Available online at www.elixirpublishers.com (Elixir International Journal)

Agriculture

Elixir Agriculture 72 (2014) 25434-25439

ISSN: 2229-712X

Application of mathematical method to optimization of energy usage in greenhouse cucumber

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ARTICLE INFO

Article history:

Received: 6 June 2014;
Received in revised form:
19 June 2014;
Accepted: 1 July 2014;

Keywords

Data envelopment analysis,
Efficient units,
Greenhouse cucumber,
Technical efficiency.

ABSTRACT

In this study a mathematical Analysis is used to estimate the energy efficiencies of cucumber producers based on eight energy inputs including human labor, diesel fuel, machinery, fertilizers, chemicals, water for irrigation, electricity and seed energy and single output of cucumber production. Data were collected using face-to-face surveys from 20 greenhouses in Isfahan province of Iran. Energy indices, technical, pure technical and scale efficiencies were calculated by using Data Envelopment Analysis (DEA) approach for 20 cucumber greenhouses. Total energy input and output were calculated as 163994 MJha-1 and 62496 MJha-1, respectively, whereas diesel fuel consumption with 45.15% was the highestlevel between energy inputs. Energy output-input ratio, energy productivity and net energy gain were 0.38, 0.47 kg MJ−1, -101498MJ ha−1, respectively. Results showed that DEA approach was a very useful tool for benchmarking and improving the energy efficiency in agricultural production. The use of this methodology provides an important knowledge about the wasteful uses of energy.

Introduction

The effective and efficient use of limited resources like water, soil and human power that are of particular importance to provide food requirements for people in developing countries, including Iran. Successful efforts to achieve self-sufficiency and growth of gross national income like any other activity requiring deep knowledge of the practical and economic processes and applying the latest knowledge and technology around the world. Greenhouse production technology led to increase the efficiency of limited water and soil resources. And its importance is undeniable with respect to the dry climate and low rainfall in most parts of Iran. The major disadvantage of this method is high energy consumption because in most cases greenhouse production is off-season. Increase in energy efficiency in greenhouse cultures is of the most important energy studies in agriculture, and any success in increasing energy efficiency in greenhouse cultures can cause efficient use of valuable energy resources.

In recent years, Data Envelopment Analysis (DEA) has become a central technique in productivity and efficiency analysis applied in different aspects of economics and management science that helps us to manage efficient use of resources and ultimately more profit. The DEA is a non-parametric method for estimating the production function. The major drawback of these methods is initial necessary for the production function consequently parametric methods are not suitable for evaluation the units under control that may be inconsistent with the nature of the units under evaluation (Gheisari et al., 2007).

Also in recent years, many authors applied DEA in agricultural enterprises; such as: evaluation efficiency of greenhouse strawberry (Banaeian et al., 2011), optimization of energy consumption for apple production (Mousavi-Avval et al., 2011), a comparative study of parametric and non-parametric energy use efficiency in paddy production (Nassiriandsingh, 2010), energy use pattern and benchmarking of selected greenhouses in Iran (Omid et al.,2011), study on energy use pattern and efficiency of corn silage in Iran (Pishgarkomleh et al., 2011), analysis farming system in citrus farming in Spain (Reig-Martinez and Picazo-Tadeo, 2004), energy use efficiency for walnut producers (Banaeian et al.,2010).

The aim of this research was to determine energy use pattern and energy use efficiency in the cucumber greenhouses in the Isfahan provinceusing data envelopment analysis (DEA) and presentation methods for optimization energy consumption.

Materials and methods

Energy equivalents of input and output

The data included the quantity of various energy inputs used per hectare of greenhouse cucumber production including: human power, machinery, diesel fuel, chemicals, fertilizers, water for irrigation, fertilizer and seed, electricity, and the production yield as output. In order to analysis the performance of greenhouses from an energy use efficiency point of view, all of inputs and output were then converted into energy equivalents by multiplying the quantity of input use with their corresponding energy equivalent coefficients. Energy equivalents, shown in Table 1, were used for estimation; these coefficients were adapted from several literature sources that best fit the conditions in Iran.

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Following the calculation of energy input and output equivalents, the indices of energy consumption including energy ratio, energy productivity and net energy gain were estimated using the following Eqs. (Rafiee et al., 2010):

$$Energy\ \text{ratio}=\frac{Energy\ \text{Output}\ (MJ/ha)}{Energy\ \text{Input}\ (MJ/ha)} \quad (1)$$

$$Energy\ \text{productivity}=\frac{Cucumber\ \text{Output}(kg/ha)}{Energy\ \text{Input}(MJ/ha)} \quad (2)$$

$$Net\ \text{Energy}=Cucumber\ \text{Output}(kg/ha)-Energy\ \text{Input}(MJ/ha) \quad (3)$$

Data envelopment analysis technique

The efficiency of production units is measured either by parametric or by non-parametric methods. The first approach estimates the parameters of the production or cost functions statistically. The second one, in contrast, builds a linear piece-wise function from empirical observations of inputs and outputs. Currently, the most popular approach employs nonparametric techniques such as DEA, which introduced by Charnes, Cooper and Rhodes (CCR) in 1978 (Charnes et al, 1978). This approach is a data driven frontier analysis technique that floats a piecewise linear surface to rest on top of the empirical observations, considered as efficient frontier [20]. The main advantages of nonparametric method of DEA compared to parametric ones is that it assumes neither a preconceived functional relationship imposed between inputs and outputs to determine the efficient units nor the prior information about weights of inputs and outputs in contrast to parametric statistical approaches. Some other advantages are that, in DEA analysis inputs can be used in the form of different scales because the model adjusts with weights, also the results are presented clearly (efficiency scores as a percentage of the maximum sample efficiency) so it is possible to simply compare efficient DMUs with inefficient ones (Charnes et al, 1978).

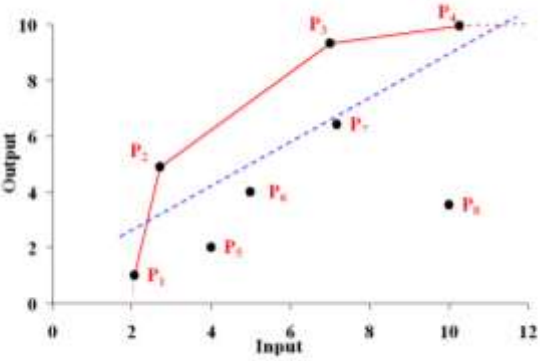

Fig.1. Comparison of DEA and regression analysis

Fig. 1 shows the difference between data envelopment analysis and regression analysis. As it is shown, the vertical and horizontal axes demonstrate the input and output, respectively. And the case of eight single input and single output DMUs with various output- input ratios is considered at points P_1 to P_8. The dotted line shows the linear regression line in the parametric approach and presents the trend in the data points. In this method all DMUs lying on or above of this line are recognized as efficient ones (DMUs P_2, P_3 and P_4). However, in the case of nonparametric approach a piecewise line is drawn as an envelope on the top of the data set by joining the boundary points by straight lines. With considering to the Fig. 1, P_1, P_2, P_3 and P_4 are the frontier points. The solid line joining these points forms the envelope for the data set. The DMUs situating on the boundary line are considered as efficient ones (DMUs P_1, P_2, P_3 and P_4) while other DMUs are recognized as the inefficient ones (Chauhan et al, 2006).

In DEA an inefficient DMU can be made efficient either by reducing the input levels while holding the outputs constant (input oriented), or, symmetrically, by reducing the output levels while holding the inputs constant (output oriented). In this study the input oriented approach was deemed to be more appropriate because there is only one output while multiple inputs are used; also as a recommendation, input conservation for given outputs seems to be a reasonable logic (Chauhan et al, 2006); so the kiwifruit production yield is hold fixed and the quantity of source wise energy inputs can be reduced. In order to separate efficient farmers from inefficient ones, arrange them and to specify the efficiency score of each farmer the technical, pure technical and scale efficiency indices were investigated (Chauhan et al, 2006).

Technical efficiency

Technical efficiency is basically a measure by which DMUs are evaluated for their performance relative to other DMUs in a sample; it is also called global efficiency which it can be expressed by the following equation (Cooper et al, 2004):

$$TE_j=\frac{u_1y_{1j}+u_2y_{2j}+...+u_ny_{nj}}{v_1x_{1j}+v_2x_{2j}+...+v_mx_{mj}}=\frac{\sum_{r=1}^{n}u_ry_{rj}}{\sum_{s=1}^{m}v_sx_{sj}} \quad (1)$$

where TE_j is the technical efficiency of the DMU under consideration, x and y denote input and output and v and u are input and output weights, respectively. s is the number of inputs (s = 1, 2, . . ., m), r is the number of outputs (r = 1, 2, ..., n) and j represents j^{th} DMUs (j = 1, 2, . . ., k). Eq. (1) is a fractional problem, so it can be translated into a linear programming problem which intruduced by Charnes, Cooper and Rhodes (Cooper et al, 2004):

$$\text{Maximize} \quad \theta_j=\sum_{r=1}^{n}u_ry_{rj} \quad (2.a)$$

$$\text{Subjected to (i)} \quad \sum_{r=1}^{n}u_ry_{rj}-\sum_{s=1}^{m}v_sx_{sj}\leq 0 \quad (2.b)$$

$$\text{(ii)} \quad \sum_{s=1}^{m}v_sx_{sj}=1, \text{ for all } j=1,2,...,k \quad (2.c)$$

$$\text{(iii)} \quad u_r\geq 0, \text{ for all } r=1,2,...,n \quad (2.d)$$

$$\text{(iiii)} \quad v_s\geq 0, \text{ for all } s=1,2,...,m \quad (2.e)$$

where θ is the technical efficiency. Model (2) is known as the input-oriented CCR DEA model which assumes that there is no significant relationship between the scale of operations and efficiency.so the large producers are just as efficient as small ones in converting inputs to output.

Pure technical efficiency

The CCR model comprehend both technical and scale efficiencies. So in 1984, Banker, Charnes and Cooper developed a model in DEA, which was called BCC model to calculate the technical efficiency of DMUs, called pure technical efficiency or local efficiency. In an input-oriented framework, the BCC model can be discribed by a dual linear programming problem as follow (Cooper et al, 2004):

Maximize $z=uy_j - u_j$ (3.a)

Subjected to (i) $vx_j=1$ (3.b)

(ii)$-vX+uY - u_o e \leq 0$ (3.c)

(iii) $v \geq 0$, $u \geq 0$ and u_o is unconstrained in sign. (3.d)

where z and u_0 are scalar and free in sign. u and v are output and inputs weight matrixes, and Y and X are corresponding output and input matrixes, respectively. The letters x_j and y_j refer to the inputs and output of j^{th} DMU. VRS means a change in inputs is expected to result in a disproportionate change in outputs. It is employed when a significant correlation between DMU scale size and efficiency can be demonstrated.

Scale efficiency

Scale efficiency gives quantitative information of scale characteristics; it is the potential productivity gain from achieving optimal size of a DMU. Scale efficiency can be calculated by the relation between technical and pure technical efficiencies derived in above, as bellow (Cooper et al, 2004):

$$\textit{Scale efficiency} = \frac{\textit{Technical efficiency}}{\textit{Pure technical efficiency}} \quad (4)$$

In Fig. 2 the concept of three types of efficiencies have been graphically illustrated. In this figure the envelope of the data set with constant return to scale is represented by the straight line of MN that passes through the origin and the extreme data point. The piecewise line joining P_1, P_2, P_3 and P_4 represents the envelope of the data set with variable returns to scale. The DMU lying on the line MN is considered as efficient and has a technical efficiency equal to unity. Also all the DMUs situated on the piecewise line, have a pure technical efficiency equal to unity. Finally, the scale efficiency for DMUs which have the both technical and pure technical of equal to 1 is unity such as P_1; whereas for the other DMUs, it is less than unity.

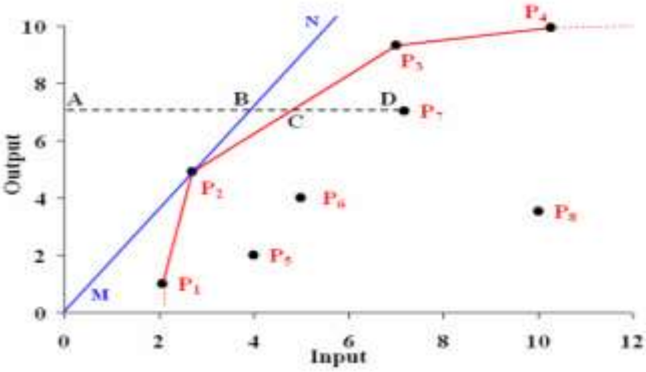

Fig.2. Relation between input and output from DEA

With considering the DMU P_7 in Fig. 2, 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 piecewise line of the envelope of the data set. One can interpret that AB is the ideal input required to produce the output B on MN, if constant returns to scale were to prevail. However, considering variable 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 (Cooper et al, 2004):

Pure Technical Efficiency = AC/AD (5)

Technical Efficiency = AB/AD (6)

Scale Efficiency= AB/AC (7)

Cross efficiency

The results of standard DEA models separate the DMUs into two sets of efficient and inefficient ones; so many units are calculated as efficient and can not to be ranked. Also in DEA because of the unrestricted weight flexibility problem, it is possible that some of the efficient units are better overall performers than the other efficient ones [13]. To overcome this problem and improve the discrimination among decision-making units, a well-known method is cross-efficiency model initially developed by Sexton et al.(Sexton et al, 1986).

In this method the results of all the DEA efficiency scores can be aggregated in a matrix, called cross efficiency matrix. In this matrixE_{ij}, the element in the i^{th} row and j^{th} column, represents the efficiency score for the j^{th} farmer calculated using the optimal weights of the i^{th} farmer which is computed by the CCR model. In general, the efficient farmers can be ranked according to their average cross efficiency score which can be achieved by averaging each column of cross-efficiency matrix and it is a mater of judgment for analysis to select the highly ranked farmers as truly efficient ones; so, a farmer with a high average cross efficiency score is a good performer .

Results and discussion

Analysis of energy input and output in greenhouse cucumber production

Amount of inputs, output and their energy equivalents for greenhouse cucumber production is presented in Table 2. The total energy consumption for greenhouse cucumber production was calculated as 163994 MJ ha^{-1};also, the percentage distribution of the energy associated with the inputs is seen in Table 3. It is evident that, the greatest part of total energy input (45.15%) was consumed bydiesel Fuel consumption. Also, fertilizers and seed was the second main energy consuming input. Similar studies had also reported that diesel fuel and fertilizers were the most intensive energy inputs (Zangeneh et al.,2010;Esengun et al., 2007; Cetin and Vardar, 2008).In order to improve the greenhouse environment as well as reduction of diesel fuel consumption, it is strongly suggested that the heating system efficiency is raised or replaced with alternative sources of energy such as natural gas and solar energy (Omid et al., 2011).

The results also revealed that electricity was the third main energy consuming input because of rising temperatures on some days; the ventilation systemis used to regulate the greenhouse temperature. The water for irrigation was the least energy demanding inputs for greenhouse cucumber production. On the other hand, the average cucumber yield obtained was found to be 78120 kg ha^{-1}; accordingly, the total energy output was calculated as 62496 MJ ha^{-1}, in the enterprises that were analyzed.

The energy output-input ratio, energy productivity and net energy gain of greenhouse cucumber production are presented in Table 3.Energy ratio was calculated as 0.38, showing the inefficiency use of energy in greenhouse cucumber production. It is concluded that the energy ratio can be increased by raising the crop yield and/or by decreasing energy input consumption. Similar results obtain0.64 for the energy ratio of greenhouse cucumber production(Omid et al., 2011; Mohammadi and Omid, 2010). The average energy productivity of greenhouse cucumber production was 0.47 kg MJ^{-1}.

Table 1- Energy equivalent of energy output and input in agricultural production

Inputs	Unit	Energy equivalent (MJ per unit)	Reference
1- Human power	Hour	1.96	Mandal et al., 2002
2-Fertilizers			
Potassium (K_2O)	Kg	11.15	Esengun et al., 2007
Nitrogen (N)	Kg	47.1	Kaltschmitt et al., 1997
Phosphate (P_2O_5)	Kg	15.8	Kaltschmitt et al., 1997
3- Chemicals			
Pesticide	Kg	101.2	Kaltschmitt et al., 1997
Herbicide	Kg	238	Kaltschmitt et al., 1997
4- Machinery	Kg	62.7	Mandal et al., 2002
5- Cucumber Seed	Kg	1	Omid et al., 2011
6- Diesel Fuel	Lit	56.31	Omid et al., 2011
7- Electricity	kWh	11.93	Omid et al., 2011
8- Water for irrigation	m^3	1.02	Zangeneh et al., 2010
Output (cucumber)	Kg	0.8	Omid et al., 2011

Table 2. Energy used status for cucumber production

Input	Quantity per unit area (ha)	Equivalent energy MJ/ha	Unit	Percent
a- Input				
1- Fuel consumption	1315	74047	Lit	45.15
2- Human power	4165.2	8163	Hour	4.97
3- Machinery	51.6	3235	Kg	1.97
4- Fertilizer (sum: potassium, nitrogen, phosphate) and seed	1050.2	39907	Kg	24.33
5- Chemicals (sum: pesticide, herbicide)	120.2	9696	Kg	5.91
6- Water for irrigation	1250	1275	Lit	0.8
7- Electricity	2319.5	27671	kwh	16.87
Total energy input	-	163994	$MJha^{-1}$	100
b- Output				
Cucumber	78120	62496	Kg	-
Total energy output	-	62496	$MJha^{-1}$	-

Table.3. output-input ratio and forms in greenhouse cucumber production

Items	Unit	cucumber	Percent of total
Crop yield	kg ha^{-1}	78120	
Energy ratio	-	0.38	
Energy productivity	kg MJ^{-1}	0.47	
Net energy gain	MJ ha^{-1}	−101498	
Energy forms [1]			
Direct energy [2]	MJ ha^{-1}	109881	67.52
Indirect energy [3]	MJ ha^{-1}	52838	32.47
Renewable energy [4]	MJ ha^{-1}	8163.13	5.01
Non Renewable energy [5] − renewable energy [5]	MJ ha^{-1}	154555.87	94.98
Total energy input	MJ ha^{-1}	163994	100

1. Energy equivalent of water for irrigation is not included.
2. Includes human power, diesel and electricity.
3. Includes seeds, fertilizers, chemicals and machinery.
4. Includes human power and seeds.
5. Includes diesel, fertilizers, chemicals, electricity and machinery

Table 4. Evaluation of cucumber greenhouse with reference units via CCR and BCC input oriented models

	Model BCC		Model CCR	
DMU's	**reference units with coefficients of decision**	**Efficiency (%)**	**reference units with coefficients of decision**	**Efficienc y (%)**
1	5(78.24)	92	11(65.2), 6(70.12)	91
2	21(74.6712(56.18),	86	12(37.3), 11(39.16)	83
3	12(38.12), 5(67.34)	95	11(58.4), 21(81.4)	92
4	12(89.34), 6(45.23)	89	21(84.14)	81
5	-	100	6(81.7)	91
6	-	100	-	100
7	12 (19.3), 5 (22.7)	89	11(56.5), 21(59.16)	87
8	19(70.16), 6(56.34)	90	6(71.8), 12(61.73)	85
9	19(60.18), 5(34.89)	94	6(81.9), 21(92.12)	89
10	5 (34.7), 6 (56.12)	92	6(69.14)	87
11	-	100	-	100
12	-	100	-	100
13	11(76.11), 5(71.46)	95	6(70.8), 21(82.71)	93
14	21(34.56)	91	12(72.9),21(81.53)	85
15	12(56.67)	80	12(80.24)	79
16	21(70.29), 11(45.23)	85	11(72.16)	83
17	22.1), 11 (39.4)(6	89	6(60.70), 11(39.13)	87
18	6(59.12),12(57.23)	82	12(50.42),21(62.5)	79
19	-	100	6(51.71)	90
20	21(30.17), 11(67.45)	90	21(61.2)	87
Average of efficiency	-	91.95	-	84.35

This means that 0.47 units output was obtained per unit energy. Similar results have been reported0.39and 0.8 kg $MJ^{-1}$for the energy productivity of greenhouse cucumber production (Mohammadi and Omid, 2010).The net energy gain of greenhouse cucumber production was $-$101498 MJ ha^{-1}. Net energy gain is negative (less than zero). Therefore, it can be concluded that in greenhouse cucumber production, energy is being lost. Similar results obtain $-$53027 MJ ha^{-1}.16 and $-$55552.83 MJ ha^{-1} for the net energy of greenhouse cucumber production (Mohammadi and Omid, 2010; Omid et al., 2011).

The distribution of inputs used for greenhouse cucumber production in groups of direct, indirect, renewable, and non-renewable sources is shown in Table 3. The ratio of direct and indirect energy sources are 67.52% and 32.47%, respectively. Also, there is a significant difference between renewable and non-renewable energy sources. Renewable energy sources are clean sources of energy that have a much lower impact on the environment than do conventional energy technologies. In the studied greenhouses, 94.98% of the input energy comes from non-renewable energy sources, which are finite and will someday be depleted. Also, many of these energy sources are harmful to the environment (Unakitan et al., 2010). Several researchers showed that the ratio of direct energy is higher than that of indirect energy, and the rate of non-renewable was much greater than that of renewable consumption in cropping systems (mohammadi et al., 2008).

Energy use efficiency for unit greenhouses

In this study, we used CCR and BCC models to evaluate technical, pure technical and scale efficiencies (TE, PTE and SE, respectively) of cucumber greenhouses. The results of CCR and BCC models are shown in table 4. Based on CCR results, this study shows that only 3 greenhouses were relatively efficient and the remaining 17 where inefficient, i.e. their efficiency score were below 1. But from the results of BCC model 5 greenhouses (out of total 20 greenhouses) were efficient, meaning they have an efficiency score of 1(Table4). Other greenhouses who have efficiency score less than 1, are inefficient in energy use.

For example, in the case of the greenhouse 15, the reference composite DMU is formed by the greenhouse 12(Table 4,CCR model). This means the greenhouse 15 is close to the efficient frontier segment formed by this efficient DMU. The production efficiency can be obtained for greenhouses 15 with the introduction of efficient greenhouse reference 12. The selection of this efficient DMUis made on the basis of its comparable level of inputs and output yield to the greenhouse 15.

Slack and surplus energy consumption in each of greenhouses

According to the results obtained from Table 5 greenhouses 6, 11and 12 have constant efficiency but the remains have increasing efficiency. Table 5 shows the obtained results from analyzing greenhouses by using input oriented constant returns to scale model. Data of this table are used for determining extra input and deficiency of efficiency. The specific quantity of input that each inefficient unit needs to decrease in order to become efficient is determined. asTable 5 shows, the greenhouse 1 with the efficiency of 91% has to decrease 22154 units of diesel fuel, 7894 units of fertilizers and seed and 9540 units of electricity and 7894 units of fertilizers and seed to stand on the efficiency partition line.

Conclusion

This study applied a mathematical model to calculate the efficiency of 20 cucumber greenhouses in the Isfahan province of Iran. This procedure allows the determination of greenhouses6, 11, and 12 as the best practice greenhouses that can be providing useful insights for other greenhouse management. Diesel fuel, total fertilizers and electricity energy inputs had the highest potential for saving energy; so, if inefficient greenhouses would pay more attention towards these sources, they would considerably improve their energy productivity.

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