IMPROVEMENT OF COST EFFICIENCY IN STRAWBERRY GREENHOUSES BY DATA ENVELOPMENT ANALYSIS

BANAEIAN N., OMID M., AHMADI H.

Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, School of Agriculture & Natural Resources, University of Tehran, Karaj: Iran

Abstract

In recent years, Data Envelopment Analysis (DEA) has become a central technique in productivity and efficiency analysis used in different aspects of economics and management sciences. The aim of this study is using the DEA technique to investigate the technical and scale efficiency of Iranian greenhouse strawberry production. Also this research focused on comparing and optimizing the performance of greenhouses. Required data were collected using face to face questionnaire from personnel of 25 greenhouses. Analyzes were based on the amount of four important inputs: human labour (h ha^{-1}), fertilizers (kg ha^{-1}), capital (\$ ha^{-1}) and other expenses (\$ ha^{-1}) as input, and gross return of produced strawberries (\$ ha^{-1}) as output. According to the average technical (0.73) and pure technical (0.96) efficiency, there is a suitable potential for more efficient and sustainable input utilization in production. Comparison between the present and target amount of inputs demonstrated that the differences caused by the lack of inputs consumption management and calculate that on average 54716.65 \$ ha^{-1}, interpreting that if greenhouse holders follow the recommendation and use the projected amount of inputs can save 45716.65 \$ ha^{-1}. Analysis showed that the most wastage of cost is fertilizers and greenhouses can save 29% of that by improving management practices.

Keywords: *Data envelopment analysis; fertilizers; cost saving; management practices*

1. INTRODUCTION

Agricultural producers need to adapt to required changes in management practices and input usage if they are going to remain profitable. The reduction of input wastes and costs may prove the most effective means of enhancing the viability of greenhouses; given that greenhouses have more control over inputs. Strawberry belongs to the family *Rosaceae*, genus *Fragaria*, and is among the most widely consumed fruits throughout the world. Currently, United State of America, Spain, Turkey, Russian Federation, and Republic of Korea are the main strawberry producer countries (FAO, 2007). For many years in Iran, conventional strawberry growers have routinely cultivated them in open field. Today's demand for locally and off-season produce of fresh fruits and viable crop exhorts the producers to spread greenhouses. Cultivating strawberry varieties for commercial production (Fragaria × Ananassa) has recently started in greenhouses (Hancock, 1999).

The greenhouse business is a capital-intensive branch with the basic structure depending on major options. Choosing the best treatment program for a greenhouse operation is required for providing economical and effective results. In greenhouse production, management practices can be defined as a set of alternative production techniques such as structure, nutrient injection system, heating and ventilation systems, labour, cultivating programs and etc.

Several researchers have focused on determining efficiency in agricultural units and various products ranging from cultivation and horticulture to aquaculture and animal husbandry (e.g. Shafiq and Rehman, 2000; Sharma et al., 1999a; Iraizoz et al., 2003; Galanopoulos et al., 2006; Singh et al., 2004; Chauhan et al., 2006; Banaeian et al., 2010c). A further comparative review of frontier studies on agricultural products can be found in Thiam et al. (2001). Applications in assessing the efficiency of greenhouses are growing (Omid et al., 2010; Banaeian et al., 2010b) but none of them focused on commercial points. This study was conducted in the Alborz province of Iran. According to annual statistics of agricultural jihad ministry, Alborz province is the main greenhouse production area of Iran (MAJ, 2010). DEA technique is subjected to data of twenty five commercial greenhouse strawberry producers in this area. The selection of greenhouses was based on random sampling method (Mohammadi and Omid, 2010; Zangeneh et al., 2010).

Basically, the DEA methodology is centered on determining the most efficient producers of the sample to be used as a reference, with which the efficiency of the rest of the producers is compared. The most efficient greenhouses are those for which there is no other greenhouse or linear combination of greenhouses that produce more of a product (given the inputs) or use less of each input (given the gross return). Economic theory asserts that the goal for efficient management is the optimal utilization of inputs to produce outputs in such a manner that maximizes economic returns.

The methodology presented in this paper demonstrates how greenhouse producers may benefit from using operational management tools to assess their performance. It focuses on the application of DEA to benchmark and rank the technical efficiency of strawberry growers based on the amount of four important inputs (human labour, fertilizers, capital and other expenses) use, and gross return of strawberry as output. Also this paper proposed potential cost saving in greenhouses based on efficiencies.

2. MATERIALS AND METHODS

There are several parametric and non-parametric techniques to evaluate the efficiency. Data Envelopment Analysis (DEA) is a non parametric method which is used recently for estimation of resource use efficiency and ranking production units on the basis of their performances. Production units are termed decision-making units (DMUs) in DEA terminology. The DEA model has been described in detail by several authors (Banker et al., 1984; Charnes et al., 1978, 1994).

According to Farrell (1957), technical efficiency (TE) represents the ability of a DMU to produce maximum output given a set of inputs and technology (output-oriented) or, alternatively, to achieve maximum feasible reductions in input quantities given input prices and output (input-oriented). The choice between input- and output-oriented measures is a matter of concern, and selection may vary according to the unique characteristics of the set of DMUs under study. Greenhouse production relies on finite and scarce resources. Producer has more control over inputs rather than output levels, which may often be exogenously bounded (e.g., CAP provisions). In addition, the inelastic demand of most agricultural products renders cost reduction a better means of increasing profitability than output growth, notwithstanding that in many cases the choice of orientation has only minor influences upon the scores obtained (Coelli, 1996). Therefore the use of input-oriented DEA models are more appropriate to reduce inputs consumed in the production process (Malana and Malano, 2006; Chauhan et al., 2006).

Assuming constant returns to scale (CRS), TE for a unit that produces k outputs using m different inputs is obtained by solving the following model:

$$\begin{aligned} &\text{Min}_{\theta,\lambda}\theta \\ &\text{Subject to } Y_i \leq Y\lambda \qquad (1) \\ &\qquad \theta x_i \geq Y\lambda \\ &\qquad \lambda \geq 0, \end{aligned}$$

where Y_i is the $(k \times 1)$ vector of the value of outputs produced and x_i is the $(m \times 1)$ vector of the value of inputs used for unit i. Y is the $(k \times n)$ vector of outputs and X is the $(m \times n)$ vector of inputs of all n units included in the sample. k is a $(n \times 1)$ vector of weights and θ is a scalar with boundaries of one and zero that determines the efficiency score of each DMU, i.e., $\theta = 1$ shows a technically efficient DMU; $\theta < 1$ shows a technically inefficient DMU. In order to obtain efficiency scores for each greenhouse, Eq. (1) has to be solved n times, once for each greenhouse. The efficiency score (θ) in the presence of multiple- input and -output factor is defined as (Nassiri and Singh, 2009):

Efficiency = Weighted sum of outputs/Weighted sum of inputs (2)

Banker et al. (1984) developed a variable returns to scale (VRS) frontier by which technical efficiency scores are obtained from a reformulation of Eq. (1) with a convexity constraint $N'\lambda = 1$ (where N is an n × 1 vector of ones) included. By imposing the convexity constraint the data points are enveloped more tightly so that the projected "green house" for a technically inefficient unit are only efficient units of a similar size. Correspondingly, because the VRS is more flexible and envelops the data in a tighter way than the CRS, the score or pure TE (θ_{VRS}) is equal to or greater than the CRS or overall TE score (θ_{CRS}).

DEA models can evaluate the relative technical efficiency of each unit, thereby allowing a distinction to be made between efficient and inefficient DMUs. Those identified as "best practice units" (i.e., those determining the frontier) are given a rating of one, whereas the degree of technical inefficiency of the rest is calculated on the basis of the Euclidian distance of their input–output ratio from the frontier (Coelli et al., 1998). For each inefficient DMU, target input and output levels have to be prescribed. These targets are the results of respective slack values added to outputs (Thanassoulis, 2001). To calculate the target values for inputs, the input value is multiplied with an optimal efficiency score, and then slack amounts are subtracted from this amount (Onut and Soner, 2006; Omid et al., 2011).

Thomas and Tauer (1994) showed that the use of value-aggregated inputs may result in failure to distinguish between technical and allocative effects and also that the ranking of the DMUs can change with different aggregation levels. The multi-stage DEA method that is applied in this paper is invariant to units of measurement (Coelli, 1998), thereby ensuring that the ranking of the DMUs will be consistent regardless of aggregation levels.

Economic analysis was done (Banaeian et al., 2010) for achieving important factors in commercial greenhouse strawberry production. DEA model in economical aspect was applied to identify efficient and inefficient greenhouses and the sources of inefficiency. The current study consists of one output (gross returns of strawberry greenhouse) and four inputs. Gross returns include revenues from strawberry production only. Inputs are including labour, capital, fertilizer expenses and all other expenses per hectare in the year 2010. Capital includes interest costs (short and long-term debt), depreciation, maintenance, insurance and other annual expenses of fixed assets (i.e., construction, irrigation, ventilation and machinery equipments). Labour includes family and hired labour and is measured in hours. Since the hydroponic cultivation method is used in strawberry greenhouses, fertilizer expenses represent the annual quantity for plant nutrition and are measured in kilograms whereas other expenses are the summation of all other variable costs (water for irrigation, chemicals, transportation, electricity, taxes and etc.).

The data analysis was carried out with the help of the Excel 2007 spreadsheet, SPSS 16.0 software and DEA-Solver professional Release 6. The DEA-solver software was used to calculate constant and variable returns to scale with radial distances to the efficient frontier and to rank DMUs using the benchmark method.

3. RESULTS AND DISCUSSION

3.1. Economic analysis

Economic analysis of strawberry greenhouses is shown in Table 1 and investigated by Banaeian et al. (2010a). About 76% of the total expenditure was variable costs, whereas 24% was fixed. The benefit to cost ratio of strawberry (1.74) indicate that strawberry production is a highly profitable agricultural operation and the net return was +15 1907.91 $ ha^{-1}, in the year of 2009. Productivity calculated 0.59 kg $^{-1}$ that means 590 grams strawberry is produced by expending each dollar in strawberry production.

Table 1: Economic analysis of greenhouse strawberry production

Cost and return components	Unit	Value
Yield	kg ha^{-1}	64 153.33
Sale price	$ kg^{-1}	4.05
Gross value of production	$ ha^{-1}	259 821
Variable cost of production	$ ha^{-1}	82 344.91
Fixed cost of production	$ ha^{-1}	25 568.18
Total cost of production	$ ha^{-1}	107 913.09
Total cost of production	$ kg^{-1}	1.68
Gross return	$ ha^{-1}	177 476.09
Net return	$ ha^{-1}	151 907.91
Benefit to cost ratio	-	1.74
Productivity	kg $$^{-1}$	0.59

3.2. Inputs and output of DEA model

Total cost of production includes four sections of fertilizer, labour, capital (fixed cost) and other costs (water, diesel, electricity and etc.). Table 2 presents descriptive statistics of variables used in the analysis. A wide variation in both input use and output is noticeable. About 51% of total cost of production is related to fertilizer and human labour inputs which are the most cost consuming inputs in greenhouse strawberry production. In this study these four sections of total cost of production were selected as inputs and gross return as output of DEA model. In some cases output and inputs obtained is more than ten times larger than that achieved by other greenhouses. Such a variation in input levels certainly suggests that certain levels represent poor resource management by producers. Considering this variation and high benefit to cost ratio, the proper potential for improvement of economic efficiency in strawberry greenhouses was seen and detailed study was seriously required.

3.3. Efficiency review

3.3.1. Technical, pure technical efficiency of green-houses

Results obtained by application of the input-oriented DEA are illustrated in Table 3. The mean radial technical efficiencies of the samples under CRS and VRS assumptions are 0.73 and 0.96, respectively. These implies first, that on average, greenhouses could reduce their inputs by 27% (4%) and still maintain the same output level, and second, that there is a considerable variation in the performance of greenhouses.

Table 2: Descriptive statistics of the variables used in the DEA model

	Labour (h ha^{-1})	Fertilizer (kg ha^{-1})	Capital ($ ha^{-1})	Other costs ($ ha^{-1})	Gross return ($ ha^{-1})
Max	33 600	18 330	53 396	83 622	584 589
Min	6 832	1 800	16 047	11 554	32 508
Average	15 364	5 104	25 568	33 257	177 476
SD[a]	5 379	3 713	6 982	15 580	109 530

[a]Standard Deviation

Figure 1: Comparison of Technical and Pure technical efficiencies between greenhouses

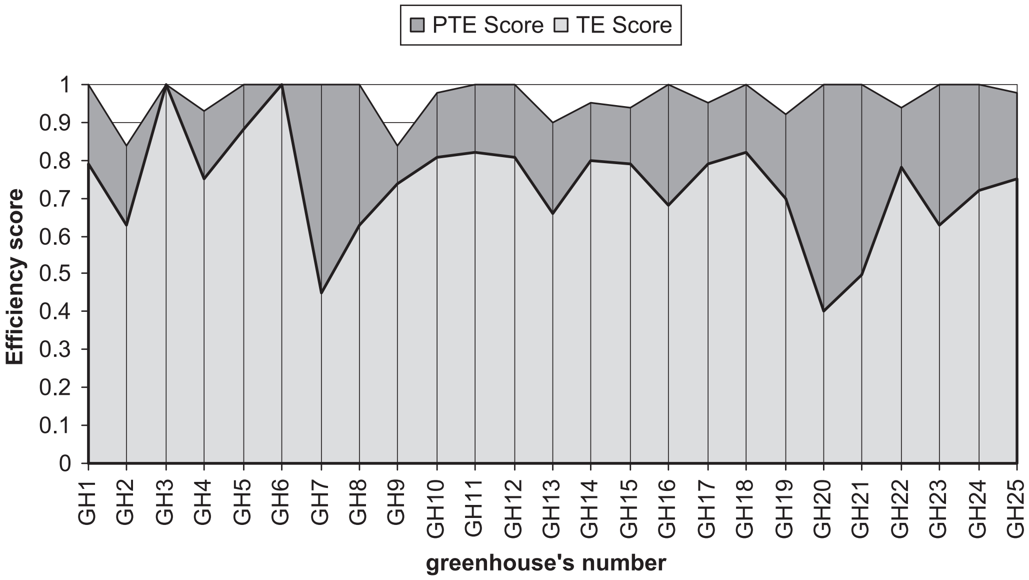


Fig.1 shows the efficiency score of greenhouses. It can be seen that greenhouses number 3 and 6 are technical and pure technical efficient. Increasing the technical efficiency of a greenhouse actually means less input usage, lower production costs and, ultimately, higher profits, which is the driving force for producers motivation to adopt new techniques.

3.3.2. Actual and target inputs of inefficient Greenhouse number 1

TE score for GH1 is 0.79, implying that the greenhouse could become technically efficient (under the Farrell definition) provided it reduces all its inputs proportionally by 21%. Hence, the analysis suggests that input use could be reduced to those shown in the third row of Table 3 while maintaining current production levels, assuming no other constraining factors. However, this greenhouse would not be Pareto-efficient, as it would be operating on the vertical section of the production frontier. In order to project a Pareto-efficient point, a further slack adjustment is necessary. Ultimately, GH1 has to reduce all inputs by 21% and labour, fertilizer and capital expense by another 20, 2 and 15%, respectively, in order to be operating at a fully technically efficient point (last row of Table 3). It can be seen that labour is the most inefficient source in GH1, so the greenhouse holder should pay more attention to management of human labour hours.

For a sample of DMUs, DEA separates the efficient units from the inefficient ones and computes the efficient input levels for inefficient units in terms of linear combinations of input and output levels of efficient units. Optimal use of fertilizer, labour and other factors not only is a way of improving the fruit quality characteristics, but also may have a crucial impact on the performance of greenhouse from an economic point of view as well.

3.3.3. Average cost saving

For each inefficient greenhouse, target input and output levels have to be prescribed (part 3.3.3). These targets are the results of respective slack values added to outputs. Table 4 shows average cost saving from different sources if recommendations of the study are followed. Using the information of Table 4, it is possible to advise an inefficient greenhouse owner regarding the better operating practices followed by his peers in order to reduce the input cost level to the target

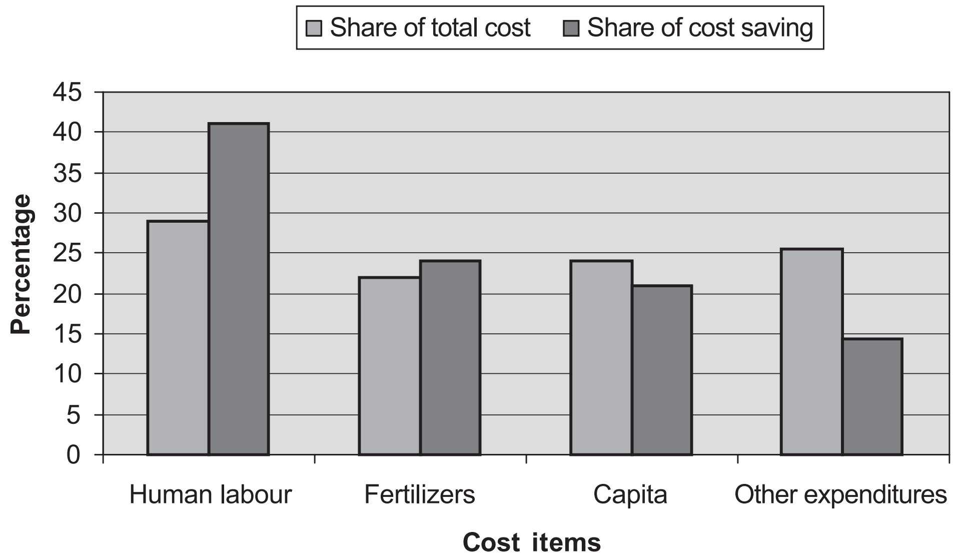
Table 3: Actual and efficient input use level of GH1

Items	Inputs			
	Labour ($h\ ha^{-1}$)	Fertilizer ($kg\ ha^{-1}$)	Capital ($\$\ ha^{-1}$)	Other expenditure ($\$\ ha^{-1}$)
Actual values	23 520	3 600	27 803	26 083
Radial movement	-8 558	-619	-5 818	-4 140
Projected point	14 962	2 981	21 985	21 943
Slack adjustment	4 792	43	4 214	0

Table 4: Average cost saving ($ ha^{-1}) if recommendations of study are followed

Input	Present Use	Target Use (Projection)	Difference	Coefficient	Cost saving ($ ha^{-1})	Share of saving (%)
Human labour (h ha^{-1})	16 107.37	4 381.98	11 725.39	1.87 ($ h^{-1})	21 926.47	41
Fertilizer (kg ha^{-1})	5 047.38	815.14	4 232.24	3.18 ($ kg^{-1})	13 458.52	24
Capital($ ha^{-1})	24 701.56	13 238.45	11 463.11	-	11 463.11	21
Other expenditure ($ ha^{-1})	28 916.03	21 047.47	7 868.55	-	7 868.55	14
Total input cost ($ ha^{-1})					54 716.65	

Figure 2: Share of four section of total cost of production (Inputs used in DEA model) and share of average energy saving based on TE score



values indicated in the analysis while achieving the output level presently achieved by him. Comparing the present and target amount of inputs demonstrated the differences caused by the lack of inputs consumption management and calculated that on average 54 716.65 $ ha^{-1} could be saved.

Primary cost analysis showed that labour, fertilizers, capital and other expenditure consumed 29, 22, 24 and 25% of total cost of production, respectively. On the other hand, DEA analysis showed that if greenhouse owners followed the recommendation, they will be able to use the optimum amount of inputs. Based on Fig. 2, considerable waste of cost in fertilizer and labour demonstrated the good potential of cost saving in this part of strawberry production. Human labour presents the highest cost and has the most potential for management and cost saving.

Table 5: Results of pure technical efficiency analysis

DMU	PTE score	Benchmark
GH02	0.84	3(0.04) 24(0.96)
GH04	0.93	3(0.07) 12(0.14) 24(0.79)
GH09	0.84	1(0.66) 3(0.16) 6(0.18)
GH10	0.98	3(0.01) 11(0.74) 12(0.10) 18(0.15)
GH13	0.90	1(0.6) 3(0.02) 5(0.38)
GH14	0.95	3(0.06) 6(0.02) 11(0.4) 18(0.52)
GH15	0.94	3(0.05) 11(0.2) 12(0.13) 18(0.61)
GH17	0.95	3(0.01) 6(0.03) 11(0.66) 18(0.3)
GH19	0.92	1(0.34) 12(0.05) 16(0.41) 18(0.15) 24(0.05)
GH22	0.94	1(0.11) 3(0.04) 6(0.07) 18(0.78)
GH25	0.98	3(0.04) 12(0.02) 24(0.94)

3.4. Benchmarking

3.4.1. Benchmarking of inefficient greenhouses

With the help of the DEA method, the performance can be assessed by comparing a particular system with key competitors having the best performance within the same group or another group performing similar functions (Malan and Malano, 2006). This process is called benchmarking. Table 5 shows the results of pure technical efficiency analysis for the inefficient

Table 6: Input use levels of GH14 and of its peers

	GH14	Input use level of peers				Input target
		GH3	GH6	GH11	GH18	
Lambda		0.06	0.02	0.40	0.52	
Input						
Labour (h ha^{-1})	13 580	15 866	24 528	9 520	14 746	12 918
Fertilizer (kg ha^{-1})	5 553	2 400	18 330	3 000	3 600	3 582
Capital ($ ha^{-1})	26 919	53 396	16 047	25 656	22 815	25 650
Other expense ($ ha^{-1})	37 651	83 622	63 262	32 364	32 122	35 931
Output						
Gross return ($ ha^{-1})	212 280	584 589	348 883	187 547	184 559	212 280

greenhouse unit (DMUs). Efficient DMUs can be selected by inefficient DMUs as best practice DMUs, making them a composite DMU instead of using a single DMU as a benchmark. A composite DMU is formed by multiplying the lambda value λ (intensity vector) by the inputs and outputs of the respective efficient DMUs.

3.4.2. Detailed benchmarking of inefficient GH14

Detailed benchmarking of inefficient GH14 is shown in Table 6, the composite DMU that represents the best practice or reference composite benchmark DMU is formed by the combination of GH3, GH6, GH11 and GH18. The summation of all lambda values in a benchmark DMU must equal 1. The lambda values are weights to be used as multipliers for the input levels of a reference greenhouse to indicate the input targets that an inefficient greenhouse should aim at in order to achieve efficiency. Based on the lambda values obtained by solving Eq. (1), the higher value calculated for GH18 (=0.52). It is clear that GH18 is the most influential benchmark and its level of inputs and output is closer to GH10 compared to the other four DMUs.

Input targets are shown in the last column and compare the actual input mix against those of its peers. It can be seen that the inefficiency of GH14 is attributed to the excessive use of inputs, especially regarding labour and fertilizer expenses. Because GH14 has more than one peer, it is essential to identify how much each peer influences the projected efficient production point.

The preceding analysis provides useful information to a greenhouse manager in determining excessive use of inputs and assessing alternative production strategies. The identification of the greenhouses that should be used in terms of benchmarking allows the establishing of the most appropriate best-practice management relative to the particular characteristics of each individual greenhouse.

4. CONCLUSIONS

Investigation of strawberry greenhouses showed a big variation of data and high mean benefit to cost ratio (1.74), so the proper potential was seen for improvement of economic efficiency and management in strawberry greenhouses and detailed study was seriously required. This paper described an in-depth application of input-oriented DEA model to investigate the degree of technical and scale efficiency of 25 commercial strawberry greenhouses in the Alborz province of Iran. This procedure allows the determination of GH 3 and 6 as the best practice greenhouses that can be providing useful insights for other greenhouse management.

The practices followed by the truly efficient greenhouses form a set of recommendations in terms of efficient operating practices for the inefficient ones. By using these greenhouses as benchmark, inefficient greenhouses can determine which changes in resource use are necessary in order to increase their overall performance and, ultimately, their profitability. If producers can reach a higher level of technical efficiency, this would bring about an increase in gross return or a reduction in the consumption of inputs. On average, a potential 27% reduction in input use could be achieved provided that all strawberry greenhouses operated efficiently, assuming no other constraints on this adjustment. This would cut down the average cost of production and improve the competitiveness of greenhouse. Differences between present and target amounts of inputs showed that on average greenhouse holders can save 54716.65 dollars per hectare, it means that from total cost of production (107913.09 $ ha^{-1}), 50.7% of cost could be saved if recommendation followed. Considerable waste of cost in labour and fertilizer (40 and 24 percentage) demonstrated the good potential of cost saving in this part of strawberry production.

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REFRENCES

Adler N., Friedman L., Sinuany-Stern Z. (2002): Review of ranking methods in the data envelopment analysis context. European Journal of Operation Research, 140: 249-265.

Banaeian N., Omid M., Ahmadi H. (2010a): Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran. Energy Conversion and Management, 52(2):1020-1025.

Banaeian N., Omid M., Ahmadi H. (2010b). Energy use pattern and benchmarking of greenhouse strawberry by Data Envelopment Analysis. In: 8th International conference of Data Envelopment Analysis (DEA 2010), 10 -12 June, Beirut, Lebanon, p. 39.

Banaeian N., Zangeneh M., Omid M. (2010c): Energy use efficiency for walnut producers using Data Envelopment Analysis (DEA). Agricultural Journal of Crop Science, 4(5): 359-362.

Banker R.D., Charnes A., Cooper W.W. (1984): Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis. Management Science, 30: 1078-1092.

Charnes A., Cooper W.W., Golany B., Seiford L., Stutz J. (1985): Foundations of Data Envelopment Analysis for Pareto-Koopmans efficient empirical production functions. Journal of Econometrics, 30: 91-107.

Charnes A., Cooper W.W., Rhodes E. (1978): Measuring the efficiency of decision making units. European Journal of Operational Research, 2: 429-444.

Coelli T. (1996): A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Papers, Dept. of Econometrics, University of New England, Australia.

Coelli T. (1998): A multi-stage methodology for the solution of orientated DEA models. Operations Research Letters, 23: 143-149.

Chauhan N.S., Mohapatra P.K.J., Pandey K.P. (2006): Improving energy productivity in paddy production through benchmarking – an application of data envelopment analysis. Energy Conversion and Management, 47: 1063-1085.

Fao (Food and Agriculture Organization). (2007): Agricultural statistics. Available online at <http://www.fao.org>. Accessed 20-07-2010.

Farrell, M.J. (1957): The measurement of productive efficiency. Journal of the Royal Statistical Society Series A, 120: 253-281.

Galanopoulos K., Aggelopoulos S., Kamenidou I., Mattas K. (2006): Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. Agricultural Systems, 88: 125-141.

Hancock J.F. (1999): Strawberries. Wallingford: CAB International p. 237.

Iraizoz B., Rapun M., Zabaleta I. (2003): Assessing the technical efficiency of horticultural production in Navarra, Spain. Agricultural Systems, 78: 387-403.

Maj (The Ministry of Agriculture of Jihad), (2010). Annual agricultural statistics. Ministry of Jihad-e-Agriculture of Iran; available online at <http://www.maj.ir/english/main/default.asp >.

Malana N.M., Malano H.M. (2006): Benchmarking productive efficiency of selected wheat areas in Pakistan and India – data envelopment analysis. Irrigation and Drainage, 55: 383-394.

Mohammadi A., Omid M, (2010): Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Applied Energy, 87: 191-196.

Nassiri M.S., Singh S. (2009): Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. Applied Energy, 86: 1320-1325.

Omid M., Ghojabeig F., Ahmadi H., Delshad M. (2011): Energy use pattern and benchmarking of selected greenhouses in Iran using data envelopment analysis. Energy Conversion and Management, 52(1): 153-162.

Onut S., Soner S. (2006): Analysis of energy use and efficiency in Turkish manufacturing sector SMEs. Energy Conversion and Management, 48: 384-394.

Shafiq M., Rehman M. (2000): The extent of resource use inefficiencies in cotton production in Pakistan'S Punjab: an application of Data Envelopment Analysis. Agricultural Economics, 22: 321-330.

Sharma K.R., Leung P.S., Zaleski H.M. (1999): Technical, allocative and economic efficiencies in swine production in Hawaii: a comparison of parametric and nonparametric approaches. Agricultural Economics, 20: 23-35.

Singh G., Singh S., Singh J. (2004): Optimization of energy inputs for wheat crop in Punjab. Energy Conversion and Management, 45: 453-465.

Tauer L., Stefanides Z. (1998): Success in maximizing profits and reasons for profit deviation on dairy farms. Applied Economics, 30: 151-156.

Thanassoulis E. (2001): Introduction to the theory and application of data envelopment analysis. Norwell: Kluwer Academic Publishers.

Thiam A., Bravo-Ureta B.E., Rivas T.E. (2001): Technical efficiency in developing country agriculture: a meta-analysis. Agricultural Economics, 25: 235-243.

Zangeneh M., Omid M., Akram A. (2010): A comparative study on energy use and cost analysis of potato production under different farming technologies in Hamadan province of Iran. Energy, 35: 2927-2933.

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Corresponding author:

Narges Banaeian
Department of Agricultural Machinery Engineering,
Faculty of Agricultural Engineering and Technology,
University of Tehran, Karaj, Iran.
tel +98-261-2801038
fax +98-261-2808138
m +98-918-9110115
e-mail: nrgsbanaei@ut.ac.ir