Journal of the Korea Academia-Industrial cooperation Society
Vol. 22, No. 8 pp. 555-565, 2021

https://doi.org/10.5762/KAIS.2021.22.8.555
ISSN 1975-4701 / eISSN 2288-4688

An Empirical Analysis of Production Efficiency of Vegetable Industry in Hebei Province

Shuang-Yu Hu, Sung-Chan Kim, Yu-Cong Sun, Zhi-Run Li,
Wen Ju, Shi-Yong Piao, Jong-In Lee*
Department of Agricultural & Resource Economics, Kangwon National University

중국 허베이성 채소산업의 생산효율성에 대한 실증연구

호쌍우, 김성찬, 손우총, 이지윤, 극문, 박세영, 이종인*
강원대학교 농업자원경제학과

Abstract The development of the vegetable industry in Hebei province has become an important way to increase a farmer's income. Under the background of increasingly serious problems, such as environmental pollution and the shortage of natural resources, it is necessary to improve the production efficiency of the vegetable industry to achieve high-quality development of the vegetable industry. Based on collating research results at home and abroad, this study selected the 2011-2018 vegetable production input and output data of Hebei Province. The production efficiency of Hebei Province's industry was studied based on the Malmquist index and DEA model. The analysis showed that technological progress is an important factor in improving the vegetable production efficiency in Hebei Province. Based on the research results, the level of vegetable production technology, combined with the specific conditions of vegetable production in Hebei Province, can be improved by developing and applying vegetable production technology, mechanized production, and intensive management development.

요 약 중국 허베이성의 채소 산업의 발전은 이미 농민의 소득 증대를 촉진하는 중요한 경로로 되고 있으며 생태환경 오염, 자연 자원 부족 등 문제가 날로 심각해지는 상황에서 채소 산업의 고품질 발전을 실현하기 위해서는 반드시 채소 산업의 생산효율을 제고함으로써 실현해야 한다. 농가의 생산성 제고를 위한 효율성 측정이 중요하다. 특히 효율성 계측 시 농가의 자본투입, 토지투입 등 현실적 투입 고려가 필요하다. 본 연구는 국내외 연구 성과를 바탕으로 허베이성 2011-2018 채소 생산 투입량, 산출량 데이터, 맴퀴스트 지수와 DEA 모델을 바탕으로 허베이성 산업의 생산 효율성을 연구하였다. 효율성 계측 결과를 이용하여 비효율성의 원인을 규명하고, 농가 효율성 향상을 위한 대안을 제시한다. 분석을 통해 기술 진보 요인이 허베이성의 채소 생산능률의 증가에 영향을 미치는 중요한 원인이라는 것을 발견했다. 연구결과에 따라 본 연구는 채소 생산기술 수준을 제고하는 목적에 기초하여 허베이성 채소 생산의 구체적인 조건과 결합하여 채소 생산기술의 개발과 응용, 기계화 생산, 집약화 경영 발전 등 방면에서 상응하는 대책과 건의를 제기할 것이다.

Keywords : BCC-DEA, Hebei Province, Malmquist Index, Production Efficiency, Vegetable Industry

*Corresponding Author : Jong-In Lee(Kangwon National Univ.)
email: leejongin@kangwon.ac.kr
Received April 9, 2021　　Revised May 27, 2021
Accepted August 5, 2021　　Published August 31, 2021

1. Introduction

At present, the vegetable industry has become a pillar industry in China, which plays an important role in increasing Chinese farmers' income and accelerating the development of rural areas. As an important part of China's agriculture, the vegetable industry occupies a critical position in the development of China's agriculture[1]. According to China Rural Statistical Yearbook 2019, the total vegetable planting area in China reached 20438.9 thousand hectares in 2018, with a total output of 700 million tons. Among them, the vegetable planting area in Hebei Province was 787.6 thousand hectares, accounting for 3.9% of China's total planting area. The vegetable output of Hebei Province was 51.545 million tons, accounting for 7.4% of the total national output, ranking fourth in China. In 2018, the vegetable industry's total output value in Hebei Province was 133.53 billion yuan, accounting for 43.27% of the agricultural output value of 308.59 billion yuan in Hebei Province 4.68 percentage points higher than 38.59% in 2017. These ratios were higher than those of Shandong (36.96%) and Henan (35.21%), two major vegetable producing areas. The vegetable industry's gross output value was higher than that of the grain industry in Hebei Province, so vegetables are a veritable cash crop. Because of its good economic benefits, the vegetable planting industry plays an essential role in promoting farmers' income increase, realizing rural revitalization and building a well-off society in an all-around way. It is also an essential source of income for tens of thousands of vegetable farmers. With the continuous improvement of the economic benefits of the vegetable industry, to obtain short-term economic benefits, most farmers usually invest a large number of pesticides and fertilizers in the vegetable production process to increase vegetable production, and then the extensive production method with high input is no longer suitable for Eco-environmental protection, and the green development of the vegetable industry is increasingly conflicting between the shortage of natural resources and the high input of factors. At the present stage, the development of China's vegetable industry is facing the challenge of transformation and upgrading. To achieve high-quality and sustainable development of the vegetable industry, improving the production efficiency of the vegetable industry is an important part of the current and next work. As a major vegetable production region, Hebei Province has significantly less vegetable planting area than other major vegetable provinces. Under the constraints of effective land resources and ecological environment protection, the vegetable industry development in Hebei Province must improve the production efficiency of the vegetable industry to increase vegetable output. However, most of the research on the vegetable industry in Hebei Province is limited to analyzing the current situation and development trend, and there are few pieces of research on the production efficiency of the vegetable industry[2]. Therefore, it is vital to assess the input-output efficiency of vegetables in Hebei Province and seek ways to improve the input-output efficiency, which will be of great practical significance for Hebei Province to understand more clearly the current situation of its vegetable industry, formulate policies for the development of the vegetable industry and boost economic development.

It is an important way to reflect the economic benefits of vegetables by calculating the vegetable production efficiency, and also an important argument of most existing research literature. It is mainly carried out from vegetable production benefits and the scale and layout of vegetable planting, focusing on the vegetable production itself. Currently, the Data Envelopment Analysis (DEA) is used worldwide to study and comprehensively evaluate production efficiency. This method has been applied in China to analyze the production efficiency of some agricultural products, such as the production efficiency of wheat in China, the production efficiency of apples in Henan Province, and the efficiency of agricultural land use[3]. Lv Chao et al. (2011) used the Malmquist index method of DEA to calculate and decompose the total factor productivity and its changes in the vegetable industry in China and all provinces from 1994 to 2007. The results showed that the annual average growth rate of total factor productivity and technological progress of the vegetable industry in China was negative, while the growth rate of technical efficiency was positive. Besides, the vegetable production scale was reasonable, and the industrial resources of the vegetable industry in China were well allocated[4]. Zhang Biao et al. (2016) constructed a transcendental logarithmic production function model using 164 sets of sample data from 30 provinces and cities in 2011 and 2012 to investigate the changes in technical efficiency of vegetable production in China and its influencing factors. The results showed that the average technical efficiency of vegetable production in China was 0.8099, and three input factors, fertilizer cost, labor cost, and land input, had different degrees of redundancy[5]. Huang Sheng et al. (2017) distributed 300 questionnaires and conducted research through vegetable growers in five cities of Fujian Province, and also used the DEA method to analyze the capital and labor input-output of vegetable production empirically while analyzing the influencing factors by introducing farmer and household characteristics, vegetable production conditions, institutions and policies[6]. Zhang Debin (2018) used the survey data of the main vegetable production areas in China from 2009 to 2016 and used Malmquist-DEA as a tool to calculate the production efficiency of farmers in five main open field vegetable production areas in China, and proposed related guidance policies according to the main production areas[7]. Wang Bin et al. (2019) used DEA method to analyze the efficiency of inputs and outputs of 12 vegetables in Shandong Province. They found that eight vegetables did not reach DEA efficiency, and the main reason for DEA inefficiency was low scale efficiency and proposed factor optimization solutions[8]. By analyzing the existing research literature, we found that the current research on productivity measurement and technical efficiency of the vegetable industry is mainly based on DEA analysis and the decomposition analysis of productivity index through the data envelope analysis using DEAP2.1. The vegetable industry is the largest agricultural sector in Hebei Province. Since there are few studies on the production efficiency of the vegetable industry in Hebei Province, this paper uses DEA model to analyze the vegetable production efficiency in Hebei Province, to evaluate the problems in the input and output of the vegetable industry in Hebei Province, and propose countermeasures to help the sustainable development of the vegetable industry in Hebei Province.

2. Theoretical Analysis

Farrel (1957) believes that the company's efficiency can be divided into two parts: technical efficiency, which reflects the company's ability to obtain the maximum output under a given input situation. The second is allocation efficiency, reflecting the ability to use the optimal ratio given the respective input prices. The above two measures are combined to give the measure of total economic efficiency[9]. Since technical efficiency was formally proposed in 1957, scholars from various countries have focused on two aspects of research: The theoretical aspect is mainly the measurement method of technical efficiency. That is, the method of determining the frontier is studied. The empirical analysis focuses on measuring the technical efficiency of different methods for enterprises and regions and then analyzing the differences and making policy recommendations. The efficiency of production technology reflects the effectiveness of the current technological level in the production process, that is, the relationship between input and output level under given production conditions. Under the appropriate scale of production, certain inputs of production factors give full play to the level of management and science and technology, and the maximum output that can be achieved forms the frontier of production. In the actual production process, the output often fails to reach the frontier of production. The gap between the two reflects the efficiency of production technology. The smaller the gap between the two, the higher the level of technical efficiency. The research on the production frontier is mainly dicided into two categories, non-paprametric estimation method and parametric estimation method.

3. Method and Data

3.1 Research Method

Data Envelopment Analysis (DEA) is the most commonly used method to study the input-output productivity. DEA is a mathematical liner programming method to construct a non-parametric piecewise surface (or frontier) over the data, which could be able to calulate efficiencies relative to this surface Coelli[10]. DEA is an efficient evaluation method developed by Farrell on the basis of relative efficiency in 1957[9]. Charnes et al.[11], Fare and Lovell[12], and Banker et al.[13] establish some models for further study. In this research, each of the selected vegetable varieties was considered as one DMU. Introduced by Banker, Chames and Cooper (1984), this model measures Technical Efficiency as the convexity constraint and ensures that the composite unit is of similar scale size as the unit being measured. The variable returns to scale (BCC) model show that the addition of a convexity constraint to the constant returns to scale (CCR) model results in a DEA model that allows increasing, constant, and decreasing returns to scale. The envelopment form of BCC is:

$$\min \theta_o \tag{1}$$

$$s.t \sum_{j}^{n} \lambda_j x_{ij} - \theta_o x_{io} \le 0, i = 1,2,\cdots m$$

$$\sum_{j}^{n} \lambda_j y_{rj} - y_{ro} \ge 0, r = 1,2,\cdots,s$$

$$\sum_{j}^{n} \lambda_j = 1$$

$$\lambda_j \ge 0$$

There are n DMUs each employs m similar inputs and produces s similar outputs. Note that BCC model differs from CCR in that it has the additional convexity constraint, $\sum_{j}^{n} \lambda_j = 1$. A DMU_o is BCC-efficient if it has an optimal solution of $\theta = 1$, $\lambda = 1$ and $\lambda \ne 0$.

A typical method of studying total factor productivity is Malmquist exponential methods based on nonparametric. In this paper, TFP is decomposed Technical Progress Change (TPCH) and Technical Efficiency Change (TECH) by Malmquist Index, Technical efficiency changes can be further decomposed into pure technical efficiency change (PECH) and scale efficiency change (SECH)[14]. The Malmquist index was originally proposed by the Swedish economist Sten Malmquist in 1953[15]. Caves[16] constructed the productivity index by the ratio of distance functions, which is named Malmquist productivity index, and applied this idea to production analysis in 1982.

According to Fare's research results, the measure of an output-based Malmquist index can be expressed as:

$$M(x^{t+1},y^{t+1},x^t,y^t)=\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \times\left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}\times\frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right]^{\frac{1}{2}} = TECH\times TPCH \quad (2)$$

Where (x^t,y^t), (x^{t+1},y^{t+1}) represent input and output vector of the t and t+1 period independently. D^t, D^{t+1} represent the distance function of t and t+1 period. TECH represent the "catching up index" and it measures the distance between the period t and the period t+1. If the TECH is greater than 1, the technical efficiency is increased, otherwise the technical efficiency is decrease. If the TPCH is greater than 1, indicating that the technology is progressive or technical setback.

3.2 Data and Index Selection

This study used the vegetable industry's cost and benefit data in Hebei Province in the Compilation of National Agricultural Products Cost-Benefit Data from 2011 to 2018. It adopted DEA to compare the production efficiency of open-field vegetables and greenhouse vegetables in Hebei Province. Based on the references, the input indicators were selected from labor, capital and land. Labor person-days were chosen for labor input (input 1), and land cost was chosen as land input (input 2). For capital inputs, capitalized inputs in fertilizer (input 3), pesticide (input 4) and agricultural machinery (input 5) were selected. In terms of outputs, the output of various vegetables was selected as the output

Table 1. Summary descriptive statistics of variables

		Output	Input 1	Input 2	Input 3	Input 4	Input 5
2011	Min	1603.63	135.35	9.06	136.87	6.28	31.52
	Max	7481.19	285.48	76.74	760.04	368.80	68.48
	Mean	4166.95	228.02	34.93	357.41	112.01	45.45
	SD	1443.98	44.29	22.29	207.27	98.58	10.88
2012	Min	1480.16	167.06	7.58	128.56	6.96	32.25
	Max	7671.69	331.54	77.67	989.35	382.62	68.21
	Mean	4272.53	254.16	34.78	393.29	121.92	52.79
	SD	1515.39	26.64	21.95	274.13	106.26	9.17
2013	Min	1603.40	150.40	7.73	169.13	9.08	36.81
	Max	7234.82	400.00	84.14	863.34	350.90	73.49
	Mean	4345.68	277.95	35.69	351.04	107.74	57.02
	SD	1484.99	72.88	23.45	185.33	95.66	9.11
2014	Min	1467.87	150.40	8.47	152.39	7.93	34.68
	Max	6332.54	564.00	71.00	1015.25	332.06	77.16
	Mean	4269.77	286.09	35.77	355.94	107.35	58.21
	SD	1288.06	106.54	20.59	239.91	98.21	9.92
2015	Min	1446.42	150.40	7.90	140.94	9.10	42.33
	Max	6743.43	552.00	62.75	916.08	350.64	80.24
	Mean	4328.85	293.17	37.17	338.53	116.60	61.62
	SD	1371.73	106.73	19.12	210.11	106.52	10.53
2016	Min	1620.74	150.40	8.15	169.49	12.68	32.88
	Max	6591.91	736.00	68.11	1186.43	341.74	83.18
	Mean	4232.92	324.04	34.36	369.33	108.06	62.64
	SD	1359.94	140.17	18.75	271.10	90.98	13.13
2017	Min	1558.57	188.53	8.08	158.43	12.69	33.31
	Max	6852.97	773.50	67.34	966.74	399.85	85.48
	Mean	4179.59	341.05	33.35	359.49	120.80	64.42
	SD	1390.84	145.60	18.93	347.45	106.64	13.46
2018	Min	1593.52	213.45	8.01	155.89	12.48	38.03
	Max	7524.32	439.73	70.58	968.20	359.53	90.78
	Mean	4251.46	320.96	35.28	362.87	126.45	67.34
	SD	1405.26	61.69	20.69	244.71	97.63	12.61

variable of production efficiency (Zhang Debin, 2018; Wang Bin, 2019; Xu Qiuyan, 2020). Also, in order to eliminate the price effect, the data were standardized to 2011 as the base period. In this paper, the Malmquist index method was used to estimate the changes in total factor productivity of vegetable production in Hebei Province in analyzing open-field vegetables and greenhouse vegetables (tomatoes, cucumbers, eggplants, and bell peppers). Moreover, the changes in technical efficiency (combined efficiency) and returns to scale of open-field vegetables (tomatoes, cucumbers, eggplants, bell peppers, cabbage, Chinese cabbage, potatoes, cauliflower, radishes, and beans) were analyzed using BCC-DEA model.

4. Empirical Analysis

In this paper, the Malmquist index method was used to estimate the changes in total factor productivity of vegetable production in Hebei Province when analyzing open-field vegetables and greenhouse vegetables (tomatoes, cucumbers, eggplants, bell peppers). The BCC-DEA (Variable Return to Scale, VRS) was used to analyze the changes in technical efficiency and returns to scale of open-field vegetables (tomatoes, cucumbers, eggplants, bell peppers, cabbage, Chinese cabbage, potatoes, cauliflower, radish, and beans).

4.1 Total Factor Productivity Indexes of Greenhouse Vegetables and Open-field Vegetables

DEAP2.1 was run to calculate total factor productivity (TFP), change in integrated Technical Efficiency Change (TECH), Technical Progress Change (TPCH), pure technical efficiency change (PECH), and scale efficiency change (SECH) for tomatoes(X_1), cucumbers(X_2), eggplants(X_3), and bell peppers(X_4) by Greenhouse(G) and Open-field(O) production in Hebei Province.

Table 2. Total factor productivity indexes of greenhouse vegetables and open-field vegetables from 2011 to 2018

Varieties	TPCH	PECH	SECH	TFP	TECH
X_1-O	0.989	1.000	1.000	0.989	1.000
X_1-G	0.945	1.011	1.009	0.965	1.020
X_2-O	0.933	1.000	0.984	0.918	0.984
X_2-G	0.937	1.000	1.000	0.937	1.000
X_3-O	0.965	1.000	0.986	0.951	0.986
X_3-G	0.944	0.998	0.978	0.921	0.976
X_4-O	0.972	1.000	0.973	0.946	0.973
X_4-G	0.959	0.985	1.015	0.958	0.999
mean	0.955	0.999	0.993	0.948	0.992

(1) Technical Progress Change (TPCH): Technical Progress Change indicate the application of new technologies in the production process. From Table 2, it can be seen that vegetable farming in Hebei Province adopts insufficient new technologies. The progress of new technologies in open-field and greenhouse tomato cultivation was -1.1% and -5.5% in 8 years, respectively. Open-field and greenhouse cucumbers applied new technologies at similar levels, 0.933 and 0.937 respectively, which shows that there is still much room for development. Next, the technological changes of eggplant and bell peppers show that there is still much room for improvement in the development of new technologies for vegetable cultivation in Hebei Province in the past eight years.

(2) Pure technical efficiency (PECH) and scale efficiency (SECH): The pure technical efficiency reflects the degree of utilization of the applied technology, the scale efficiency reflects the returns to scale of all types. The average of the eight years shows that greenhouse tomatoes in Hebei Province have the highest degree of application of existing technologies. Its scale efficiency was greater than 1, which was in scale optimization, indicating that the scale of greenhouse tomatoes in Hebei Province reached the optimal. The mean values of pure technical efficiency and scale efficiency for open-field

tomatoes and greenhouse cucumbers were both 1, indicating that they were close to the optimum in the past eight years.

(3) Total factor productivity (TFP): The total factor productivity is the outcome of the combined effect of technological change and scale change. As shown in Table 2, the mean values of TFP for open-field vegetables and greenhouse vegetables in Hebei Province were 0.989, 0.965, 0.918, 0.937, 0.951, and 0.921, indicating a decline in TFP, mainly due to insufficient efforts in developing and applying new technologies. In conclusion, the combined technical efficiency, technical efficiency, pure technical efficiency and total factor productivity may either be efficient or inefficient in different cases, regardless of vegetable varieties or cultivation methods.

4.2 Scale Efficiency of Planting Open-Field Vegetables

Crste denotes the technical efficiency with the returns to scale, so it is the combined efficiency. Vrste denotes the technical efficiency without the returns to scale, so it is the pure technical efficiency. Technical efficiency refers to using the available resources optimally to maximize output at a certain level of input or minimize input at a fixed level of output. The productivity of open-field vegetables in Hebei Province in 2018 was measured according to DEAP2.1, and the BCC model was used to calculate the pure technical efficiency (PTE), scale efficiency (SE) and combined technical efficiency (TE) of each decision-making unit (DMU). Accordingly, the input-output efficiency was judged, and the radial and slack adjustments of each factor of inefficient vegetables were evaluated to propose the plan for optimizing factor inputs.

4.2.1 Production Efficiency Analysis

Based on the input-output data of 10 vegetables in Hebei Province, the production efficiency of open-field vegetables (tomatoes (X_1), cucumbers (X_2), eggplants (X_3), bell peppers (X_4), cabbage (X_5), Chinese cabbage (X_6), potatoes (X_7), cauliflower (X_8), radish (X_9), and beans (X_{10})) in Hebei Province in 2017 and 2018 was measured using DEAP2.1, and the results are shown in Table 3.

Table 3. Production efficiency of open-field vegetables in Hebei Province from 2017 to 2018

	2017				2018			
	TE	PTE	SE	RTS	TE	PTE	SE	RTS
X_1	1.000	1.000	1.000	-	1.000	1.000	1.000	-
X_2	1.000	1.000	1.000	-	0.932	0.951	0.981	irs
X_3	0.684	0.860	0.796	irs	0.627	0.709	0.885	irs
X_4	0.957	1.000	0.957	irs	0.834	1.000	0.834	irs
X_5	0.989	1.000	0.989	irs	1.000	1.000	1.000	-
X_6	1.000	1.000	1.000	-	1.000	1.000	1.000	-
X_7	1.000	1.000	1.000	-	1.000	1.000	1.000	-
X_8	0.479	0.717	0.669	irs	0.629	0.828	0.759	irs
X_9	1.000	1.000	1.000	-	1.000	1.000	1.000	-
X_{10}	0.476	0.785	0.606	irs	0.719	0.952	0.756	irs
Mean	0.858	0.785	0.606		0.874	0.944	0.921	

According to the combined technical efficiency, pure technical efficiency and scale efficiency, open-field tomatoes, open-field Chinese cabbages, open-field potatoes and open-field radish reached DEA efficiency in 2017 and 2018. It indicates that the inputs and outputs of these four open-field vegetables were at the forefront of production, and there was no input redundancy or insufficient output, and the planting scale of vegetables reached the optimal state. The open-field cucumbers and open-field cabbages reached their efficient state in one of the two years. The open-field cucumber reached DEA efficiency in 2017, but its scale efficiency was less than 1 in 2018 and its returns to scale increased, indicating that the main reason for the inefficiency of DEA in 2018 was that the planting scale was too small. As long as the planting scale was increased, it could achieve an optimal state of production. Among the remaining vegetables where DEA was inefficient in both years, open-field bell peppers had a pure technical efficiency of 1, but its scale efficiency

Table 4. The input redundancy of open-filed vegetables in Hebei province, 2018

Varieties		Input 1	Input 2	Input 3	Input 4	Input 5
X_2	Original value	313.380	46.310	331.460	140.690	62.190
	RM	-15.491	-2.289	-16.384	-6.954	-3.074
	SM	0.000	-9.311	-108.194	-69.597	0.000
	Projected value	297.889	34.710	206.882	64.139	59.116
X_3	Original value	389.650	30.620	427.750	86.860	68.770
	RM	-113.362	-8.908	-124.446	-25.270	-20.007
	SM	0.000	0.000	-85.505	-11.276	0.000
	Projected value	276.288	21.712	217.799	50.314	48.763
X_8	Original value	304.240	17.680	248.580	148.860	66.690
	RM	-52.264	-3.037	-42.703	-25.572	-11.456
	SM	0.000	0.000	-22.457	-93.388	0.000
	Projected value	251.976	14.643	183.420	29.900	55.234
X_{10}	Original value	259.960	23.900	186.470	115.910	66.840
	RM	-12.572	-1.156	-9.018	-5.605	-3.233
	SM	0.000	-0.030	0.000	-70.891	-0.978
	Projected value	247.388	22.714	177.452	39.414	62.629

value was low, indicating that DEA efficiency could be achieved as long as the seed size was adjusted correctly. However, the pure technical efficiency and scale efficiency of open-field eggplant, open-field cauliflower and open-field bean were insufficient and their returns to scale increased. More technologies should be applied for these three vegetables, and their planting area should be increased to achieve DEA efficiency.

4.2.2 Analysis of Optimizing Factor Inputs

The DEA method can figure out why an evaluation unit is inefficient (either technically inefficient or regularly inefficient) and give specific improvement methods. This study used DEAP2.1 to analyze and found that there was input redundancy in open-field vegetable cultivation in Hebei Province in 2018. For ineffective DMUs, in order to further analyze the causes of their input-output inefficiency and give an optimization path, an input-oriented DEA projection analysis was conducted on 10 DMUs in Hebei Province in 2018. The results found that it was found that the input factors of open-field cucumber (X_2), open-field eggplants (X_3), open-field cauliflower (X_8) and open-field beans (X_{10}) have different degrees of input redundancy. The input-oriented factor adjustment was divided into two parts: Radial Movement (RM) and Slack Movement (SM). The results are shown in Table 4. From the slack movement results, it can be concluded that the focus of slack factor movement varies among vegetables. It is also evident that land inputs do not require slack movement among all vegetables that need to be adjusted. The overall redundancy of factor inputs is seen from the sum of radial movement and slack movement, and the higher the redundancy, the lower the factor utilization. According to the redundancy degree, the factors of vegetable inputs in Hebei Province are fertilizer input, pesticide input, land input, agricultural machinery input and labor input in descending order.

5. Conclusions and Suggestions

The results show that, with the exception of tomatoes, the total factor productivity (TFP) of greenhouse vegetables is higher than that of open field vegetables. Technological progress is the reason for the increase of greenhouse vegetables' TFP, and the development and application of new technologies are also the influencing factors that hindered the increase of TFP in Hebei Province.

And analyzing different types of open field vegetables from 2017 and 2018, tomatoes, Chinese cabbages, potatoes and radish reach DEA efficiency, it indicates that the inputs and outputs of these four open-field vegetables are at the production frontier, and there was no input redundancy or insufficient output, and the planting scale of vegetables reached the optimal state, it indicates that the cultivation techniques have reached a high level. but the input factors of cucumber, eggplants, cauliflower and beans have different degrees of input redundancy, so it is necessary to improve the input-output factors on this basis to make its DEA efficiency.

To sum up, the technological progress is an important factor in promoting the vegetable industry's production efficiency, and its influence will gradually increase with the continuous popularization of the large-scale and standardized production of the vegetable industry. Therefore, the government should pay attention to the development and application of science and technology in vegetable production, and increase the investment in the research and development of science and technology in vegetable production.

It can be seen from the conclusions, the production efficiency of open field vegetables and greenhouse vegetables is relatively high. So it is necessary to give full play to the advantages of existing technologies, improve comprehensive technical efficiency, and increase the farmers' cultivation to make the vegetable industry the dominant industry in Hebei Province. Meantime, to enhance technological innovation, through the research and development and introduction of advanced technology, innovation management mode, and technical level, from factor input and output rate, factor allocation, and technical level, improving vegetable production efficiency in Hebei Province.

References

[1] D. X. Zhang, Z. W. Zhang, P. Han, J. F. Zhang, "Status and Prospect of Development of Vegetable Industry in Hebei Province", *Northern Horticulture*, Vol.37, No.1, pp.184-187, 2013.

[2] F. Z. Wang, "The Comprehensive Competitiveness Analysis of Vegetable Industry in Hebei Province", *Tianjin Agricultural Sciences*, Vol.18, No.2, pp.75-79, 2012.

[3] D. P. Zhang, J. H. Feng, "The DEA Analysis of Wheat Production Efficiency in China", *Journal of Agrotechnical Economics*, Vol.24, No.3, pp.48-54, 2005.

[4] C. Lv, Y. H. Zhou, "An Empirical Study of Agri-industrial Agglomeration and Agri-economic Growth: Based on the Test and Analysis on Vegetable Industry", *Journal of Nanjing Agricultural University*, Vol.11, No.2, pp.72-78, 2011.

[5] B. Zhang, L. X. Zhang, Z. T. Fu, X. X. Li, "Technical Efficiency and Influence Factors of Vegetable Production", *Journal of China Agricultural University*, Vol.21, No.12, pp.133-143, 2016.

[6] S. Huang, W. P. Liu, "Vegetable Production Efficiency and Influencing Factors in Fujian Province", *Fujian Journal of Agricultual Sciences*, Vol.32, No.3, pp.332-335, 2017.

[7] D. B. Zhang, "Study on Vegetable Production Efficiency by Scale: Evidence from 2009-2016 Surveys in Main Vegetable Production Areas", *Journal of Agrotechnical Economics*, Vol.37, No.7, pp.41-50, 2018.

[8] B. Wang, Y. D. Shen, "Study on production efficiency of vegetable industry in Shandong Province", *China Collective Economy*, Vol.32, No.11, pp.24-25, 2019.

[9] M. J. Farrell, "The Measurement of Productive Efficiency", *Journal of the Royal Statistical Society: Series A (General)*, Vol.120, No.3, pp.253-290, 1957. DOI: https://doi.org/10.2307/2343100

[10] T. Coelli, A Guide to DEAP version 2.1: A Data Envelopment Analysis (computer) Program, CEPA working paper, Center for Efficiency and Productivity Analysis, Australia, pp.1-49.

[11] A. Charnes, W. W. Cooper, E. Rhodes, "Measuring the Efficiency of Decision Making Units", *European Journal of Operations Research*, Vol.2, No.6,

pp.429-444, 1978.
DOI: https://doi.org/10.1016/0377-2217(78)90138-8

[12] R. Fare, C. A. K. Lovell, "Measuring the Technical Efficiency of production", *Journal of Econimic Theory*, Vol.19, No.1, pp.150-162, 1978.
DOI: https://doi.org/10.1016/0022-0531(78)90060-1

[13] R. D. Banker, A. Charnes, W. W. Cooper, "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis", *Management Science*, Vol.30, No.9, pp.1031-1142, 1984.
DOI: https://doi.org/10.1287/mnsc.30.9.1078

[14] Z. Chen, H. Z. Zhong, "Analysis of China's Regional Total Factor Energy Efficiency Based on DEA-Malmquist Index Method", *Journal of Changsha University*, Vol.28, No.2, pp.97-101, 2014.

[15] S. Malmquist, "Index Numbers and Indifference Surfaces", *Trabajos de estadistica*, Vol.4, No.2, pp.209-242, 1953.
DOI: https://doi.org/10.1007/BF0300686

[16] D. W. Caves, L. R. Christensen, W. E. Diewert, "The Economic Theory of Index numbers and the measurement of input, output, and productivity", *Journal of the Econometric Society*, Vol.50, No.6, pp.1393-1414, 1982.
DOI: https://doi.org/10.2307/1913388

Yu-Shuang Hu [Regular member]

- Jun. 2017 : Yanbian Univ., Agriculture and Forestry Economic Management, BM
- Jun. 2019 : Yanbian Univ., Rural Regional Development, MSC(Agr)
- Sept. 2019 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, PhD Program

〈Research Interests〉
Agriculture Circulation, Consumer Behavior

Sung-Chan Kim [Associate member]

- Feb. 2021 : Kangwon Univ., Agricultural and Resource Economics, BSAE
- Mar. 2021 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, MSAE Program

〈Research Interests〉
Livestock Economy, Food Consumption

Yu-Cong Sun [Regular member]

- Jun. 2012 : JiLin Agricultural Univ., Information and Computing Science, BS
- Jun. 2018 : JiLin Univ., Agriculture and Forestry Economic Management, MM
- Sept. 2018 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, PhD Program

〈Research Interests〉
Livestock Economy, Consumer Behavior

Zhi-run Li [Regular member]

- Jun. 2014 : Jilin Univ., Agriculture and Forestry Economic Management, BM
- Jun. 2019 : Jilin Univ., Rural Regional Development, MSC(Agr)
- Sept. 2019 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, PhD Program

〈Research Interests〉
Green Agriculture, Sustainable Agriculture

Wen Ju [Regular member]

- Jun. 2016 : Henan University of Science and Technology, Computerized Accounting, BM
- Sept. 2020 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, Master Program

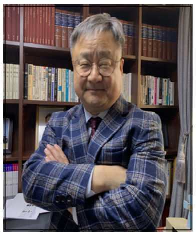
〈Research Interests〉
Green Agriculture, Sustainable Agriculture

Shi-Yong Piao [Regular member]

- Jun. 2015 : Yanbian Univ., Agriculture and Forestry Economic Management, BM
- Jun. 2018 : Kangwon Univ., Agricultural and Resource Economics, MSAE
- Sept. 2018 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, PhD Program

〈Research Interests〉
Livestock Economy, Food Consumption

Jong-In Lee [Regular member]



- Feb. 1987 : Kangwon Univ., Animal Science, BSC(Agr)
- Feb. 1993 : Kangwon Univ., Livestock Management, MM
- Aug. 1997 : Missouri Univ., Agricultural Economics, MSAE
- Dec. 2000 : Oklahoma Univ., Agricultural Economics, PhD
- Feb. 2006 ~ current : Kangwon Univ., Dept. of Agricultural and Resource Economics, Professor

〈Research Interests〉
Livestock Management, Livestock Economy,
Food Consumption