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Effect of ownership on energy use efficiency in watermelon farms –A Data Envelopment Analysis Approach–

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Abstract- The aims of this study were to determine the amount of input-output energy and exploring a non-parametric data envelopment analysis (DEA) technique which permits efficiency estimation to investigate the efficiency of watermelon farms under different farming technologies in Hamadan province, Iran. The population investigated was divided into two groups, Group II non-owner of land, machinery and low level of farming technology and Group I farms owner of land, machinery and high level of farming technology. Technical and pure technical efficiency of watermelon production was estimated 0.82 and 0.91. Frequency distribution of technical and pure technical efficiency represented farmers in Group II was more efficient. Separate analysis of groups and technical efficiency also followed same results for Group II, farms with high farming technology are more efficient and waste less source of energy. Present and target use of energy and energy saving of inefficient farms calculated. The results reveal that, on an average, in Group I and II about 68% and 28% of the total input energy could be saved respectively if the farmers follow the input package recommended by the study and farms with high technology can decrease waste of energy and costs and increase productive efficiency.

Keywords- Watermelon; productive efficiency; data envelopment analysis; farming technologies.

1. Introduction

1.1. Energy in agricultural production

Energy in agriculture is important in terms of crop production and agro processing for value adding. Human, animal and machinery is extensively used for crop production in agriculture. Energy use depends on mechanization level, the quantity of active agricultural worker and cultivable land. Efficient use and study impacts of these energies on crop production help to achieve increased production and productivity and help the economy, profitability and competitiveness of agricultural sustainability of rural communities [10].Nowadays, utilization of integrated production methods are considered as a sustainable way to reduce production costs, to efficient use of human labour and to protect the energy budgets for agricultural production [8]. Agricultural production relies on finite and scarce resources; therefore the use of input oriented DEA models is more appropriate to reduce inputs consumed in the production process [23]. Here DEA is used for the estimation of resource use efficiency and ranking of farms or production units on the basis of their performances. The present study explores Data Envelopment Analysis (DEA) technique which permits efficiency estimation of watermelon farms without assuming an a priori functional form for frontier production.

1.2. Overview of watermelon production in Iran

Watermelon (Citrullus lanatus) is a member of the cucurbit family (Cucurbitaceae). The crop is grown commercially in areas with long frost-free warm periods [12]. Watermelon is utilized for the production of juices, nectars and fruit cocktails, etc. [3]. Management of plant pests is essential during the production period. The fruit are harvested by hand, with the most experienced workers doing the cutting (removal of the fruit from the vine) and the others loading the bins or trucks. The watermelon fruit is 93% water, with small amounts of protein, fat, minerals, and vitamins. The major nutritional components of the fruit are carbohydrates, vitamin A, and lycopene, an anticarcinogenic compound found in red flesh watermelon. Lycopene may help reduce the risk of certain cancers, such as prostate, pancreas, and stomach [12]. Iran is the 3th largest producer of watermelon in the world after China and Turkey, respectively [7]. In 2008, Iran produced about 3,400,000 tones of watermelon in 135000 hectares. Hamadan province is a one of important watermelon producers in Iran. The province is located in the west of Iran, within 59° 33' and 49° 35' north latitude and 34° 47' and 34° 49' east longitude. In 2008, for example, the crop was planted in 13717 ha in this province [4].

2. Material and Method

2.1. Model specification

The current paper uses the DEA approach to analyze the data. DEA optimizes the performance measure of each production unit or decision-making unit (DMU) [1]. It results in a revealed understanding about each DMU instead of depicting the features of a mythical ‘‘average’’ DMU as in parametric analysis. In other words, the focus of DEA is on the individual observations as represented by optimizations (one for each DMU) in contrast to the focus on the average and the estimation of parameters that are associated with single optimization statistical approaches in parametric analysis.

In parametric analysis, a single regression equation is assumed to be applicable to all DMU. The approach requires the imposition of a specific functional form (i.e., regression equation, production function, etc.) relating the independent variables to the dependent variable. The selection of functional form also requires specific assumptions about the distribution of errors (independently and normally distributed) and many other restrictions. In contrast, DEA does not require any assumption about the functional form. It calculates a maximum performance measure for each DMU relative to all other units in the observed population with the sole requirement that each farmer lies on or below an external frontier. Each DMU that is not on the frontier is scaled against a convex combination of the DMUs on the frontier side closest to it. In addition, DEA can also analyze problems having multiple outputs with different units of measure.

The concepts used in the parametric and DEA approaches are demonstrated in Figure 1 where the case of seven DMUs with single inputs and single outputs is considered. The input and output are shown on the x and y axes, respectively. The filled rhombuses represent different DMUs in the data set. The dotted line represents the linear regression line in the parametric approach, depicting the trend in the data points. This approach implicitly recognizes all DMUs on or above this line as efficient.

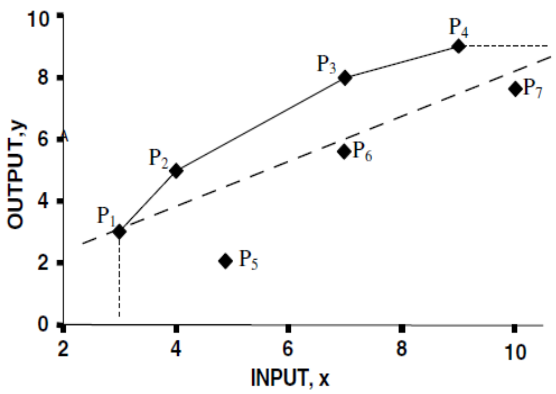

Fig. 1. Comparison of DEA approach and parametric approach (Regression Analysis)

In the case of DEA, however, one draws the envelope (or frontier) of the data set by joining the boundary points by straight lines. In Figure 1, P_1, P_2, P_3 and P_4 are the boundary points. The solid line joining these points forms the envelope for the data set. The DMUs lying on the boundary and represented by points P_1, P_2, P_3 and P_4 are considered as efficient DMUs.

A unit can be made efficient either by reducing the input levels and getting the same output (input orientation) or by increasing the output level with the same input level (output orientation). The input oriented analysis is becoming more common in DEA applications because profitability depends on the efficiency of the operations. Further, on a tentative basis, it has been suggested in the literatures that inputs are generally more predictable and credible compared to the output oriented DEA models [13]. In the present study, we have adopted an input oriented DEA approach for efficiency estimation.

It is evident in Figure 1 that many DMUs that were considered efficient in the parametric analysis are not considered efficient in the DEA approach. Further, this approach can spell out the degree of inefficiency for each DMU and, thus, pinpoint the source of inefficiency. The DEA approach can even help rank the efficient DMUs and isolate the truly efficient DMUs from the others. Thus, the practices followed by the truly efficient DMUs can form a benchmark as the best operating practices for the inefficient farmers.

2.2. Estimation of various efficiencies

DEA defines efficiency in three different forms: technical efficiency, pure technical efficiency and scale efficiency. Technical efficiency is basically a measure by which DMUs are evaluated for their performance relative to other DMUs. Its value is, however, influenced by scale efficiency, which quantifies the effect of the presence of variable returns to scale in the DMUs. Pure technical efficiency is, thus, technical efficiency that has the effect of scale efficiency removed. The concept of these efficiencies is illustrated in Figure 2.

In Figure 1, we drew an envelope of the data set for the DMUs considering variable returns to scale. In Figure 2, the line *MN* represents the envelope of the data set with constant returns to scale. It is a straight line that passes through the origin and the extreme data points. DMUs lying on this line are considered efficient. The DMU P_1, the only point lying on this line, is, thus, efficient under the assumption of constant returns to scale, but due to the onset of decreasing returns to scale; the other DMUs do not lie on this line. So, the scale efficiency for P_1 is unity, whereas for the other DMUs, it is less than unity.

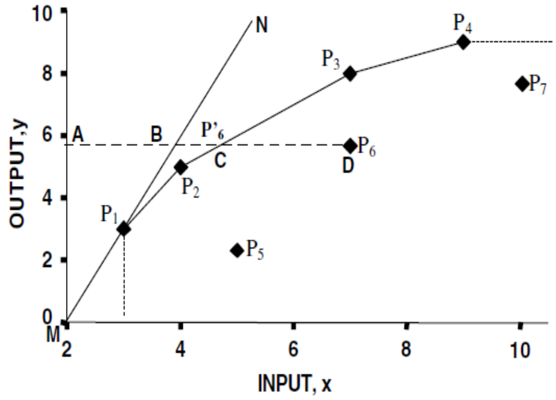

Fig. 2. Demonstration of various efficiencies

Let us consider DMU P_6. Its input and output are given by *AD* and *MA*, respectively. *B* and *C* are the points of intersection of the line *AD* with the line *MN* and the line segment of the envelope of the data set. One can interpret *AB* as the ideal input required to produce the output *B* on *MN*, if constant returns to scale were to prevail. However, considering decreasing returns to scale to be a realistic phenomenon, one can relax the input requirement to be equal to *AC* to be able to produce the output *B* on *MN*. One can now define the various efficiencies as follows:

Pure Technical Efficiency = AC/AD;

Technical Efficiency =AB/AD;

Scale Efficiency =AB/AC.

The relationship among these forms of efficiency is given as [24]:

Technical Efficiency = [Pure Technical Efficiency] × [Scale Efficiency].

It may be noted here that the technical efficiency combines the effects of both pure technical efficiency and scale efficiency. Determining these efficiencies of DMUs facilitates planners pinpointing the sources of inefficiencies. Awareness about the sources of inefficiencies is crucial to policy planners, especially for planning the strategies that are meant to improve performance [6].

In Figure 2, P'_6 is a hypothetical DMU having input equal to *AC* and acts as a benchmark for the inefficient DMU P_6. One may notice that P'_6 is represented as a convex combination of the efficient DMUs P_2 and P_3. Thus, a DMU is said to be inefficient in producing the output from a given input if any other DMU or combination of DMUs can produce a larger output for the same or less amount of inputs or if any other DMU or combination of DMUs can reduce amount of inputs without reducing the output [5]. Such a DMU will always lie inside the envelope rather than on it.

It is easy to graph and visualize the case of DMUs having single inputs and single outputs. However, in the multiple inputs, multiple outputs case; we cannot always visualize the efficient units graphically. We need to resort to analytical means to identify these efficient units.

The usual measure of efficiency (i.e., Efficiency = Output/Input) is often inadequate due to the existence of multiple inputs and outputs. The measurement of pure technical efficiency, where there are multiple and incommensurate inputs and outputs, was first addressed by Farrell [19] and developed by Farrell and Field house [18]. It focuses on the concept of a hypothetically efficient DMU, defined as a weighted average of efficient DMUs, to act as a comparator for an inefficient DMU. This hypothetically efficient DMU is known as a virtual DMU and acts as a benchmark for an inefficient DMU. A common measure of efficiency is:

Efficiency = Weighted sum of outputs/Weighted sum of inputs.

2.3. Sample selection and data description

Sample farms were randomly selected from the Hamadan province. The size of each sample was determined using Eq. (1) [9]:

$$n = [N(s\times t)^2]/[(N-1)d^2 + (s\times t)^2] \qquad (1)$$

where n is the required sample size; N is the number of holdings in target population; s is the standard deviation; t is the t value at 95% confidence limit (1.96); and d is the acceptable error (permissible error 5%). Thus calculated sample size in this study was 85. The population investigated was divided into two strata based on land, tractor and farm machinery ownership and levels of farming technology. Group I was consisted of 36 farms which were non-owners of machinery and exercised low level of farming technology. Group II was consisted of 49 farms which were the owners of machinery and practiced high level of farming technology.

Firstly, the amounts of inputs (chemicals, human labor, machinery, seed, manure, fertilizers, fuel and irrigation water) used in the production of watermelon was specified in order to calculate the energy equivalences in the study. The units in Table 1 were used to find the input amounts. The amounts of input were calculated per hectare and then, these input data were multiplied with the

Table 1. Energy equivalent of inputs in agricultural production

Inputs	Unit	Energy equivalent (MJ unit)	References
1. Human labor	h	1.96	[11]
2. Machinery	h	62.7	[11]
3. Diesel fuel	L	56.31	[17]
4. Chemical fertilizers	kg		
(a) Nitrogen (N)		66.14	[20]
(b) Phosphate (P_2O_5)		12.44	[20]
(c) Potassium (K_2O)		11.15	[14]
(d) Sulphur (S)		1.12	[2]
5. Farmyard manure	kg	0.30	[25]
6. Chemicals	kg	120	[2]
7. Water for irrigation	m^3	1.02	[15]
8. Seeds (potato)	kg	1.9	[16]

coefficient of energy equivalent. The previous studies were used to determine the energy equivalents' coefficients. These sources are given in Table 1. The energy equivalences of unit inputs are given in mega joule (MJ) unit. The total input equivalent can be calculated by adding up the energy equivalences of all inputs in mega joule (MJ).

The data (for eight Inputs MJ ha^{-1} and 0ne output tone ha^{-1}) analysis was carried out with the help of the DEA solver software, Version7.1. The software was used to calculate constant and variable returns to scale with radial distances to the efficient frontier.

3. Results and discussion

3.1. Analysis of input energy in watermelon

Table 2 shows the basic statistics of watermelon output and major inputs used. The most energy consuming inputs for watermelon production in the different farming technologies investigated were fertilizers (28566MJ ha^{-1}) water (9274 MJ ha^{-1}) and Diesel fuel (3025MJ ha^{-1}).

3.2. Energy efficiency estimation using Data Envelopment Analysis (DEA) technique

Frequency distribution of technical and pure technical efficiency represented farmers in Group I had less efficiency than Group II (Table 3). The data of pure technical efficiency showed farmers in Group II were more BCC-efficient as well, and 34 farms of 49 could shift on BCC frontier. It means, except 15 inefficient farmers, all farmers technologically had efficiency. The data of pure technical efficiency showed just 25 farmers of Group I were efficient. In other words, farmers in Group I (non-owner of land, machinery and low level of farming technology) had considerable use of energy and production in the yield. Technical and pure technical efficiency of watermelon production was estimated 0.8 and 0.97.

Separate analysis of groups and technical efficiency also followed same results for Group II, farms with high farming technology are more efficient and waste less source of energy. The average technical efficiency (resource use) provides information about the potential resource savings that could be achieved while maintaining the same output level, Average technical efficiency score were calculated 67% for group I and 89% for group II.

3.3. Scale efficiency

Using BCC model, the pure technical efficiency of a DMU is measured relative to an efficient frontier at the same scale size. BCC is modeled by setting the convexity constraint. In this case, the scale efficiency is determined by measuring the divergence between the actual scale size and the most productive scale size.

The scale efficiency of farms showed that farms in group II are more efficient.

Table 2. Basic statistics of watermelon output and major inputs used

Item	Max	Min	Average	Standard Deviation
Inputs(MJ ha^{-1})				
Human labor	3047.8	765.38	1281.60	480.50
Machinery	1755.6	1034.55	1311.05	158.70
Diesel fuel	4896.80	1903.80	3025.77	615.75
Fertilizer	52642	11739.3	28566.22	9200.715
Farmyard manure	3000	1800	2598	139.78
Seed	5.7	1.9	2.72	1.07
Water	18800.64	4847.04	9274.29	3196.91
Chemicals	720	120	289.2	139.78
Output(tone ha^{-1})				
Yield	90	25	49.1	13.84

Table 3. Frequency distribution of technical and pure technical efficiency of watermelon farmers under different groups

Efficiency score		**50-60**	**60-70**	**70-80**	**80-90**	**90≫**	**efficient**	**Median of efficiency scores**
CCR Model	Technical efficiency							
	Group I	12	8	6	4	4	2	**0.67**
	Group II	3	1	5	12	11	17	**0.89**
	Total	15	9	11	16	15	19	**0.80**
BCC Model	Pure technical efficiency							
	Group 1	-	-	1	5	5	25	**0.96**
	Group 2	-	-	-	1	14	34	**0.98**
	Total	-	-	-	12	12	26	**0.97**

The interpretation of the scale efficiency scores allows for some interesting remarks. Mean scale efficiency in group II (owner of land, machinery and high level of farming technology) is 0.91, implying that the average size of these farms is not far from the optimal size, although an additional 9% productivity gain would be feasible – assuming no other constraining factors – provided they adjusted their farm operation to an optimal scale.

Mean scale efficiency for watermelon farms calculated 0.86. By contrast, Banaeian et al. [21] reported a lower (0.76) scale efficiency for strawberry greenhouses in Tehran province.

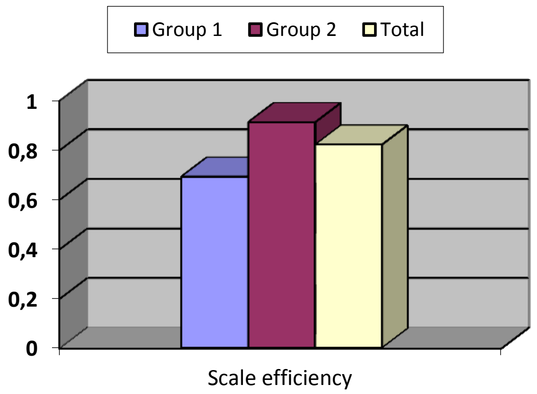

Fig. 3. Various distribution of scale efficiency

3.4. Energy saving in inefficient watermelon farms

For each inefficient farm, target input and output levels have to be prescribed. These targets are the results of respective slack values added to outputs. Table 4 shows energy saving from different sources if recommendations of study are followed. Using the information of Table 4, it is possible to advise an inefficient farmer regarding the better operating practices followed by his peers in order to reduce the input energy level to the target values indicated in the analysis while achieving the output level presently achieved by him.

Analysis showed that in Group I, 2 farms were efficient and in Group II, 17 farms were efficient. The most share of energy saving were in total fertilizers 75.03% and water for irrigation 66.95% in Group I, water for irrigation 35.21%, fertilizer 28.1%, 27.26% diesel fuel and 27.25% seed in Group II. Contribution share of each input for Group I and II is compared in Figure 1. Based on Figure 1 considerable waste of energy in Group I (low level of technology) demonstrated the good potential of energy saving in this part of watermelon producers also farmers in high level of technology and owners of land and machinery use the sources better.

Table 4. Energy saving (MJ ha^{-1}) from different sources if recommendations of study are followed

Input	Present Use (MJ ha^{-1})	Target Use (MJ ha^{-1})	Energy Saving (MJ ha^{-1})
Group I			
Human	1188.99	645.27	543.72
Machinery	1336.06	771.33	564.72
Diesel	3073.49	1520.73	1552.76
Fertilizer	30074.12	7508.62	22565.5
Farmyard manure	2602.94	1293.89	1309.05
Seed	2.68	1.18	1.50
Chemical	261.17	145.10	116.07
Water	11161.26	3687.96	7473.29
Total input energy (MJ ha^{-1})	49700.74	15574.11	34126.63

Group II			
Human	1189.10	994.20	194.90
Machinery	1306.90	956.35	350.54
Diesel	3111.92	2263.59	848.32
Fertilizer	29590.56	21274.68	8315.87
Farmyard manure	2653.12	2095.26	557.86
Seed	2.93	2.13	0.8
Chemical	285	226.98	58.01
Water	11095.06	7187.41	3907.64
Total input energy ($MJ\ ha^{-1}$)	49234.62	35000.64	14233.98

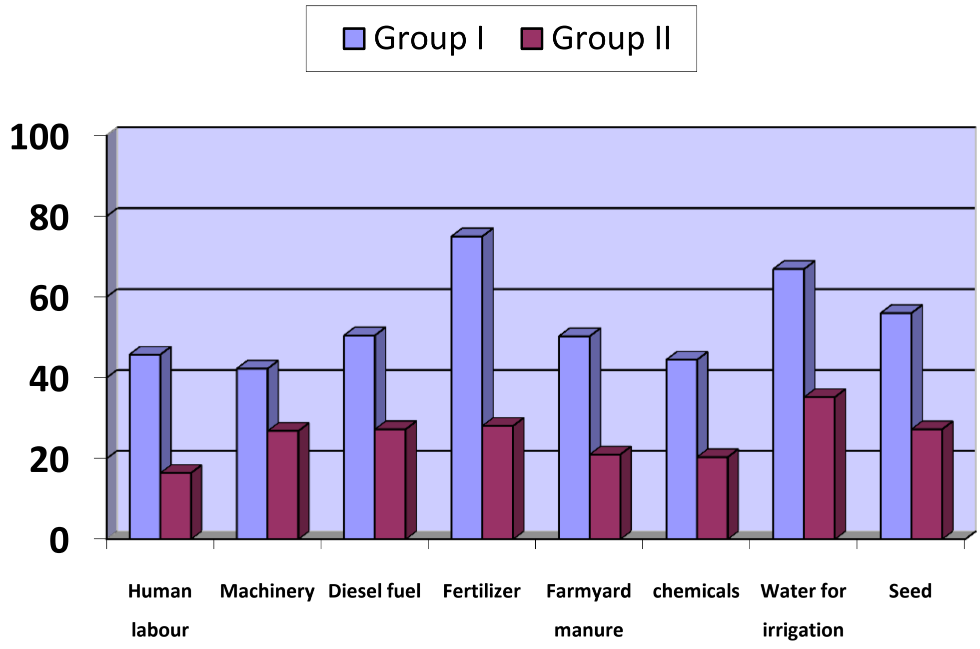

Fig. 4. Comparison between Group I and II in the case of contribution input to energy saving

4.Conclusions

In this study, the population investigated was divided into two strata based on land, tractor and farm machinery ownership and levels of farming technology. Group I which was non-owners of machinery and exercised low level of farming technology and Group II which was the owners of machinery and practiced high level of farming technology. Energy use of inputs and output in watermelon production in Hamadan province of Iran were determined. The most energy consuming inputs for watermelon production in the different farming technologies investigated were fertilizers (28566MJ ha-1) and water for irrigation (9274MJ ha-1).

Data envelopment analysis was done in order to investigate the efficiency of two groups of farms. Total data were tested in both CCR and BCC models, result showed in different efficiency scores, farms in Group II are more efficient. Technical and pure technical efficiency of watermelon production was estimated 0.82 and 0.97.

Technical and scale efficiency, target energy use and energy saving of inefficient farms in groups calculated separately. Waste energy in group I & II determined 68.66% & 28.91% respectively. If farmers operate efficient, overall 24180.3 $MJ\ ha^{-1}$ will be saved which is mostly by total fertilizers and water for irrigation energy.

Finally result showed that farmers in group II (owners of land, machinery and high level of technology) were more efficient in using inputs, energy and scale. Energy management is an important issue in terms of efficient, sustainable and economic use of energy. It can be expected that all these measurements would be useful not only for reducing negative effects to environment, human health, maintaining sustainability and decreasing production costs, but also for providing higher productive efficiency.

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