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Energy use efficiency for walnut producers using Data Envelopment Analysis (DEA)

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Abstract

In this paper, Data Envelopment Analysis (DEA) technique was subjected for walnut producers in Hamadan province, Iran. The study has helped to segregate efficient farmers from inefficient ones, identify wasteful uses of energy by inefficient producers and to suggest reasonable savings in energy uses from effective sources. Pure technical efficiency was calculated by using DEA-BCC model for orchards area-wise. The results indicated 13 walnut producers were producing at an efficient scale, whereas 24 producers were inefficient. Results also revealed 7745 MJ ha^{-1} of the total input energy could be saved if the producers follow the input package recommended by the study. The biggest share of energy savings appertain to fertilizers (69% nitrogen). Results of analysis demonstrate that DEA is a suitable tool for analyzing productive efficiency of agricultural units.

Keyword: Walnut; Orchard; DEA; BCC model; Energy savings; Pure technical efficiency.

Introduction

Walnuts do not only provide healthy fatty acids and high calorie, they are also rich in vitamins and minerals that help us to stay healthy. It includes potassium, magnesium, phosphorus, iron, calcium, zinc, copper, vitamin B9, B6, E, A and etc (Prasad, 2003). Currently, China, United States and Iran are the main walnut producer countries (FAO, 2007). Energy use in agriculture has developed in response to increased population, limited supply of arable land and desire for an increasing standard of living. In order to sustain agricultural production, effective energy use in agriculture is required, since it provides financial savings, preservation of fossil resources and reduction of air pollution. Therefore, research efforts have emphasized energy analysis of various agricultural productions for planning resources in the ecosystem, considering both acceleration of the pace of crop production and the efficient utilization of farm resources (Singh et al., 2002). Although numerous studies have been conducted on energy analysis to determine the energy efficiency of plant production, there are few studies on the energy use pattern and benchmarking of crops production (Chauhan et al., 2006, Diaz et al., 2004, Malana and Malano, 2006, Nassiri and Singh, 2009, Zhou, 2008). Recently DEA has gained great popularity in energy and environmental (E&E) modeling. DEA is a non-parametric analysis method to measure the relative efficiency of a homogeneous number of organizations that essentially perform the same tasks (Cooper et al., 2006). The aims of this research were to determine the energy use efficiency per hectare for the production of walnut, and compare input energy use in efficient with inefficient Decision Making Units (DMUs). This study will benchmark productive efficiency of selected walnut orchards in Iran by DEA. Basically, the most efficient DMUs are those for which there is no other orchard or linear combination of orchards that produce more of a product (given the inputs) or use less of each input (given the walnut products).

Material and methods

Site of study

Hamadan province has 1.2% of total area of the country with high fruit growing potential and located in the west of Iran, within 36° 40′ latitude and 48° 31′ longitudes. Hamadan province is the first producer of walnut production per hectare and provided one of the most desirable walnuts of the world. Approximately 80% of the walnut produced in Hamadan province is exported. The reminder is sold to merchants for the domestic market (Moazzen, AA, 2007).

Sampling design

Data were collected from walnut orchards in the Hamadan province of Iran by using a face-to-face questionnaire performed in July-August 2009. In the studied region all operations (plowing, irrigation, harvest and post harvest) accomplished just by human labor. Water for irrigation delivered from the mountains current river and irrigation period was 15 times a year between April and September. The size of sample of each stratification was determined using Eq. (1) derived from Neyman technique (Yamane, 1967).

$$n = \frac{\sum N_h S_h}{N^2 D^2 + \sum N_h S_h^2} \tag{1}$$

Table1. Energy equivalent of inputs and outputs in walnut production

Inputs	Unit	Energy equivalent (MJ Unit^{-1})	References
A. Inputs			
Human labor			
Woman	h	1.96	(Yaldiz, 1993)
Man	h	1.57	(Yaldiz, 1993)
Transportation	tonne km	1.6	(Gezer et al., 2003)
FYM	tonne	303.1	(Demircan et al., 2006)
Fertilizer			
Nitrogen (N)	kg	66.14	(Helsel and Fluck, 1992)
Phosphate (P_2O_5)	kg	12.44	(Helsel and Fluck, 1992)
Potassium (K_2O)	kg	11.15	(Helsel and Fluck, 1992)
B. Outputs			
Walnut	kg	1.9	(Singh and Mittal, 1998)
Wooden shell	kg	10	(Pervanchon, 2002)
Green shell	kg	18	(Pervanchon, 2002)

where *n* is the required sample size; *N* is the number of holdings in target population; N_h is the number of the population in the *h* stratification; S_h is the standard deviation in the *h* stratification, S^2_h is the variance of *h* stratification; *d* is the precision *(x- X)*; *z* is the reliability coefficient (1.96 which represents the 95% reliability); $D^2 = d^2/z^2$. The permissible error in the sample size was defined to be 5% for 95% confidence, and sample size was calculated as 37 orchards. Stratification in sampling design means orchards category comprising, which were small (less than 2 ha), medium (between 2 and 4 ha) and large (over 4 ha). The data included hours or amount of inputs used from effective energy sources: human for different operations (land preparing, irrigation, harvest and post harvest), farmyard manure (FYM), fertilizers (nitrogen, phosphate and potassium) and transportation, and yield as output. Data transformed to energy term by appropriate energy equivalent factors (Table 1). The DEA model has been described in detail by several authors (Banker et al., 1984, Charnes et al., 1978, Coelli, 1996, Seiford and Thrall, 1990). The efficient frontier is established by efficient DMUs from a group of observed units. Efficient DMUs are those with the highest level of productive efficiency. Charnes, Cooper and Rhodes (1978) developed an optimization model known as the CCR (after their initials) which exhibits constant returns to scale (CRS). Later, Banker, Charnes and Cooper (1984) extended the model in such a way that it would permit the existence of variant returns to scale (VRS) and the CCR model becomes the BCC model. 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. In this paper, we adopt an input oriented DEA approach for efficiency estimation. The data analysis was carried out using Excel 2007 spreadsheet, SPSS 16.0 software and DEA-Solver professional Release 6. The DEA-solver software was used to calculate VRS with radial distances to the efficient frontier and determine the amount of energy loss and energy saving of inefficient DMUs.

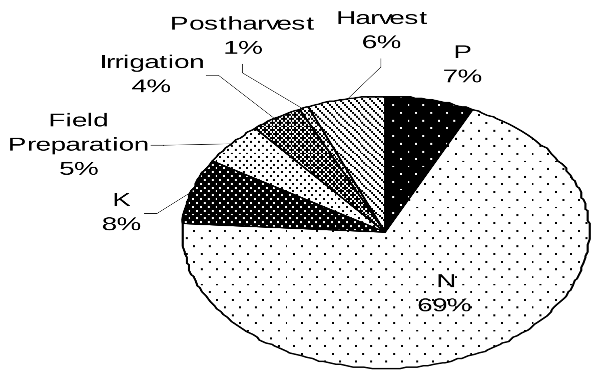

Fig1. Energy saving (MJ ha^{-1}) from different sources if recommendation of study are followed

Results

ANOVA test showed that large orchards noticeably consumed less FYM and human energy than other groups also the impact of transportation and farmyard manure inputs on area garden was insignificant, so human labor in different operations and chemical fertilizer energies are effective inputs in gardens with various areas. Comparing specific energy in groups showed that orchards over 4 hectare consumed less energy. The ANOVA test revealed that in three groups (small, medium and large) human labor in different operations and fertilizers are significant and effective inputs. Accordingly, input-oriented DEA analysis was performed with mentioned inputs and single output (walnut yield). The value of inputs and output weights were calculated so that, the value of technical efficiency approaches to the maximum value. Using the 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, scale efficiency is determined by measuring the divergence between actual scale size and most productive scale size (MPSS). BCC model results indicated that of the total of 37 orchards considered for this analysis, 13 producers have an efficiency score of unity and thus they are efficient. The pure technical efficiency score of a producer that is less than one indicates that, at present, he is using more energy than required from the different sources. Therefore, it is desired to suggest realistic levels of energy to be used from each source for every inefficient grower in order to avert wastage of energy without reducing the yield level. This

Table2. Energy inputs (MJ kg^{-1}) and specific energy (MJ ha^{-1}) of walnut orchards

Item	Percentage (%)	Mean	Small	Medium	Large
Grand total			1.2	3.5	7
FYM energy	24	2591.5	2550.5^{a}	2273.4^{a}	3043.1^{a}
Fertilizer energy	58	6194	10708.6^{a}	2900.4^{b}	3375.7^{b}
Human energy	14	1545	2509.9^{a}	755.5^{b}	729.6^{b}
Transportation energy	1	358	559.2^{a}	240^{a}	200.8^{a}
Specific energy		9.1	13.7^{a}	6.5^{b}	5.1^{b}

Table 3. The actual and suggested values of energy use from different sources for inefficient farmers (based on BCC Model)

DMU No.	TE VRS	Actual energy use, (MJ ha^{-1})							Target energy use, (MJ ha^{-1})							
O		Human labor				Fertilizer			Human labor				Fertilizer			
		FP	I	H	PH	N	K	P	FP	I	H	PH	N	K	P	Saving (%)
2	0.22	392	940	842	112	15150	1675	666	84	129	174	11	799	38	125	0.93
3	0.50	168	504	429	53	13851	1531	951	84	136	178	4	655	15	111	0.93
4	0.28	470	294	78	235	6060	670	1110	116	48	78	26	920	101	115	0.84
5	0.30	490	245	587	43	6060	670	1110	105	73	176	56	1645	176	210	0.73
6	0.25	490	326	548	235	6060	670	1110	119	80	135	43	1501	164	1110	0.66
7	0.31	470	235	564	188	6060	670	1110	102	73	175	57	1678	180	213	0.73
10	0.23	830	415	796	88	7129	788	522	189	94	120	7	770	75	119	0.86
11	0.53	3763	1509	3008	601	36360	4020	3996	156	81	161	161	1166	120	163	0.96
12	0.42	329	282	1353	0	12120	1340	1110	139	119	139	0	974	84	170	0.9
14	0.42	784	1254	1566	752	0	0	0	289	252	660	136	0	0	0	0.69
15	0.29	326	653	501	313	10100	1116	1850	94	77	145	56	1741	192	214	0.83
17	0.41	784	196	752	235	6060	670	333	193	81	190	21	830	75	137	0.83
18	0.93	601	169	1253	40	6464	714	444	560	151	1116	37	6031	667	362	0.07
19	0.91	653	163	1253	38	6060	670	370	529	145	1024	34	5547	613	339	0.1
21	0.78	265	132	188	0	2121	234	139	189	104	89	0	728	73	109	0.58
22	0.82	180	274	226	75	727	80	111	148	137	185	15	570	40	91	0.29
23	0.82	180	314	226	75	727	80	111	148	137	185	15	569	40	91	0.30
24	0.71	186	245	188	47	1060	117	166	132	117	134	5	754	53	117	0.34
25	0.89	183	131	188	0	2020	223	370	162	112	108	0	695	57	108	0.60
27	0.77	142	122	564	56	1515	167	277	110	95	200	36	1173	101	168	0.33
29	0.31	353	327	627	94	4040	670	1110	109	100	146	29	1244	119	169	0.73
30	0.97	336	84	387	21	4328	478	238	194	82	187	21	827	75	136	0.74
34	0.83	282	113	602	6	6060	670	1110	197	94	102	5	774	82	117	0.84
36	0.91	184	274	188	45	727	80	99	168	131	172	16	596	54	91	0.23
Mean	0.57	535	383	705	140	6702	750	767	180	110	249	32	1341	133	191	0.63

can be done by using the value of slacks. According to Coelli (1996) slacks are related to allocative inefficiency. Allocative efficiency indicates a DMU's capacity to use inputs in optimal proportions. DMUs have to reduce their inputs by the amounts indicated by the respective slacks in order to become allocatively efficient. The zero value of slacks for seeds, fertilizer and some other resources use showed that the input has been used in the right proportions by all the DMUs. For each inefficient producer, we calculated the pure technical efficiency, actual energy use, recommended target energy use for each (Eq. 8a) input and percent saving in total energy use. For O6, 12, 23, 19, 34, we found the percent saving of 66%, 90%, 30%, 10% and 30%, respectively. Therefore, the producer wise percent saving ranges from 7 % for O18 to as much as 96% for O11, in average we can save 7745MJ ha^{-1} energy (68 percent of total energy consumed). Table 6 summarizes the energy saving (MJ ha^{-1}) from different sources.

Discussion

An input-oriented BCC, DEA model is used for estimating technical efficiencies in 37 walnut orchards. Pure technical efficiency specification revealed that 13 orchards were producing at an efficient scale and 24 orchards were inefficient. Also Data envelopment analysis (DEA) used to evaluate and rank productivity performance of selected wheat growing areas in Pakistan and India based on three inputs: irrigation (m^{3} ha^{-1}), seed (kg ha^{-1}) and fertilizer use (kg ha^{-1}) and 3 of 19 DMU were efficient at regional level (Malana and Malano 2006). The pure technical efficiency of the walnut orchards, on average, was calculated as 72%. Researcher in prior studies calculated technical efficiency by use of DEA, average pure TE calculated for Asparagus 0.8 and for tomato 0.89(Iraizoz et al. 2003), mean levels of technical efficiency was 77%, 73% and 75%, respectively, for groundnut monocrop, maize monocrop and maize–groundnut farming systems suggesting existence of substantial gains in output and/or decreases in cost with available technology and resources (Binam et al. 2004) and mean pure technical efficiency of commercial pig farming in Greece was 0.83, indicating that there is ample potential for more efficient input utilisation in domestic pig farming (Galanopoulos et al. 2006). Also Technical, pure technical and scale efficiencies calculated (by using CCR and BCC models) for farmers category-wise and zone-wise of paddy producers in Punjab state of India (Nassiri and Singh 2009). According to Table 3, it is possible to advise a producer regarding 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. It gives the average energy spent and targeted (MJ ha-1), possible energy savings and percent contribution of each energy source in the total energy savings. Figure 1 shows the share of various sources in total input energy saving. It is evident from Fig. 1 that the maximum contribution to the total energy saving is 84% from fertilizer (69%N, 8%K and 7%P) followed and 16% human labor (harvest 6%, field preparation 5%, irrigation 4% & 1% post harvest). A similar study to determine the efficiencies of farmers with regard to energy use in rice production activities in the alluvial zone in the state of West Bengal in India showed that on an average, about 11.6% of the total input energy could be saved if the farmers follow the input package recommended by the study (Singh Chauhan et al. 2006).

Conclusions

Based on the present study following conclusions are drawn: 1) Walnut production consumed 9.1MJ kg^{-1} energy, which was mainly due to fertilizers (58% of total energy). 2) The analysis showed that inefficient DMUs may save fair amount of resources by adopting the best practices of high-performing benchmarks. Comparing actual energy use and target energy use of inefficient orchards showed in average we can save up to 7745MJ ha^{-1} energy (63 percent of total energy consumed). 3) The biggest share of energy saving appertain to fertilizers (69% N). The study suggests that better use of fertilizers, walnut producer consume high fertilizer specially nitrogen in response to inattention and low fertilizer energy prices in Iran. It should be noted that low productive orchards may not become efficient by simply reducing the level of inputs. Instead a detailed analysis is required to determine other underlying causes of inefficiencies, including environmental factors and agricultural practices in walnut orchards of Iran.

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