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Evaluation of farmers' wheat production technical efficiency based on income increasing

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ABSTRACT: Based on the goal of income increasing, this research uses the DEA-BCC model under the input and the output orientation to estimate the differences and changes in the technical efficiency of wheat production by farmers of different scales based on the survey data of 1669 farmers' wheat production from China's main wheat-producing regions. Results showed that there are significant differences in the technical efficiency of farmer's wheat production and the optimal scale of efficiency under the input and the output orientation. The relationship between farmers' planting scale and efficiency is characterized by U-shaped curves and inverted U-shaped curves respectively. The wheat production technical efficiency of farmers in most major grain production areas is in a DEA ineffective state, and agricultural technical efficiency needs to be improved.
Key words: farmers, wheat production, technical efficiency, DEA-BCC model.

Avaliação da eficiência técnica da produção de trigo dos agricultores com base no aumento da renda

RESUMO: Com base no objetivo de aumentar a renda, esta pesquisa utiliza o modelo DEA-BCC sob a orientação input e output para estimar as diferenças e mudanças na eficiência técnica da produção de trigo por agricultores de diferentes escalas, com base nos dados do levantamento da produção de trigo de 1669 de agricultores das principais regiões produtoras de trigo da China. Os resultados mostram que existem diferenças significativas na eficiência técnica da produção de trigo do agricultor e na escala ótima de eficiência sob a orientação de insumo e saída. A relação entre escala de plantio e eficiência dos agricultores é caracterizada por curvas em U e curvas em U invertidas respectivamente. A eficiência técnica da produção de trigo dos agricultores na maioria das principais áreas de produção de grãos está em um estado ineficaz DEA, e a eficiência técnica agrícola precisa ser melhorada.
Palavras-chave: agricultores, produção de trigo, eficiência técnica, modelo DEA-BCC.

INTRODUCTION

The improvement of wheat production efficiency can promote an increase in farmers' income (HUETH, 2000). As for the study of wheat production efficiency, the existing literature mainly focuses on the calculation of wheat production efficiency and in the factors affecting wheat production efficiency. There are two main methods to measure wheat production efficiency, the stochastic frontier production function method (SFA)(BRIAN et al., 2007; AHEARN et al., 2006; SUN, 2014; SU & FU, 2011) and the data envelopment analysis method (DEA) (HUETH, 2000; KIM & CHAVAS, 2002; MORRIS et al., 2007; MCINTOSH et al., 2007; CHEN et al., 2012; HAO et al., 2016; MIAO, 2014). The relationship between land scale and production efficiency has always been a research hotspot in the field of the agricultural economy, and existing studies have concluded that the relationship between land scale and production efficiency can be divided into a positive relationship, negative relationship and a nonlinear relationship (SEN, 1962; LI et al., 2010; NI & CAI, 2015).

There are many factors that affect wheat production efficiency. WESTCOTT et al (2002) and MILLER et al (2003) reported that agricultural subsidy policy reduced the risk of agricultural income, alleviated farmers' uncertainty of income, and thus improved wheat production efficiency. CAHILL (1997) believed that the direct grain subsidy

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policy reduced the impact of government intervention on the market, which is conducive to the use of market mechanisms to promote the improvement of food production efficiency. GAO (2017) studied the changes of wheat production efficiency in Henan Province, China, and reported that the government's subsidy policy of income decoupling from 2009 to 2014 promoted the improvement of wheat technical efficiency, but the impact on wheat total factor productivity was not obvious. GAO et al (2017) used the Heckman model to study the efficiency loss of wheat production in Henan Province, China, and reported that the wheat production efficiency in Henan Province has been improving. However, there is a serious loss of efficiency, and the agricultural subsidy policy has improved the production efficiency of poor farmers, which is conducive to reducing the efficiency losses. MATHIJS & NOEV (2004) believed that increasing the input of production factors such as machinery, fertilizer and labor improved the technical efficiency of wheat production in Eastern European countries. KAN (2006) believed that the policy of the minimum purchase price could promote wheat total factor productivity by improving cultivated land quality and increasing cultivated land area. ZENG et al (2018) investigated the wheat technical production efficiency of 346 farmers in China's main wheat producing areas and reported that land transfer promoted the improvement of wheat technical efficiency.

Meanwhile, the improvement of agricultural labor education, agricultural capital investment and agricultural informatization were all conducive to the improvement of wheat technical efficiency. QU et al (2019) studied the wheat production efficiency of 873 farmers in Ningxia and Henan provinces of China, and reported that the transfer of cultivated land expanded the scale effect and promoted the improvement of the comprehensive wheat efficiency. The influence of the transfer area of cultivated land on the scale efficiency and comprehensive wheat production efficiency showed an inverted U-shaped change. LIU et al (2019) conducted research on wheat technical efficiency in major wheat producing areas in China, and reported that increasing the input of agricultural mechanization services and optimizing the allocation of wheat production factors can significantly promote the improvement of wheat technical efficiency. ZHOU et al (2021) studied the spatial variation technical efficiency of cereal crops in China, and found that both local socio-economic factors and environment have a significant impact on farmers' technical efficiency. CHEN et al (2022) conducted research on the impact of e-commerce on the technical efficiency of wheat production of Chinese farmers, they employed the model of selectivity-corrected stochastic production frontier and propensity score matching (PSM), and reported that adoption of e-commerce may increase the technical efficiency of wheat by 2.75 percentage points.

In summary, the existing literature mostly calculates the wheat production efficiency of the province from the macro perspective, while there is little research on the calculation of farmers' wheat production efficiency from the micro perspective, especially in the main grain producing regions. Based on the objectives of increasing farmers' income, this paper used the DEA-BCC model to calculate the wheat production efficiency of 1699 farmers in 9 provinces in China's main wheat producing regions, to analyze the differences and change laws of farmers' production efficiency under the input and the output orientation of different planting scales. Finally, putting forward some suggestions to improve the efficiency by optimizing the allocation of wheat production factors and selecting an appropriate planting scale. It would provide meaningful reference for improving farmers' production efficiency and increasing farmers' income in main grain producing regions, and further ensuring national food security.

MATERIALS AND METHODS

In this paper, DEA-BCC model (LOVELL et al., 1978; CHARNES et al., 1979) was used to measure farmers' technical efficiency of wheat production in major grain producing areas, mainly based on the two advantages of this model :(1) DEA model is a non-parametric method to evaluate the relative efficiency of DMU based on input-output perspective, without determining whether there is correlation between input and output variables in advance; (2) BCC model decomposed technical efficiency (comprehensive efficiency) into pure technical efficiency and scale efficiency, which can directly analyze the overall scale efficiency of wheat production factors of farmers. Due to the significant difference between input-oriented efficiency and output-oriented efficiency, in order to determine the optimal operation scale of farmers' wheat production efficiency, this paper adopts both input-oriented and output-oriented efficiency methods.

To measure the technical efficiency of wheat production, we assumed the quantity of decision units (DMU) is "k" and $\{DMU_r: r = 1,2,\dots,k\}$. Assuming that the quantity of input and output of DMU in each are respectively "m" and "n", that is, $X_r = \{x_{ir}, i = 1,2,\ldots,m\}$, $Y_r = \{y_{jr}, j = 1,2,\ldots, n\}$.The production possible set of BCC modelis (P^{VRS}) defined as follows:

$$P^{VRS} = \{(X,Y) \mid X \geq \sum_{r=1}^{k} \lambda_r X_r, Y \leq \sum_{r=1}^{k} \lambda_r Y_r, \sum_{r=1}^{k} \lambda_r = 1, \lambda_r \geq 0, r = 1,2, \ldots k\} \quad (1)$$

The input--oriented model of BCC is as follows:

$$\begin{aligned} & \min\theta_\mu \\ & s.t. \quad \theta_\mu x_{iu} \geq \sum_{r=1}^{k} \lambda_r X_{ir}, i = 1,2,\ldots m \\ & \quad y_{ju} \leq \sum_{r=1}^{k} \lambda_r Y_{jr}, j = 1,2,\ldots n \\ & \quad \sum_{r=1}^{k} \lambda_r = 1, \\ & \quad \lambda_r \geq 0, r = 1,2,\ldots k. \end{aligned} \quad (2)$$

In the model, x_{iu} and y_{ju} represent the i-th input and the j-th output of the u-th DMU respectively. The objective function in equation (2) is to solve the minimum value of $min\theta_\mu$, whose minimum value is denoted as θ_u^*, and $\theta_u^* \leq 1$. The key to judge whether a DMU is "effective" is whether it falls on the production front of P^{VRS}. If in the production possibility set P^{VRS}, the input x_u of DMU cannot be reduced in the same proportion when the output y_u remains constant, then the optimal value $\theta_u^*=1$. At this point, the DMU is located at the production front surface, and input-oriented BCC is effective. On the contrary, when the output y_u of DMU remains constant, its input x_u can be reduced in the same proportion, then the optimal value $\theta_u^*<1$. In this case, the DMU cannot fall on the production front surface, so the input-oriented BCC is not effective.

The output--oriented model of BCC is as follows:

$$\begin{aligned} & \max\varphi_u \\ & s.t. \quad x_{iu} \geq \sum_{r=1}^{k} \lambda_r X_{ir}, i = 1,2,\ldots m \\ & \quad \varphi_u y_{ju} \leq \sum_{r=1}^{k} \lambda_r Y_{jr}, j = 1,2,\ldots n \\ & \quad \sum_{r=1}^{k} \lambda_r = 1, \\ & \quad \lambda_r \geq 0, r = 1,2,\ldots k. \end{aligned} \quad (3)$$

The objective function of equation (3) is to solve the maximum value of $max\varphi$, and the optimal value of equation (3) is denoted as φ_u^*, and $\varphi_u^* \geq 1$. For the output-oriented model, if in the production possible set P^{VRS}, the output y_u of DMU cannot increase in the same proportion when the input x_u remains constant, and the optimal value $\varphi_u^* = 1$, the DMU is located at the production front surface, and the output-oriented BCC is effective. In addition, when the input x_u of DMU remains constant, its output y_u can increase in the same proportion, then the optimal value $\varphi_u^* > 1$. In this case, the DMU also cannot fall on the production front surface, so the output-oriented BCC is not effective.

It is necessary to construct a scientific evaluation index system to measure farmers' wheat production technical efficiency. For food production is a matter of farmers' income growth and the national food security. To respond the different goal of main participant for food production, this paper through the establishment of farmers' income from the comprehensive efficiency, pure technical efficiency and scale efficiency to evaluate the efficiency of wheat farmers production and management. Firstly, the variables of wheat production input and output indexes were established. According to the classic Cobb-Douglas production function theory and the characteristics of the observations, input indexes of land, labor and capital were selected (ZHANG & QIAN, 2010). The selected measurement input indexes are the acreage of wheat planted by farmers ($x1$), the labor costs of wheat production ($x2$), the capital costs of wheat production ($x3$). As for the output index of farmers' technical efficiency of wheat production, the income from wheat production ($y1$) and the total yield of wheat production ($y2$) was selected as the output index which could best reflect the goal of farmers' income increasing. The specific evaluation index system is shown in table 1.

Income from wheat production ($y1$): the food sales price multiplied by grain yield and its unit is yuan. The yield of wheat production ($y2$): the total amount of wheat harvested by farmers and its unit is kilogram. Land($x1$): including farmers' own land and rent and its unit is mu (Chinese unit of measurement, 1mu=1/15 hectare). Labor ($x2$): including the wages of their own labor and employees and its unit is yuan. Capital ($x3$): including material consumption expenses such as seeds, pesticides, chemical fertilizers and agricultural films, as well as service expenses such as outsourced machinery, irrigation, transportation and insurance.

Wheat, together with rice and corn, constitute the three main grains in China. The planting area and output of wheat in China both rank the third in the planting area and output of food crops. The stable supply of wheat plays a role in guaranteeing China's food security. According to the data released by the National Bureau of Statistics of China, the wheat planting area in China in 2020 was 23.38 million hectares, accounting for about 20% of the total grain planting area, and the wheat output was 134.25 million tons, accounting for about 20% of the total grain output. In terms of the main producing regions of wheat, Henan, Shandong, Anhui, Hebei, Jiangsu, Xinjiang, Hubei, Shanxi and Sichuan provinces are the main producing areas of wheat in China.

Table 1 - Evaluation index system of peasant household wheat production and management efficiency.

Efficiency evaluation	Output index	Input index	
Comprehensive efficiency	Income from wheat production ($y1$) Yield of wheat production ($y2$)	Land ($x1$)	the areas of wheat planted by farmers
Pure technical efficiency		Labor ($x2$)	the labor costs of wheat production
Scale efficiency		Capital ($x3$)	total cost of material consumption and services

According to the statistical data of China Agricultural Yearbook 2020, the wheat output of the 9 provinces accounted for 91.9% of the total wheat output of China in 2019. Henan, Shandong, Anhui, Hebei and Jiangsu ranked 1st to 5th respectively, accounting for 27.58%, 18.57%, 12.24%, 11.20% and 9.64% of the total wheat output in China, respectively. Therefore, it is representative to select farmers in 9 provinces as the research object. Data for this study were provided by the Rural Household Survey Team of the National Bureau of Statistics, including wheat planting input and output of 1,669 farmers in Henan, Shandong, Anhui, Hebei, Jiangsu, Xinjiang, Hubei, Shanxi and Sichuan provinces in 2018 （Table 2）. According to the model and evaluation index system mentioned above, the objective of this paper was to evaluate the technical efficiency of farmers' wheat production. Since the wheat planting scale of 1669 farmers is in the range of 0-320 mu. Firstly, the observation data are processed, and the farmers of different sizes are clustered according to the wheat planting scale of farmers, using the aggregation method of hierarchical clustering method. That is, each farmer will be classified according to the farmer's wheat planting scale and wheat yield. SPSS20.0 statistical software was used for cluster analysis of farmers' wheat planting scale, and the final results were shown in table 3.

It can be seen from table 3 that 1669 farmers of different sizes are divided into 19 regions of different sizes by cluster analysis, and the input and output data of each region of different sizes are the average value of farmers in that region. From the perspective of the changes in input and output in different scale regions, the capital input shows a continuously increasing trend with the expansion of farmers' business scale, and the labor input shows the characteristics of first increasing and then decreasing,. This mainly due to the large-scale farmers' increasing mechanical input to replace labor; The total yield of wheat planting and the total income of grain planting showed an upward trend with the increase of farmers' planting scale.

RESULTS AND DISCUSSION

As the microscopic main participant of food production, farmers have the rational attribute of "economic man", and the pursuit of maximizing income is an important goal of their food production and management. Therefore, when measuring the wheat production efficiency of farmers, first analyze the technical efficiency under the goal of increasing farmers' income, that is, take the income of growing grain $y1$ as the output item, and land $x1$, labor $x2$, and capital $x3$ as the input items. DEAP (Version 2.1) software is used to calculate the comprehensive efficiency, pure technical efficiency, and scale efficiency of farmers' planting in 19 regions with different scales from the perspectives of input and output. The calculation results are shown in table

Table 2 - Descriptive statistics of the sample (n = 1696).

Variable	Mean	Std. Dev.	Min	Max
Yield	4457.17	11020.86	30.00	147000.00
Income	9975.76	24970.30	78.00	352800.00
Land	11.78	30.21	0.18	320.00
Labor	1484.13	2752.59	20.00	40800.00
Capital	4323.46	11397.96	22.50	164864.00

Table 3 - Input and output of wheat production in different grain land scale regions.

No.	Scale area（mu）	------------------------------Input------------------------------			-------------------Output---------------------	
		Capital（yuan）	Labor（yuan）	Land（mu）	Yield（kg）	Income（yuan）
1	0-1（≤1）	168.38	229.84	0.75	204.54	461.30
2	1-6（≤6）	1298.94	856.33	3.61	1369.15	3062.11
3	6-12(≤12)	3299.12	1419.98	8.79	3574.98	7972.26
4	12-25(≤25)	6265.26	1992.03	16.77	6723.15	14879.66
5	25-45(≤45)	12353.24	4490.85	34.72	13366.57	29723.42
6	45-60(≤60)	20016.23	5360.91	54.55	20481.82	44101.91
7	60-85(≤85)	27403.14	11914.29	76.93	27646.36	60841.35
8	85-110(≤110)	39845.48	3902.56	97.67	35196.33	80633.48
9	110-130(≤130)	44199.50	2250.00	125.00	42900.00	96090.00
10	130-159(≤159)	59224.60	5160.00	159.00	43725.00	118057.50
11	159-170(≤170)	74509.73	6470.67	166.67	71200.00	162253.33
12	170-200(≤200)	70266.67	22654.67	200.00	70000.00	155813.33
13	200-212(≤212)	73004.00	17500.00	212.00	83740.00	184228.00
14	212-230(≤230)	93584.00	13200.00	230.00	94300.00	207460.00
15	230-250(≤250)	77500.60	19700.00	250.00	82153.00	185227.00
16	250-261(≤261)	88708.50	10140.00	260.50	82045.00	185294.50
17	261-280(≤280)	90214.00	10730.00	273.67	102345.67	240622.00
18	280-300(≤300)	131950.00	17000.00	300.00	99000.00	221760.00
19	300-320(≤320)	124468.33	14383.33	319.33	116264.67	259956.33

4-5. Table 4 shows the technical efficiency of wheat production of farmers under the input orientation, and table 5 shows the technical efficiency of wheat production of farmers under the output orientation.

In table 4 based on the input-oriented measurement results of wheat production efficiency of farmers of different scales; the scale efficiency value of the scale area is 170-200 mu and 200-212 mu is 1. Their pure technical efficiency values are all lower than 1, indicating that the input of other elements besides land by farmers is ineffective, so the comprehensive efficiency is ineffective. The pure technical efficiency, and scale efficiency of farmers' wheat planting and management scale of 0-1 mu, 110-130 mu, 159-170 mu and 261-280 mu are all 1, indicating that the comprehensive efficiency of input elements of these regional scales are the most optimal. In addition, the efficiency values of farmers' management in other scale areas are less than 1, indicating that the input factors of farmers of these scales are not effective as a whole. In view of the small input scale of 0-1 mu and the low income of farmers from growing grain, considering the overall scale efficiency of farmers' families, it can be determined that the comprehensive efficiency of farmers in the three scale areas of 110-130 mu, 159-170 mu and 261-280 mu is the optimal. Further analysis of the change law of scale and efficiency, it can be seen from table 3 that the scale efficiency of farmers in different scale areas under the input orientation are different. From the range of 1-320 mu, the scale efficiency increases first and then decreases with the expansion of scale. The U curve changes law, that is, the scale efficiency of small-scale farmers under 110 mu increases with the expansion of the scale, and the scale efficiency decreases with the expansion of the scale after the scale exceeds 212 mu. It shows that the scale of farmer's planting and efficiency is not a simple linear relationship; the scale of farmer's planting in grain should be moderate, and it is not the larger the scale of planting, the better the efficiency is.

It can be seen from the calculation results in table 5 that the scale efficiency value of 170-200 mu and 200-212 mu is still 1, while the pure technical efficiency value is lower than 1, indicating that the input of other elements of farmers is still inefficient, so their comprehensive efficiency is in an inefficient state. As far as the scale efficiency of farmers' different regional scales is concerned, the results of output-oriented and input-oriented calculations are different. The efficiency state of the scale range from 1 to 110 mu is basically consistent with the input orientation,

Table 4 - Input-oriented wheat production efficiency of farmers under the goal of income increasing.

Scale area (mu)	Actual scale	Target scale	Comprehensive efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
0-1（≤1）	0.748	0.750	1.000	1.000	1.000	Constant
1-6（≤6）	3.612	3.519	0.939	0.975	0.963	Increase
6-12(≤12)	8.790	8.790	0.990	1.000	0.990	Increase
12-25(≤25)	16.773	16.353	0.970	0.975	0.995	Increase
25-45(≤45)	34.715	33.096	0.951	0.953	0.998	Increase
45-60(≤60)	54.545	48.578	0.889	0.891	0.999	Increase
60-85(≤85)	76.929	67.624	0.878	0.879	0.999	Increase
85-110(≤110)	97.667	85.819	0.876	0.879	0.997	Increase
110-130(≤130)	125.000	125.000	1.000	1.000	1.000	Constant
130-159(≤159)	159.000	135.568	0.851	0.853	0.998	Increase
159-170(≤170)	166.667	166.670	1.000	1.000	1.000	Constant
170-200(≤200)	200.000	173.798	0.869	0.869	1.000	Constant
200-212(≤212)	212.000	206.770	0.975	0.975	1.000	Constant
212-230(≤230)	230.000	228.393	0.958	0.993	0.965	Decrease
230-250(≤250)	250.000	210.719	0.893	0.896	0.997	Decrease
250-261(≤261)	260.500	209.294	0.802	0.803	0.999	Increase
261-280(≤280)	273.667	273.670	1.000	1.000	1.000	Constant
280-300(≤300)	300.000	247.917	0.764	0.826	0.924	Decrease
300-320(≤320)	319.333	319.330	0.878	1.000	0.878	Decrease
Average	11.781	28.682	0.920	0.935	0.984	-

that is, the scale efficiency value of each region is less than 1, the Returns to Scale is in the increasing stage. In addition, both the value of comprehensive efficiency and pure technical efficiency are the same as the value of the input orientation respectively; and the variation tendency is basically consistent. The Returns to Scale decline occurred for the first time in the area of 212-230 mu, indicating that with the expansion of farmers'

Table 5 - Output-oriented wheat production efficiency of farmers under the goal of income increasing.

Scale area (mu)	Actual income	Targetincome	Comprehensive efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
0-1（≤1）	461.298	461.300	1.000	1.000	1.000	Constant
1-6（≤6）	3062.112	3144.891	0.939	0.974	0.964	Increase
6-12(≤12)	7972.265	7972.260	0.990	1.000	0.990	Increase
12-25(≤25)	14879.660	15260.962	0.970	0.975	0.995	Increase
25-45(≤45)	29723.423	31186.167	0.951	0.953	0.998	Increase
45-60(≤60)	44101.909	49533.426	0.889	0.890	0.999	Increase
60-85(≤85)	60841.350	69225.153	0.878	0.879	0.999	Increase
85-110(≤110)	80633.483	91950.032	0.876	0.877	0.999	Increase
110-130(≤130)	96090.000	96090.000	1.000	1.000	1.000	Constant
130-159(≤159)	118057.500	138690.124	0.851	0.851	0.999	Increase
159-170(≤170)	162253.333	162253.330	1.000	1.000	1.000	Constant
170-200(≤200)	155813.333	179315.836	0.869	0.869	1.000	Constant
200-212(≤212)	184228.000	188890.118	0.975	0.975	1.000	Constant
212-230(≤230)	207460.000	208637.329	0.958	0.994	0.964	Decrease
230-250(≤250)	185227.000	206714.087	0.893	0.896	0.997	Decrease
250-261(≤261)	185294.500	230061.376	0.802	0.805	0.996	Decrease
261-280(≤280)	240622.000	240622.000	1.000	1.000	1.000	Constant
280-300(≤300)	221760.000	251771.210	0.764	0.881	0.867	Decrease
300-320(≤320)	259956.333	259956.330	0.878	1.000	0.878	Decrease
Average	9975.761	25643.087	0.920	0.938	0.981	-

planting scale, other production elements were not adjusted in time, resulting in the decline of farmers' scale efficiency. Compared with the input oriented, output oriented farmer's planting scale in the three regions of 110-130 mu, 159-170 mu and 261-280 mu also achieved the optimal comprehensive efficiency, pure technical efficiency and scale efficiency. Further analyzes of the change trend of farmers' planting scale and efficiency, the change trend of scale efficiency under output orientation are basically consistent with that under input orientation. This showed the change law of inverted U-shaped curve, indicating that the efficiency is the best only when farmers' planting scale is appropriate, and the efficiency will be lost if the scale is too small or too large.

From the above analysis, it can be seen that the comprehensive efficiency, pure technical efficiency and scale efficiency of 110-130 mu, 159-170 mu and 261-280 mu have achieved the optimal under both input-oriented and output-oriented, indicating that the optimal solution of farmers' scale efficiency based on the optimal comprehensive efficiency and pure technical efficiency is not unique. In order to determine a scale region with optimal efficiency, the absolute efficiency of the three scale regions is further compared. Farmers pursue profit maximization under the goal of increasing income, so the absolute efficiency of the three regions of 110-130 mu, 159-170 mu and 261-280 mu are measured and compared with the cost-profit index. The calculation of the farmer's cost of growing grain is the key to measuring its cost-profit ratio. When calculating the relevant indicator data of the farmer's wheat cost, refer to the "Compilation of National Agricultural Product Costs and Benefits 2020" compiled by the Price Department of the National Development and Reform Commission (Table 1-7-1 wheat cost-benefit). The cost of land input consists of land rent and self-owned land lease. The cost of capital input covers all material consumption and service expenses. The cost of labor input includes employee expenses and family employment discount. The total revenue consists of the output value of wheat main products and the output value of ancillary products. According to the comparative analysis of cost and profit margin of the regions with the optimal efficiency in table 6, the wheat planting cost utilization rate of farmers in the 261-280 mu region is higher than that of the other two regions. It can be seen that the absolute efficiency of farmers' operation is the highest in the area of 261-280 mu when measured by the profit margin index. Therefore, the optimal efficiency scale under the goal of increasing farmers' income is 261-280 mu.

Increasing food yield has been a perennial goal of the world's most populous nation. Compared with the micro-subject farmers who pursue the goal of maximizing profits, the government, as the macro-subject of agricultural production, pays more attention to food security, which is mainly measured by food yield indicators. The technical efficiency based on grain yield target is often different from the technical efficiency based on profit target, so it is necessary to analyze farmers' wheat production technical efficiency from a macro perspective. Taking grain yield $y2$ as output item, land $x1$, labor $x2$ and capital $x3$ as input item, the efficiency of farmers in 19 areas of different scales is measured from input-oriented and output-oriented, and the optimal scale of efficiency under the goal of food security is established.

From the results of efficiency calculation in table 7, there is a significant difference between

Table 6 - Comparative analysis of regional cost profit margin with optimal efficiency scale.

Input and output items	--Scale area (mu)---		
	110-130(≤130)	159-170(≤170)	261-280(≤280)
A:Land input（yuan）	22666.25	30222.27	49624.58
B:Labor input (yuan）	42607.50	56811.14	93283.16
C:Capital input (yuan）	44199.5	74509.73	90214
D:Total cost（yuan）	109473.25	161543.14	233121.74
E:Total revenue (yuan）	130498.75	174001.81	285708.74
F:Total profit (yuan）	21025.50	12458.68	52587.01
G:Cost-profit ratio（%）	19.21	7.71	22.56

Note: D=A+B+C；F=E-D；G=F/D.

the optimal scale area of farmers' wheat production efficiency with grain yield $y2$ as the output item under the input orientation and the area with grain yield $y1$ as the output item. In addition to the optimization of comprehensive efficiency, pure technical efficiency, and scale efficiency in the four scale areas of 0-1 mu, 110-130 mu, 159-170 mu, and 261-280 mu. The two scale areas of 6-12 mu and 200-212 mu also achieve the optimization of comprehensive efficiency, pure technical efficiency, and scale efficiency at the same time. By analyzing the efficiency of other regions; although, the 12-25 mu region achieves the optimal scale efficiency, but its pure technical efficiency value is less than 1, indicating that the input efficiency of other factors except land is invalid, so the comprehensive efficiency of farmers cannot be optimized. The pure technical efficiency of 212-230 mu and 300-320 mu of scale areas is optimal, but their scale efficiency values are both less than 1, and the returns to scale are in a state of diminishing, so their comprehensive efficiency is not effective. The comprehensive efficiency, pure technical efficiency and scale efficiency of other scale regions are in an ineffective state. Analyzing the change law of farmers' planting scale and efficiency, compared with the change law of scale efficiency under the guidance of farmers' income increasing goal, the scale and efficiency with grain output as the output item show the change law of multiple U-shaped curves, and the comprehensive efficiency value is the lowest in the scale area of 130-159 mu.

It can be seen from the efficiency calculation results in table 8 that; although, the scale efficiency value of 12-25 mu and 130-159 mu regions is 1, their pure technical efficiency value is less than 1, indicating that other input factors except land are inefficient, so the comprehensive efficiency of the two regions is not effective. The pure technical efficiency value of 212-230 mu and 300-320 mu is 1, but the scale efficiency value is less than 1, and the return to scale is decreasing, so the comprehensive efficiency is also not effective. Similar to the input orientation, the scale regions of 0-1 mu, 6-12 mu, 110-130 mu, 159-170 mu, 200-212 mu and 261-280 mu simultaneously achieved the optimal comprehensive efficiency based on pure technical efficiency and scale efficiency. Based on the analysis of the change rules of returns to scale, it reported that the macro target output leads to a declining state of farmers' returns to scale in multiple scale regions. Therefore, the larger the scale of farmers' planting is not the better, but the moderate scale of farmers' planting should be. Consistent

Table 7 - Input-oriented wheat production efficiency of farmers under food security goals.

Scale area (mu)	Actual scale	Target scale	Comprehensive efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
0-1（≤1）	0.748	0.750	1.000	1.000	1.000	Constant
1-6（≤6）	3.612	3.521	0.946	0.975	0.970	Increase
6-12(≤12)	8.790	8.790	1.000	1.000	1.000	Constant
12-25(≤25)	16.773	16.593	0.989	0.989	1.000	Constant
25-45(≤45)	34.715	33.496	0.964	0.965	0.999	Decrease
45-60(≤60)	54.545	50.906	0.933	0.933	0.999	Decrease
60-85(≤85)	76.929	69.308	0.900	0.901	0.999	Decrease
85-110(≤110)	97.667	86.119	0.879	0.882	0.997	Increase
110-130(≤130)	125.000	125.000	1.000	1.000	1.000	Constant
130-159(≤159)	159.000	115.332	0.723	0.725	0.997	Increase
159-170(≤170)	166.667	166.670	1.000	1.000	1.000	Constant
170-200(≤200)	200.000	176.233	0.880	0.881	0.999	Decrease
200-212(≤212)	212.000	212.000	1.000	1.000	1.000	Constant
212-230(≤230)	230.000	230.000	0.989	1.000	0.989	Decrease
230-250(≤250)	250.000	207.987	0.923	0.924	0.999	Decrease
250-261(≤261)	260.500	216.973	0.832	0.833	0.999	Increase
261-280(≤280)	273.667	273.667	1.000	1.000	1.000	Constant
280-300(≤300)	300.000	249.116	0.776	0.830	0.935	Decrease
300-320(≤320)	319.333	319.333	0.903	1.000	0.903	Decrease
Average	11.781	32.573	0.928	0.939	0.989	-

Table 8 - Output oriented wheat production efficiency of farmers under food security goals.

Scale area (mu)	Actual yield	Targetyield	Comprehensive efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
0-1（≤1）	204.539	204.540	1.000	1.000	1.000	Constant
1-6（≤6）	1369.146	1405.977	0.946	0.974	0.972	Increase
6-12(≤12)	3574.982	3574.980	1.000	1.000	1.000	Constant
12-25(≤25)	6723.153	6794.725	0.989	0.989	1.000	Constant
25-45(≤45)	13366.567	13854.203	0.964	0.965	0.999	Decrease
45-60(≤60)	20481.818	21946.692	0.933	0.933	0.999	Decrease
60-85(≤85)	27646.357	30684.659	0.900	0.901	0.998	Decrease
85-110(≤110)	35196.333	39973.447	0.879	0.880	0.999	Increase
110-130(≤130)	42900.000	42900.000	1.000	1.000	1.000	Constant
130-159(≤159)	43725.000	60439.201	0.723	0.723	1.000	Constant
159-170(≤170)	71200.000	71200.000	1.000	1.000	1.000	Constant
170-200(≤200)	70000.000	79438.015	0.880	0.881	0.999	Decrease
200-212(≤212)	83740.000	83740.000	1.000	1.000	1.000	Constant
212-230(≤230)	94300.000	94300.000	0.989	1.000	0.989	Decrease
230-250(≤250)	82153.000	88601.257	0.923	0.927	0.996	Decrease
250-261(≤261)	82045.000	98097.275	0.832	0.836	0.995	Decrease
261-280(≤280)	102345.667	102345.667	1.000	1.000	1.000	Constant
280-300(≤300)	99000.000	111511.119	0.776	0.888	0.874	Decrease
300-320(≤320)	116264.667	116264.667	0.903	1.000	0.903	Decrease
Average	4457.166	8564.362	0.928	0.942	0.985	-

with input-oriented, the changing trend of farmer's planting scale and efficiency also presents multiple U-shaped curves, and the comprehensive efficiency value of 130-159 mu area is at the lowest point.

In the six scale regions of 0-1 mu, 6-12 mu, 110-130 mu, 159-170 mu, 200-212 mu and 261-280 mu under the grain security goal, the comprehensive efficiency, pure technical efficiency and scale efficiency are the optimal regardless of input orientation or production orientation. Therefore, the unique scale of optimal efficiency cannot be determined only by relative efficiency value. In order to determine the unique solution of the optimal scale of farmers' efficiency, the absolute efficiency index is also used to compare with the target of farmers' income increasing. The goal of food security takes grain yield as the output item, so the absolute efficiency is measured by the index of yield per unit cost, and the cost calculation method is the same as the goal of increasing farmers' income. Since the scale of 0-1 mu is too small, the grain yield is very low. Therefore, the unit cost grain yield of the last five scale regions is compared and analyzed, and the accounting results are shown in table 9. From the comparative analysis of the absolute efficiency index of the five optimal scale regions, the yield per unit cost of the five scale regions has little difference, among which the yield per unit cost of 200-212 mu is the highest, 0.46 kg/yuan. Therefore, the optimal scale of efficiency measured by absolute efficiency index under the food security goal is 200-212 mu, which is inconsistent with the optimal scale 261-280 mu under the goal of farmers' income increasing. This indicated that there is a significant difference between the optimal scale area under the goal of grain yield and the optimal scale area aimed at grain income.

CONCLUSION

Based on the goal of farmers' income increasing, this paper uses SPSS software to cluster the wheat production survey data of 1669 farmers in 9 provinces in the main wheat producing regions. The input and output-oriented model of the DEA-BCC measures the efficiency of wheat production by farmers of different scales, and determining the optimal scale of efficiency with absolute efficiency using cost-profit ratio as indicators. The following conclusions are drawn: (1) There are obvious differences in the technical efficiency of farmers'

Table 9 - Comparative analysis of yield per unit cost at the optimal scale of grain production efficiency.

Input and output items	----------Scale area (mu)----------				
	6-12（≤12）	110-130（≤130）	159-170(≤170)	200-212（≤212）	261-280(≤280)
Total cost (yuan)	7889.17	109473.25	161543.14	183708.28	233121.74
Total yield（kg）	3574.98	42900.00	71200.00	83740.00	102345.67
Yield per unit cost（kg/yuan）	0.45	0.39	0.44	0.46	0.44

wheat production under the dual goals and the areas with the optimal efficiency scale. The optimal scale of efficiency under the food security goal is 200-212 mu, and the optimal scale of efficiency under the farmer income increasing goal is 261-280 mu. (2) From the perspective of the change law of farmer's planting scale and efficiency, the relationship between scale and efficiency is not a simple linear relationship. The changing law of scale and efficiency under the goal of food security presents multiple U-shaped curves, and the efficiency value of 130-159 mu area is at the lowest point. The changing law of scale and efficiency under the goal of farmers' income increasing shows the changing law of inverted U curve, both of which indicate that the scale of farmers' planting should be moderate, and it is not that the larger the scale of farmers' planting is, the better the efficiency is. (3) The technical efficiency of wheat production by farmers in only 4 and 6 areas of the 19 under the dual goals is effective in DEA. Farmers in other scale areas are in DEA ineffective state due to poor allocation of production factors, too small or too large planting scale and other reasons. Efficiency improvement should be made from the aspects of optimal allocation of production factors and appropriate scale planting.

The suggestions of the paper are as follows: Firstly, in view of the small planting scale of most farmers and the increasing return to scale, the government should encourage farmers to expand the planting scale through land transfer, so as to improve the efficiency of production technology and increase the income at the same time. Secondly, since farmers' participation in agricultural production provides stable food yield, which can not only improve social welfare, but also stabilize national food security. The government should improve production efficiency by providing farmers with technical training, thus increasing food yield. Thirdly, because China has a large number of people in rural areas and less land, there is a large amount of surplus labor. The government can encourage rural labor to move to cities and towns, which can not only increase income, but also rationally allocate human resources. Lastly, in view of the excessive capital input of farmers in production, especially the large use of pesticides and fertilizers, which not only increases production costs, but also causes soil pollution. Farmers should reduce the use of pesticides and fertilizers to save production costs, but also conducive to soil ecological protection.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. Funding sponsors had no role in the study design, collection, analysis, and data interpretation; during the writing of this manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

Author critically revised the manuscript and approved of the final version.

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