Preliminary discussion of agricultural cost effectiveness evaluation with drip irrigation

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Abstract

The evolution of human beings in the planet eventually entered the stage of the earth to directly use the resources prepared on the earth. Nonetheless, overuse of the resources resulted in long-term water resource crises of the world. Decreasing energy, slow economic capacity, and rising grain prices would inevitably cause social unrest. Taking Suzhou as the research object, “Delphi Method” and “Data Envelopment Analysis” are utilized in this study. The public data of statistical yearbook, as the data to select indicators of input and output performance, is used for data analyses and improvement reference. Aiming at the research object, 16 DMUs are evaluated. The research results are summarized as below. 1. According to the efficiency acquired from DEA and the information of variables, 1 DMU shows strong total technical efficiency at Stage I and Stage II, revealing that most administration areas still have to make efforts on the positioning scale orientation or traditional production performance. 2. The 2018~2019 data of administration areas are analyzed the productivity changes with Malmquist index in order to understand the intertemporal changes of DMUs in this study. According to the results, suggestions are proposed, expecting to assist in domestic water resource sustainable development and agricultural technology innovation.

Keywords: Drip irrigation. Agricultural technology. Cost effectiveness. Effectiveness Evaluation.

1. Introduction

Among sustainable water resources, sun, air, and water are three major elements for human survival. Water, as the renewable natural resource, could be constantly recovered through the looping process to keep dynamically balanced water volume and is utilized by humans, animals, and plants in the looping process. Water could maintain ecological integrity, is the substance in humans' survival environment, provides human production and life, extends the Earth life, provides service for economic development to achieve the maximal net profits, could become safer and cleaner through technology, and could reduce the consumption of energy and resources. The evolution of human beings in the planet eventually entered the stage of the earth to directly use the resources prepared on the earth. Nonetheless, overuse of the resources changed the hypothetical issue of climate change into abnormal climate of rainstorm, super typhoon, hurricane, and drought. The increasing times in real life became the real problems. The US Director of National Intelligence proposed that the world was getting into long-term water resource crises; not every place would appear water shortage, but people would soon be affected; about 20% of world population would become the first victims of water resource crises; eventually, 60% of land on the earth would appear desertification.

Water depletion would result in crises in global grain market to cause rising grain prices. Since it would also consume a lot of water in the power generation process, water shortage would affect the development of power. Such a situation occurred in Brazil, which used to be called the "economic engine of South America". Decreasing energy to slow down economic capacity and rising grain prices would inevitably result in social unrest. A lot of countries therefore move towards technological water conservation to explore the optimal irrigation from agricultural irrigation water, e.g. intelligently controlling water use according to different greening varieties and water needs for various time intervals. So far, there are still lots of people not having clean water and sufficient food. Water is closely related to the production of food as well as the development and application of energy. When water resource is tight, governmental departments should consider the promotion of water conservation mode to create win-win situation. For this reason, this study intends to preliminarily evaluate agricultural cost effectiveness of drip irrigation, expecting to assist in domestic water resource sustainable development and agricultural technology innovation.

2. Literature Review

2.1. Drip irrigation

Chai et al. (2016) named drip irrigation as micro-irrigation, which applied drips, with "maze water running channel" to slowly and evenly drip water on soil surface with constant quantity and then infiltrate to plant roots, as surface drip irrigation. Subsurface drip irrigation, on the other hand, referred to burying drips in the subsurface to directly infiltrate water to the growing area of plant root systems. Since the water supply of drips in drip irrigation was close to plant roots to drip with low pressure and low water velocity, it could accurately supply water volume required for plants, without wetting the entire farm. Acquah et al. (2018) explained the objectives of irrigation that supplying necessary water for crop growth was called humid irrigation and having soil absorb the fertilizer in irrigation water was called fertilizing irrigation. He et al. (2017) stated that, when using river water for irrigation, fertilizing ingredients in river water presented the benefits of humid irrigation and fertilizing irrigation. Wang et al. (2018) proposed following objectives of drip irrigation:

(a). Soil temperature regulation: Decreasing temperature and ground temperature at night in cold or sandy zones would be harmful to crops that irrigation during the daytime could control the earth heat dissipation at night and maintain the high temperature in the daytime to prevent crops from chilling injury and frost damage. That was the reason that grass in Northern Europe and Canada was irrigated in winter. On the contrary, irrigation could properly reduce ground temperature in summer in temperate zones.

(b). Improvement of physical property of soil: Bidzakin et al. (2018) indicated that proper irrigation and drainage could facilitate the crumble structure of soil, enlarge porosity, increase effective water coverage, and circulate air for crop root growth. Over-dry clay would appear surface soil hardening to make plowing be difficult. Slight irrigation could soften surface soil for plowing.

(c). Deinsectization and desalinization: Rao & Susmitha (2017) stated that irrigation could remove parasite and repel harmful creatures, e.g. field mice. Freshwater irrigation could be used for dissolving soil salinity in dry or coastal zones to lower the soda concentration in soil, which was called desalinization.

(d). Land improvement and colmation: When river water with large amount of silt flooded in gravel land, depleted farm or low wetland, the soil dressing of carried silt and sediment would enhance site and modify the nature of soil. It was called colmation.

(e). Prevention from wind erosion: Salamon & Bello (2017) described that most coastal sand soil was composed of coarse sand and fine sand, with tiny silt and clay; most soil presented single grain structure and could be easily blown by strong monsoon. In this case, irrigation was often used for stabilizing sandy soil and preventing from wind erosion in order to protect crop growth.

(f). Management of intensive farming: Jain et al. (2018) regarded intensive farming as the feature of modern agriculture. It became more important after joining in WTO. For instance, in addition to quality variety, synthetic fertilizers, mechanical farming, and rare culture, irrigation was the premise to plant fruit trees and vegetables. Solving such problems would achieve intensive farming.

2.2. Effectiveness of drip irrigation

Chao et al. (2018) considered drip irrigation as the modern and high-efficiency water saving irrigation technique, with following advantages:

(a). Water saving: Since channel water supply was applied to drip irrigation, water directly and evenly dripped to plant roots to reduce water leakage and loss down to the lowest. Meanwhile, sufficient water for crop roots, according to the growth period, could be supplied. Without water dissipation, the use efficiency of water would be largely enhanced. In comparison with traditional irrigation, drip irrigation could save more than 50% water (21). In the planting example, Angulo-Meza et al. (2019) compared traditional furrow irrigation and drip irrigation and found out up to 56% (22) water saving with drip irrigation. In the planting example, Ratnayake et al. (2018) pointed out up to 63.4% (23) water saving with drip irrigation, compared to furrow irrigation.

(b). Fertilizer saving: The drip irrigation fertilization system mixed fertilizer liquid into the drip irrigation channel and transmitted the mixture to dippers near crop roots so that the roots could rapidly absorb water and nutrient. Due to the small-area control, micro-irrigation, with less water and fertilizer leakage, could save fertilizer and reduce pollution. In the experiment, Jing et al. (2017) compared the amount of applied fertilizer with traditional furrow irrigation and discovered that 35~50% synthetic fertilizer could be reduced (22). In the application of plant sensing in automatic irrigation management, Chen et al. (2018) mentioned that saving fertilizer would help farmers save cost of fertilizer and remove abundant fertilizer from the environment; over fertilization and irrigation would result in culture and environmental problems.

(c). Humidity control: Saiyut et al. (2017) pointed out large irrigation requirement and long-time moist surface with traditional furrow irrigation; especially, it was more serious in greenhouse where large surface evapotranspiration appeared on rising temperature and resulted in high humidity to easily cause plant diseases and pests. Nevertheless, drip irrigation, as local micro-irrigation, allowed most soil surface keeping dry and drippers evenly and slowly supplying water to root soil to reduce water evaporation that the indoor/outdoor temperature was obviously reduced to fulfill the controllability of irrigation humidity.

(d). Soil structure maintenance: Singh et al. (2018) mentioned that, with traditional furrow irrigation, soil received more scouring, compaction, and erosion due to large irrigation requirement; without timely soil loosening, it would result in serious sealing, reduce permeability, and destroy soil structure. The micro-irrigation of drip irrigation allowed water slowly and evenly infiltrating soil to keep soil structure and form proper soil. Wang et al. (2017) stated that drip irrigation fertilization could reduce the spread of diseases, especially those spreading through water; drip irrigation fertilization simply humidified roots, without supplying water and fertilizer between rows, to significantly reduce weed growth.

(e). Output increase: With the example of planning Eustoma in Huwei Township, Yunlin, Babu et al. (2018) published the application of crop drip irrigation culture system and shared the experience. Being the same greenhouse culture, the annual capacity of planting density 30,000 plants／1000 square meter with traditional furrow irrigation single-hole multi-seedling suckering model was 60000 plants, while the annual capacity of planting density 55,000 plants／1000 square meter with single-hole single-seedling drip irrigation was 165000, with the capacity ratio 1:2.75. According to some research with environment control in the Netherlands, Kouzai et al. (2018) indicated that the most advanced dripping equipment could save water and increase 55% yield, compared to open farms.

(f). Labor saving: Since irrigation and fertilization were executed by drip irrigation systems, lots of manpower was saved. Besides, drip irrigation fertilization merely humidified roots, without supplying to field, that weed growth was remarkably reduced to save weeding labor. Graham & Wheeler (2016) pointed out the technical advantage and social benefit of drip irrigation. In sum, drip irrigation could save water, save fertilizer, increase output, reduce the use of carbon fuel, as well as increase crop arable land, slow down the worsening of aquifer, slow down or prevent from excessive multiplication of algae caused by excessive fertilization infiltrating water source through agricultural run-off, and reverse the slow shift of dessert. Moreover, it could solve global famine problem and political unrest accompanied with famine problem. Higher capacity could reduce poverty and improve women’s situations to reduce water transport time and risks.

3. Research Design and Method

3.1. Establishment of research indicator

Summing up above drip irrigation cost effectiveness evaluation indicators proposed by researchers, Delphi Method is utilized in this study for drawing up the drip irrigation cost effectiveness evaluation indicators in this study. Delphi Method, also named expert judgment, is a group decision-making method with qualitative and quantitative characteristics. Under data shortage or unknown situations of certain issues in the research process, it could acquire a commonly acceptable answer through several runs of anonymous experts' questionnaire survey to reduce the opinion difference down to the lowest.

The so-called "expert" should (1)show the interest in participate in Delphi Method survey together, (2)present rich information for sharing, (3)possess officially recognized knowledge and technology in special field, (4)present specialty on the surveyed topic, including practical experience and theory research, and (5)agree to cover the possessed special information in the research result. An expert should present knowledge level, reliability, and accuracy and reveal deeper understanding of the industry than a layman so that the judgment is closer to the fact than general people. The value of Delphi Method is established based on such answers.

3.2. Establishment of evaluation indicator

The evaluation indicators in this study are established based on Delphi Method. The variables are defined as followings:

(a). financial dimensions: input cost for applying drip irrigation.

(b). Number of employees: sum of formal employees and outsourcing personnel.

(c). Production scale: total production of crops (total weight).

(d). Development scale: areas input for drip irrigation planting.

(e). Growth: sales growth rate of crops.

(f). Revenue: total operating revenue.

3.3. Research method and object

Taking Suzhou as the research object, “Delphi Method” and “Data Envelopment Analysis” are utilized in this study. According to the public data of statistics yearbook, indicators are selected based on the input and output performance, and the data are analyzed to provide reference for improvement. Total 10 DMUs are selected.

3.4. Efficiency evaluation analysis

Data Envelopment Analysis (DEA) is used for evaluating efficiency in this study. Different from traditional regression analysis, which simply seeks for mean path through a series of data, it envelops the data of various samples and attempts to find out the relationship, presenting the advantage for a good efficiency evaluation model. Such a method applies linear programming, takes the factors in the performance among various DMUs, and compares the performance of units with similar features.

In the research structure, production and scale are regarded as a whole in DEA performance evaluation at Stage I, where merely the relationship between inputs and outputs is considered. DEA performance evaluation at Stage II is measured based on the production efficiency (the efficiency relationship between inputs and intermediate variables) at Stage I and the scale efficiency (the efficiency relationship between intermediate variables and outputs) at Stage II. In other words, the business efficiency of DMUs is analyzed with the process of “inputs—intermediate variables—outputs”, where inputs refer to the production elements required for production service, outputs reveal the level of DMUs achieving the effect, and intermediate variables stand for the level of DMUs being used (i.e. scale level).

4. Empirical Analysis of Drip Irrigation Cost Effectiveness

4.1. Analysis of drip irrigation cost effectiveness

CCR model is first used for calculating the total technical efficiency of DMUs at different stages, and BCC model is further used for calculating the pure technical efficiency. Scale efficiency could be acquired by dividing total technical efficiency by pure technical efficiency. From the comparison between pure technical efficiency and scale efficiency, the inefficiency is resulted from technical inefficiency or scale inefficiency. The efficiency mean of DMUs is analyzed, and total technical efficiency, technical efficiency, and scale efficiency of Stage I and Stage II are compared in this study. The analysis results are organized in Table 1 and Table 2.

Table 1: Relative efficiency of drip irrigation cost effectiveness

administration area	Stage I		
	total technical efficiency	technical efficiency	scale efficiency
Gusu District	0.92	0.93	0.92
Wujiang District	1.00	1.00	1.00
Wuzhong District	0.88	0.87	0.88
Xiangchen District	0.83	0.83	0.83
Industrial Park District	0.70	0.70	0.70
Huqiu District	0.85	0.84	0.86
Zhangjiagang	0.73	0.72	0.73
Kunshan	0.94	0.93	0.95
Taicang	0.90	0.90	0.91
Changshu	0.97	0.96	0.98

Table 2: Relative efficiency of drip irrigation cost effectiveness

administration area	Stage II					
	production			scale		
	total technical efficiency	technical efficiency	scale efficiency	total technical efficiency	technical efficiency	scale efficiency
Gusu District	0.94	0.95	0.94	0.93	0.93	0.93
Wujiang District	1.00	1.00	1.00	1.00	1.00	1.00
Wuzhong District	0.89	0.89	0.89	0.88	0.88	0.87
Xiangchen District	0.84	0.84	0.85	0.83	0.82	0.84
Industrial Park District	0.82	0.82	0.82	0.81	0.81	0.81
Huqiu District	0.86	0.85	0.87	0.85	0.85	0.85
Zhangjiagang City	0.75	0.74	0.76	0.74	0.73	0.75
Kunshan City	0.95	0.95	0.96	0.94	0.93	0.95

Taicang	0.91	0.91	0.91	0.90	0.90	0.91
Changshu	0.98	0.98	0.98	0.97	0.97	0.97

4.2. Analysis of productivity changes

To understand the intertemporal changes of DMUs, the 2018~2019 data of administration areas are analyzed the productivity changes with Malmquist index (MI). The analysis results, Table 3, show growing production at Stage I and Stage II as well as growing scale at Stage II in total element productivity changes of administration areas. It reveals the growing productivity of administration areas in such two years. At Stage I, 7 administration areas (about 70.00%) show growing total element productivity; 6 administration areas (about 60.00%) appear growing production and 5 administration areas (about 50.00%) reveal growing scale at Stage II.

Table 3: Analysis of productivity changes

administration area	Stage I	Stage II	
		production	scale
Gusu District	1.04	1.02	1.01
Wujiang District	1.22	1.16	1.09
Wuzhong District	1.02	1.00	1.00
Xiangchen District	0.97	0.96	0.98
Industrial Park District	0.96	0.97	0.96
Huqiu District	1.01	1.01	1.00
Zhangjiagang City	0.92	0.91	0.90
Kunshan City	1.05	1.04	1.06
Taicang	1.04	1.02	1.03
Changshu	1.14	1.11	1.10

Data source: self-organized in this study.

5. Conclusion

According to the efficiency acquired from DEA and the information of variables, merely 1 DMU (Wujiang District) shows strong total technical efficiency at Stage I and Stage II. It reveals that most administration areas should make efforts on positioning scale orientation or traditional production performance. Total efficiency mean of DMUs is lower than total efficiency mean of production and scale at Stage II. It highlights that DEA analysis at Stage II could better conform to the measurement of drip irrigation cost effectiveness than it at Stage I. Overall speaking, the production capability of DMUs is higher than the scale ability. Apparently, the water-saving effectiveness of drip irrigation is proven in the world and in this study. The water-saving effectiveness of drip irrigation is essential for sustainable agricultural development. Fertilizer inserted to crop roots along with drip irrigation also reduces unnecessary waste and presents higher effectiveness; the use of pesticide is relatively reduced. In addition to the decrease in investment costs, no extra fertilizer and pesticide flows into river to pollute water source or appear excessive multiplication of algae to damage the ecology. The discussions reveal higher capacity and better quality with drip irrigation planting than conventional irrigation. It proves that drip irrigation is a good solution to improve various agricultural dilemmas. In addition to saving water, saving fertilizer, increasing capacity, and reducing the use of carbon fuel, drip irrigation could increase crop arable land, slow down annual groundwater over-pumping, and reverse shift direction of dessert that it is the environment-friendly irrigation.

6. Suggestion

Aiming at the operation of drip irrigation, the following suggestions are proposed in this study.

- Young farmers present higher acceptance of new technology. However, it would be high costs for those who are not the second-generation farmers renting farms. The government should draft practicable programs to recover fallow land and reasonably use farms for the sustainable development of agriculture.
- Land size would affect farmers' willingness of using drip irrigation. A lot of farmers own small unit farms. However, drip irrigation presents certain scale effectiveness when facility costs reduce with increasing farm area. Investing drip irrigation equipment in fragmented farms would increase farmers' costs and prolong the recovery. The government should re-organized fragmented farms for the promotion of drip irrigation.
- Government sectors should make budgets to subsidize farmers setting up water saving equipment. Nonetheless, without standard operating procedures, it would be a great risk for farmers investing in drip irrigation equipment with different irrigation and fertilization from traditional farming, but not having the knowledge of the new

technology. To promote drip irrigation, agricultural departments are suggested to evaluate current crops with larger planning areas and study the standard operating procedures, e.g. various NPK ratios for planting cherry tomatoes with drip irrigation fertilization, fertilization period for the best economic benefits. With the research and development of experimental agriculture stations, farmers would reduce the risk in exploring time and unfamiliar new technology to enhance the acceptance of drip irrigation.

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