate scale

The results of both Tobit models show that the Log-likelihood ranged from 192.04 to 301.97, the LR chi2 ranged from 344.71 to 535.91, and the significance level of the models were relatively high (at the 1 % significant level). All parameters indicated a good model fit (Table 6). Among individual characteristic indicators, business entities' age has significant negative effects on the scale efficiencies of both the greenhouse and open-field types scale operation modes. The probable explanation is that, compared with young people, older business entities are going downhill in terms of their health status and learning ability, and thus compromising agricultural production efficiency [14]. Education level and family labor show no significant effects on the two kinds of operation modes.

Among production and operation characteristic indicators, the proportion of transferred land, land rent, and agricultural insurance all exert significant positive effects on both of the greenhouse and open-field types. The reason may be that, in the land-intensive

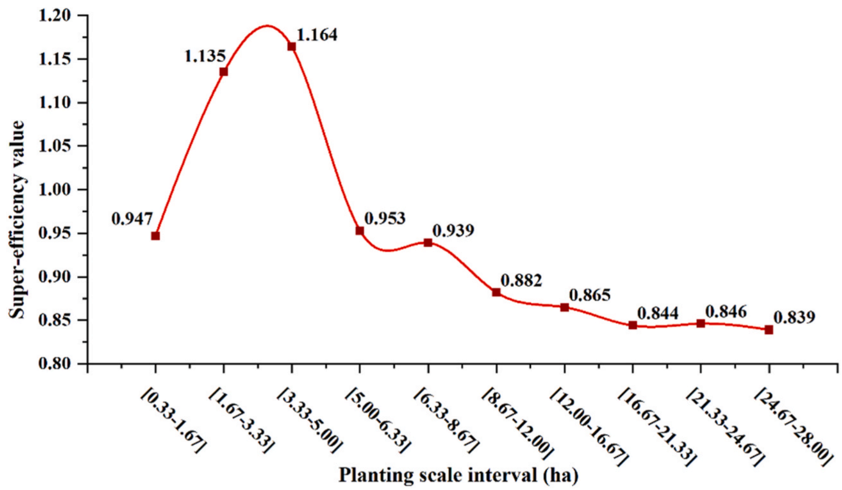

Fig. 3. Variation trend of super-efficiency under the open-field type scale operation mode.

Table 6
Regression results of the influencing factors of planting scale efficiency.

No.	Variable name	Model 1[a]	Model 2[b]
Individual characteristics			
X1	Household head age	−0.005*** (−7.68)	−0.001* (−1.81)
X2	Household head education	0.002 (0.97)	0.008 (1.52)
X3	Number of family labor	0.001 (0.51)	0.000 (0.03)
Production and operation characteristics			
X4	Fertilizer cost	0.000 (0.43)	0.000 (0.58)
X5	Pesticide cost	0.000 (1.14)	0.000** (2.11)
X6	Proportion of transferred land	0.381*** (8.15)	0.680*** (10.63)
X7	Land rent	0.000** (2.29)	0.001*** (4.19)
X8	Average depreciation of fixed assets	0.000 (0.26)	0.000 (0.03)
X9	Annual technical training frequency	0.002*** (2.77)	0.002 (0.78)
X10	Agricultural product quality certification	0.002 (1.04)	0.013*** (2.80)
X11	Loan amount	0.000 (0.37)	0.003* (1.82)
X12	Agricultural insurance	0.005* (1.81)	0.014* (1.87)
	_cons	0.624*** (7.32)	−0.080 (−0.90)
Model coefficient		LR chi2 = 344.71	LR chi2 = 535.91
		Prob > chi2 = 0.000	Prob > chi2 = 0.000
		Log likelihood = 192.04	Log likelihood = 301.97

Note: (1) T values are in brackets; (2) [a], regression results of the influencing factors of greenhouse type (n = 54); [b], regression results of the influencing factors of open-field type (n = 100); (3) ***, **, and * mean that it is significant at the level of 1 %, 5 %, and 10 %, respectively.

operations of mountainous and hilly areas, the increase in land circulation and land rent is conducive to the realization of contiguous operation, and further facilitates the improvement of planting scale efficiency. Agricultural insurance can transfer business entities' operating risks, compel them to pursue scale efficiency, and thus obtain greater benefits. Technical training has a significant positive effect on the scale efficiency of the greenhouse type, but exerts no significant effect on the open-field type. The possible reason is that the crops planted under the scale operation mode of greenhouse type are mainly grapes and strawberries, which require advanced technologies and refined production management. Thus, a higher frequency of technical training more significantly facilitates improving the planting scale efficiency. Pesticides, agricultural product certification, and loans all have significant positive effects on the open-field type, but exert no significant effect on the greenhouse type. This is possible because the crops planted under the open-field type scale operation mode are mainly plums, pears, and oranges and thus rely heavily on pesticides. Agricultural product certification helps expand sales channels and increase product income, and agricultural loans provide sufficient financial support for agricultural business entities. This may be the reason why the above two indicators positively affect the scale efficiency of the open-field types.

4. Discussion

4.1. Production efficiency and moderate scale in different regions

This study measures the comprehensive technical efficiencies, pure technical efficiencies, and scale efficiencies of the greenhouse and open-field types scale operation modes based on the DEA model (Table 5). It is found that scale efficiency and comprehensive technical efficiency both present a rise-fall trend with increasing planting scale. This indicates that agricultural scale production efficiency also has an "inverted U-shaped" curve relationship with land scale in mountainous areas, as it does in plain areas [11,12]. The study area has a generally high technical efficiency level, and the variation trend of comprehensive technical efficiency is mainly determined by scale efficiency. This finding supports the judgment that the technical efficiencies of China's major cash crops have presented an increasing trend in recent years [19]. This study also reveals that the efficient scales of the greenhouse and open-field types in the mountainous areas around the Sichuan Basin are 1.33–4.33 ha and 1.67–5.00 ha, and that their optimal scale intervals are 3.00–4.33 ha and 3.33–5.00 ha, respectively (Table 5). These findings closely match to the results of other studies. For instance, the moderate scale of land in the mountainous and hilly areas of Chongqing is 1.60–2.13 ha [21]; that of wheat and corn in the mountainous and hilly areas of Sichuan Province is 1.67–2.33 ha [42], and that of citrus orchards manged by family farms in the mountainous and hilly areas of Hunan Province is about 3.33 ha [50]. However, the results of this study differ greatly from the results of most studies on plain areas. For instance, the moderate scale of family farms in China's major apple-producing areas is 7.53–7.67 ha [19]; that of family farms in five Indian regions, including Andhra Pradesh, is 9.67 ha [51]; and that of family farms for grain in Kenya is 60–70 ha [52]. Compared with plain areas with mature land-intensive operations, NABE in the study area are still in the start-up stage, and agricultural production factors and related services are still inadequate. This may be an important reason why the moderate land scale in the study area is smaller than that in plain areas.

Considering the wide variety of cash crops planted in mountainous areas, this study differentiates the scale operation modes of agricultural land into the greenhouse and open-field types. Interestingly, this study reveals that the moderate scale interval of the open-field type (3.33–5.00 ha) is slightly bigger than the greenhouse type (3.00–4.33 ha). Nanjiang County mainly adopts the open-field type for the scale operation of cash crops. By contrast, the Anning River Basin mainly adopts the greenhouse type to grow fruits and vegetables such as grapes and tomatoes. Field surveys show that the abundant light and heat resources in the Anning River Basin have attracted large amounts of external investments and created intense competition, giving rise to soaring local land circulation price (about 45000 yuan/ha on average). In comparison, the land circulation price in Nanjiang County is only about 6000 yuan/ha. Therefore, both partially funded by agricultural loans, NABE in the Anning River Basin need to improve the output value per unit area within a relatively limited scale interval, while those in Nanjiang County can obtain higher returns by appropriately expanding the operation scale due to economies of scale. The above analysis suggests that it is necessary to distinguish between the greenhouse and open-field types scale operation modes, whether for theoretical research or practical guidance.

4.2. Influencing factors of moderate scale in mountainous areas

By analyzing the influencing factors of scale operation efficiency, it is found that business entities' age is negatively correlated with the scale efficiencies of both the greenhouse and open-field types (Table 6). A study in Tanzania reveals that younger agricultural business entities usually have a longer planning horizon and are more inclined to adopt new varieties and technologies to improve agricultural production efficiency [53]. However, a study on rice farmers in Nepal concludes that the age of agricultural business entities is inversely proportional to agricultural production efficiency. The reason is that older farmers have a richer experience, which is more conducive to improving agricultural production efficiency [46]. This conclusion, however, may only apply to the farmers of traditional food crops. As far as planting a wide variety of cash crops in mountainous and hilly areas is concerned, the application of new technologies, new crop varieties, and new ideas plays a key role in improving agricultural production efficiency, and thus young "new farmers" have prominent advantages in these aspects [2]. The proportion of transferred land, land rent, and agricultural insurance all exert significant positive effects on the scale efficiencies of both the greenhouse and open-field types (Table 6). This means that business entities in mountainous areas can reduce the degree of land fragmentation by engaging in land circulation [48] and mitigate risks by purchasing agricultural insurance [49], thus significantly improving agricultural production efficiency. Similarly, the degree of land fragmentation in rocky desertification areas in southern India is significantly negatively correlated with agricultural production efficiency and profit [54]. By contrast, a higher degree of risk mitigation means higher technical efficiency for farmers in Nepal [46]. The frequency of technical training significantly affects the scale efficiency of the greenhouse type, possibly because greenhouse planting requires business entities to have higher management levels and more advanced production technologies and to participate in more technical training for this reason. Indicators such as costs of pesticides, agricultural product certification, and agricultural loans significantly affect the scale operation mode of open-field type (Table 6). A possible explanation is that applying pesticides help farmers better deal with crop diseases and pests and that brand certification increases the publicity and sales of agricultural products [2]. Since financial loans enable business entities to overcome budgetary constraints [14], they are able to invest more capital in production and operations, and thus enhancing production efficiency.

4.3. Remaining issues and policy implications

On November 6, 2014, the General Office of the CPC Central Committee and the General Office of the State Council jointly issued the *Opinions on Guiding the Orderly Transfer of Rural Land Management Rights and Developing Agricultural Moderate Scale Operation*, which further regulates land circulation and moderate scale operations in rural areas. However, since China's land circulation policy was not introduced until very recently, agricultural industry development in China's western mountains lagged behind heavily. Field surveys also show that a majority of NABE in the study area have sprung up with the implementation of the poverty alleviation policy in the past two or three years. For this reason, it is difficult to obtain relatively stable input-output data on most NABE, which explains why the sample size of this study may be somewhat small. Moreover, the fact that different NABE are in different development stages, and thus may weaken the comparability of input-output data and compromise the judgment of moderate operation scale. This may also be an important reason for the discrepancies in the moderate operation scales identified for various types of agricultural business entities in different regions [11,12,41]. According to our field surveys, cash crops play an absolutely dominant role in the scale operation of land in the study area, whereas food crops account for an extremely low proportion. This situation has positive significance for cultivating local agricultural industry and increasing farmers' income [2], but it may potentially threaten national food security and sustainable agricultural development, thus due attention should be paid to this regard. In addition, although fertilizers and pesticides have positive effects on improving production efficiency, their possible negative effects on the environment should be closely followed and further studied.

The findings of this study provide important insights for policy-making practices regarding the improvement of agricultural production efficiency and the promotion of NABE cultivation in the study area. We suggest that policy interventions should make guidance to NABEs for their rational planting scale planning. In practice, we recommend the optimal scale intervals for the greenhouse and open-field types in the study area with 3.00–4.33 ha and 3.33–5.00 ha, respectively. Besides, we suggest that policy interventions should orderly conduct land circulation, reasonably control land rent; improve the agricultural socialization service system, and provide adequate agricultural technical training and agricultural product certification services.

5. Conclusion

Relying on field survey data, the DEA and Tobit models are used to investigate the moderate operation scales and its key influencing factors of agricultural land under different operation modes of greenhouse and open-field types in the mountainous and hilly areas around the Sichuan Basin, China. Results show that: (1) There is an approximately "inverted U-shaped" curve relationship between production efficiency and planting scale for both the greenhouse and open-field types. The failure to reach an overall efficient level for NABE in the study area is mainly caused by scale inefficiency. (2) The results obtained by the super-efficiency DEA model indicate that the optimal planting scale intervals for the greenhouse and open-field types are 3.00–4.33 ha and 3.33–5.00 ha, respectively. (3) Business entities' age, land circulation scale, land rent, and agricultural insurance are common factors that influence the scale efficiencies of both the greenhouse and open-field types. In addition, agricultural technical training has a significant positive effect on the scale efficiency of the greenhouse type, whereas agricultural product certification, fertilizers, pesticides, and agricultural loans have significant positive effect on the scale efficiency of the open-field types. (4) The concept of moderate-scale operation should be widely guided, the integrated development of NABE should be encouraged, and the agricultural socialization service system should be strengthened for improving agricultural production efficiency and promoting the development of NABE in China's mountainous areas. (5) A relatively small sample size (154 questionnaires) of this study may influence the reliability of the results. Besides, considering the fact that different NABE are in different development stages, additional empirical research on the dynamics of moderate operation scale is needed in future studies.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Ming Li: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. **Weizhao Zhao:** Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. **Congshan Tian:** Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Yaqi Li:** Data curation, Formal analysis, Investigation, Validation. **Xuechun Feng:** Formal analysis, Investigation, Validation, Visualization. **Baoyue Guo:** Data curation, Formal analysis, Investigation, Validation. **Yuqi Yao:** Data curation, Formal analysis, Validation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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