J. Agr. Sci. Tech. (2017) Vol. 19: 1453-1468

Efficiency and Sustainability of Silage Corn Production by Data Envelopment Analysis and Multi-Functional Ecological Footprint: Evidence from Sarayan County, Iran

S. M. J. Esfahani[1], K. Naderi Mahdei[1*], H. Saadi[1], and A. Dourandish[2]

ABSTRACT

The Ecological Footprint (EF) is used to understand the relationship between human activities and pressure on land and its resources. The present study combined multi-functional ecological footprint with Data Envelopment Analysis (DEA) to estimate environmental impacts of inefficient use of resources of silage corn production in the Sarayan County, Iran. In this applied survey research, data were collected using a questionnaire accompanied by face-to-face interviews with 42 farmers (N= 48). Validity of the instrument was approved by a panel of experts; while its reliability was secured via pretest-posttest method. Results showed that mean technical efficiency, pure technical efficiency and scale efficiency were 0.86, 0.93, and 0.80; respectively. The CO_2 footprints were 0.95 and 0.83 gha under current and optimum conditions; respectively, with electricity and manure comprising the highest and lowest shares. The Ecological footprint land- (gha gha^{-1} farm), yield- (gha ton^{-1}) and revenue-based (gha \$$^{-1}$ 1,000) EFs were estimated to be 1.6, 0.84, and 1.4 under current conditions but 1.57, 0.081, and 1.33 under optimum conditions, respectively. When the resources were used efficiently, the EF_{CO2} and *EF* improved by 13.42 and 3.35% respectively, in which the highest shares in terms of quantity and percentage belonged to electricity, manure and fertilizer. Findings implied that optimum usage of electricity and fertilizer could play a significant role in mitigating environmental impacts of silage corn production in Sarayan. Local agricultural extension should focus on introduction of innovative irrigation systems to reduce water, electricity and fertilizer consumption. Meanwhile, to improve silage corn efficiency, farm size expansion is recommended based on the DEA findings.

Keywords: Ecological footprint, Efficiency, Silage corn, Sustainability.

INTRODUCTION

The climate change, air pollution, loss of soil quality, and extinction of species are the main environmental hazards influencing human activities, directly or indirectly (Mamouni Limnios *et al.*, 2009). Environmental impacts of agriculture are regarded highly considerable, since it is responsible for approximately 20% of greenhouse gas emissions (United States Environmental Protection Agency, 2016). Challenged by the growing population and increasing demand for food, fiber and energy as well as higher life standards, agriculture has resorted to intensive use of exogenous inputs; such as fuel, electricity, chemical fertilizers, and herbicides; with adverse environmental impacts (Alhajj Ali *et al.*, 2013; Esengun *et al.*, 2007; Yilmaz *et al.*, 2005). Hence, studying environmental

[1] Department of Agricultural Extension and Education, Faculty of Agriculture, Bu-Ali Sina University, Hamedan, Islamic Republic of Iran.
[*] Corresponding author: e-mail: knadery@basu.ac.ir
[2] Department of Agricultural Economics, Faculty of Agriculture, Ferdowsi University of Mashhad, Islamic Republic of Iran.

[DOR: 20.1001.1.16807073.2017.19.7.7.4]

impacts of agricultural production; even those of so-called environmentally-friendly crops; have multiplied in the recent years (Lehuger *et al.,* 2009; Dendooven *et al.,* 2012; Zhang *et al.,* 2014; Taghavifar and Mardani, 2015). One important facet of studying agricultural systems is to evaluate their sustainability; however no internationally accepted standard or benchmark has been provided for identifying a sustainable production so far (Asadi *et al.,* 2013). Nowadays, there are various methods to assess adverse environmental impacts of agricultural systems at farm level. (Payraudeau *et al.,* 2005; Van der Werf *et al.,* 2007). In complex agricultural systems, those indices that could simultaneously reveal multiple aspects of environmental impacts are more useful (Bastianoni *et al.,* 2007). Therefore, while monitoring the human pressure on environment, it is necessary to have an integrated system which measures different impact categories, and includes appropriate indices (Giljum *et al.,* 2011).

Applications of the Data Envelopment Analysis (DEA) are regarded as those studies which have already integrated different sustainability measures with managerial techniques (Vázquez-Rowe *et al.,* 2010; Iribarren *et al.,* 2010; Lozano *et al.,* 2009; Mohammadi *et al.,* 2015). It is an important non-parametric method that estimates efficiency of those units that produce similar outputs from similar inputs (He *et al.,* 2016).

Efficiency is a relative concept in the DEA, while efficiency frontier is created by converging combination of efficient units (Zadmirzaei *et al.,* 2015). To turn an inefficient unit into an efficient one, its inputs and outputs should be altered. Technical efficiency shows how optimally the inputs are consumed in a certain farm (Nassiri and Singh, 2010).

Thus, integration of environmental impact assessments with the DEA allows estimation of the capacity to reduce resource exploitation and enhance sustainability. So that the environmental impacts of the production is first estimated under current production condition and then, after calculation of efficiency and estimation of optimum input rates, the environmental impacts are re-estimated under the assumption that all producers act efficiently. For instance, Mohammadi *et al.* (2015) integrated Life Cycle Assessment (LCA) with efficiency and revealed that efficient use of resources could have reduced environmental impacts of rice production up to 25% in Iran. Iribarren *et al.* (2011) combined DEA with LCA, and reported as high as 30% reduction of environmental impacts of dairy farms in Spain. Khoshnevisan *et al.* (2015) showed that efficient use of resources could have reduced environmental impacts of watermelon production by 8% in Iran.

Although there were studies integrating the DEA with different assessment methods like the LCA, no study has been carried out combining the DEA with multifunctional ecological footprint.

The ecological footprint is an important environmental index which has recently been employed by many researchers across various disciplines (Solís-Guzmán *et al.,* 2013; Mikulčić *et al.,* 2016; Lo-Iacono-Ferreira *et al.,* 2016). It specifies area required for supporting an activity by estimating biologically productive land area required for supplying consumed resources and assimilating produced wastes (Wackernagel and Rees, 1996; Herva *et al.,* 2012; Solís-Guzmán *et al.,* 2013). It is expressed in the common unit of global hectares (gha); that is equal to the hectares of land normalized to world average productivity of all biologically productive space within a given year (Fang *et al.,* 2014). Since even non-technical and ordinary people can easily understand this index, it is nowadays used as a tool for communicating environmental issues and improving public awareness (Giljum *et al.,* 2007). It is known as a strong communicative tool for understanding impact of any change in people's behavior on sustainability of natural resources (Holmberg *et al.,* 1999). Ecological footprint analysis must be available to decision-makers and policy-makers, and could be easily

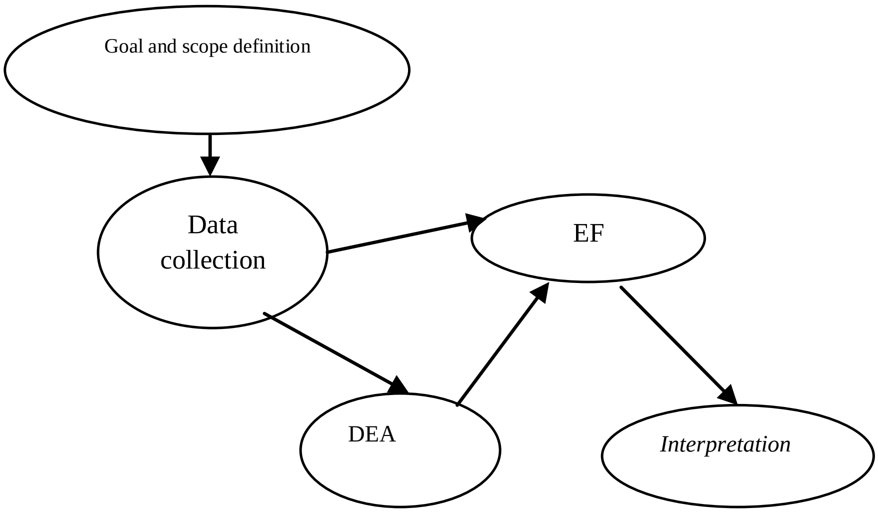

Figure1. Framework of the study.

communicated with the public (Van Vuuren and Smeets, 2000).

So, integration of the DEA with *EF* can help us well-analyze environmental impacts of both efficient and inefficient use of resources. Thus, general framework of the present study can be depicted as Figure 1.

South Khorasan Province is located in Far East of Iran, and is amongst the top three producers of the country's agricultural products such as saffron, barberry, jujube and cotton (Ministry of Agriculture Jihad of Iran, 2015).

Sarayan is one of the most important areas of cotton production in South Khorasan province, Iran. It has the highest of both Scale Advantage Index (SAI) and Aggregated Advantage Index (AAI) of cotton production in the province (Naderi Mahdeiand and Esfahani, 2015). However, water shortages and price fluctuations of recent years have caused the region's crop pattern to change. Therefore, silage corn production has increased noticeably due to the fact that it consumes less water compared to cotton. Silage corn production has been encouraged in the local media as well. On the other hand, Sarayan is the most active center of dairy production in the province (South Khorasan Jihad of Agriculture Organization, 2015). Moreover, given the geographical location of the city, it is partially capable of meeting silage corn requirements of the dairy farms in larger cities of the province.

Apart from economic analyses, investigation of environmental impacts is another important facet of crop production. Then, it is necessary to assess the environmental impacts of silage corn production in the region to inform local policy-makers. Therefore, the objective of the present study was to: (1) Assess the production sustainability using the ecological footprint under both current and optimum production conditions; (2) Estimate the capacity to reduce adverse environmental impacts of the crop, and (3) Identify the most important production input in terms of sustainability. Such findings could inform the researchers, decision-makers and policy-makers with their routine decisions.

METHODOLOGY

Description of Study Area and Data Collection

The study was carried out in Sarayan County, Iran. Sarayan is one of the most important agricultural centers in the province, where agriculture has a significant

[DOR: 20.1001.1.16807073.2017.19.7.7.4]

role in creating occupational and income opportunities for local people (South Khorasan Jihad of Agriculture Organization, 2015). Sarayan is located 160 KM north of the province on 58° 31' E. and 33° 51' N (Figure 2).

To determine efficiency and ecological footprint, data were collected using a questionnaire administered via face-to-face interviews among randomly selected farmers and experts. The questionnaire was composed of two sections: a demographic section collecting personal characteristics such as age, gender, and educational level; and a technical one aimed at finding input consumption and crop production rates. The validity of the questionnaire was confirmed via a panel of experts from rural development and agricultural economics departments of Bu-Ali Sina and Ferdowsi Universities. Its reliability was proved via pretest-posttest method (Naderi Mahdei *et al.*, 2015).

The statistical population included all silage corn farmers (N= 48) of the county. Since silage corn planting has recently been introduced to the region, only 48 farmers had accepted growing it from which 42 growers were randomly selected. The sample size was defined using the Cochran’s formula, shown by Equation (1) (Saadi and Esfahani, 2016).

$$n=\frac{\frac{z^2\times p\times q}{d^2}}{1+\frac{1}{N}\left(\frac{z^2\times p\times q}{d^2}-1\right)}=\frac{\frac{1.96^2\times 0.5\times 0.5}{0.05^2}}{1+\frac{1}{48}\left(\frac{1.96^2\times 0.5\times 0.5}{0.05^2}-1\right)}\cong 42 \qquad (1)$$

Where, *N*, *n*, *P*, *q*, *d* and *z* represent target population, sample size, quantity of an attribute present in the population, percentage of people lacking this attribute, accepted margin of error, and quantity of table *z* at 95% confidence level.

The collated data were firstly used to estimate the variables which could not have been collected directly by asking questions. Electricity consumption rate of the farmers was estimated by their well's electricity bill and corresponding irrigation length. Fuel consumption rate was measured according to working hours of the machinery.

Data Envelopment Analysis (DEA)

The DEA aims at measuring relative efficiency of Decision-Making Units (DMU) that produce similar products at different quantities using different quantities of similar inputs (Pahlavan *et al.*, 2012). It includes two distinct models from Charnes, Cooper and Rhodes (1978) and

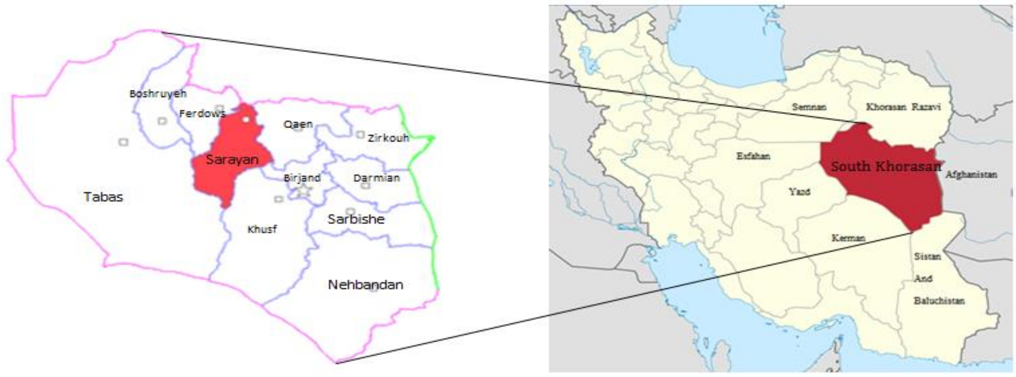

Figure 2. Map of the study area, (South Khorasan Provincial Government, 2016).

Banker,Charnes and Cooper (1984) known as the CCR and BCC models, respectively. The CCR measures technical efficiency assuming Constant Return to Scale (CRS); while the BCC divides the technical efficiency into pure technical efficiency and scale efficiency, then measures technical efficiency assuming Variable Return to Scale (VRS).

$$MaxE = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$
$$st:$$
$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$
$$u_r \geq 0, v_r \geq 0 \qquad (2)$$

General form of the CCR model is shown by Equation (2) (Azizi and Wang, 2013);

Where, E is the technical efficiency score given to unit o; x_{rj} and y_{rj} represents rth input and output of jth unit; ur and vr stand for weight of rth output and ith input, respectively.

Using Charnes and Cooper's transformation, the Equation (2) can be converted into the following Linear Programming (LP) model (Azizi and Fathi ajirloo, 2010):

$$MinE = \sum_{r=1}^{s} v_i x_{io}$$
$$s.t:$$
$$\sum u_r y_{rj} - \sum v_i x_{ij} \leq 0$$
$$\sum u_r y_{ro} = 1$$
$$u_r \geq 0, v_i \geq 0 \qquad (3)$$

If there is a set of positive weights for outputs and inputs of a unit for which $E= 1$, then the unit is said to be efficient; otherwise, it is inefficient. To simplify the Equation (2) solution, its dual form can be used as follows:

$$MaxE = \theta$$
$$s.t:$$
$$Y\lambda \geq Y_0$$
$$\theta X_0 - X\lambda \geq 0$$
$$\theta\, free, \lambda \geq 0 \qquad (4)$$

The BCC model is generally in the form of Equation (5) (Ebrahimi and Salehi, 2015).

$$Maxz = uy_i - u_i$$
$$s.t:$$
$$-vX + uY - u_0 \leq 0$$
$$vx_i = 1$$
$$u_{0\theta}\, free, v, u \geq 0 \qquad (5)$$

When effect of activity scale is eliminated from the technical efficiency, it is called pure technical efficiency (Mousavi-Avval *et al.,* 2011). Its main advantage is that the scale of inefficient farms is only compared with efficient farms of similar size (Bames, 2006). Scale efficiency is defined as the following on the basis of technical efficiency, pure technical efficiency and their relationship (Pahlavan *et al.*, 2011).

$$SE= TE_{CCR} / TE_{BCC} \qquad (6)$$

Ecological Footprint

Many studies have been carried out measuring ecological footprint of a specific activity or production. Since it is an evolving method, current studies have tried to solve only the limitations of previous methods. One important critique on estimating the ecological footprint in agriculture is that it overlooks operation type and use of exogenous inputs in farms. It seems that this footprint is estimated on the basis of prevailing land operation, hence cannot distinguish sustainable operations from unsustainable ones. Therefore, more intensive land uses can result in lower footprints (Passeri *et al.,* 2013). Such flaws question comprehensiveness of this footprint measure as a tool for biophysical assessment and robust measurement. Unsustainable agricultural practices may increase production in the short run but with long-run adverse impacts. In this case, footprint measurement will be misleading. For example, a farm that produces more is accompanied by adverse environmental

[DOR: 20.1001.1.16807073.2017.19.7.7.4]

impacts, utilizing exogenous inputs, which will distract estimation of the footprint measure (Ferng, 2005).

Huijbregts *et al.* (2008) suggested that ecological footprint should be divided into direct and indirect parts. Accordingly, ecological footprint was defined as sum of real and virtual lands that are directly or indirectly related to crop production, and are required to absorb CO_2 emitted by that production. It is expressed as Equation (7) (Cerutti *et al.*, 2013);

$$EF = EF_{real} + EF_{co2} \quad (7)$$

where, EF_{real} shows land occupied over time by croplands, built area, pastures and forests for crop production, and is calculated by Equation (8) (Cerutti *et al.*, 2013);

$$EF_{real} = \sum_{\alpha} A_{\alpha}.EQF_{\alpha} \quad (8)$$

In which, A_a represents the amount of occupied land with type *a* (cropland, forest, pasture, built area), while EQF_a resembles the equivalence factor for land type a.

The *EQF* is a global value for each land category needed to convert a specific land-use type into a universal unit of biologically productive area (global hectare) (Mamouni Limnios *et al.*, 2009).The *EQF* for different lands is presented in Table 1.

EF_{CO2} shows amount of forest required for absorbing CO_2 emitted during product's lifecycle, which is calculated by Equation (9) (Huijbregts *et al.*, 2008);

$$EF_{CO2} = M_{CO2.} \frac{1 - F_{CO2}}{S_{CO2}}.EQF_f \quad (8)$$

where, M_{CO2}, F_{CO2}, S_{CO2} *and* EQF_f show product-specific emission of CO_2 (kg CO_2), fraction of CO_2 absorbed by oceans (0.3), CO_2 sequestration rate by biomass (0.4 kg CO_2 m^{-2} yr^{-1}), and equivalence factor for forest lands; correspondingly (Huijbregts *et al.*, 2008). Emissions are calculated on the basis of CO_2 (kg CO_2.eq) as reference gas (Khakbazan *et al.*, 2009). CO_2 emissions equivalent to each input were inferred from scientific literature. Intergovernmental Panel on Climate Change (IPCC) guideline was also summarized in the Appendix.

Table 1. Equivalence factor (González-Vallejo *et al.*, 2015).

Productive land category	EQF (gha ha^{-1})
Cropland	2.51
Pastures	0.46
Forest	1.26
Productive area	0.37
Built land	2.51

Functional Unit

A key feature of ecological footprint estimation in terms of lifecycle assessment is the possibility of using different functional units. Selection of functional unit may reveal important points about the study (Cerutti *et al.*, 2013). Functional units can be selected on the basis of area, mass and finance (Knudsen *et al.*, 2010; Dalgaard *et al.*, 2008; Cerutti *et al.*, 2011); which are shown in the following equation (Cerutti *et al.*, 2013);

$$EF_{product}\left(\frac{gha}{t}\right) = \frac{\left(EF_{real} + EF_{CO_2}\right)}{Yield}$$

$$EF_{revenue}\left(\frac{gha}{1000\$}\right) = \frac{\left(EF_{real} + EF_{CO_2}\right)\times 1000}{Revenues}$$

$$EF_{land}\left(\frac{gha}{gha_{farm}}\right) = \frac{\left(EF_{real} + EF_{CO_2}\right)}{area_{farm} \times EQF_{cropland}}$$

Where, $EF_{product}$, $EF_{revenue}$, and EF_{land} represent ecological footprint based on the crop, economic value and land. Yield and Area show in tonnage the amount of production and in hectare the area of land, respectively.

RESULTS

Descriptive Analysis

Silage corn planting in the region starts from mid-June and continues until early-July. Then, the crop is harvested from miduntil late-September. The farms are irrigated 5 to 8 times (Mode= 8). Silage corn production stages, including field ploughing, planting and harvesting, are all mechanized. Average age of farmers was 46, ranging from 25 to 68. In terms of education, 39% hold a diploma. Means of cultivation area and production yield were 1.8 ha and 41.7 t ha^{-1}, respectively. A majority of the respondents (93%) were cooperative members.

Efficiency Analysis

Efficiency scores are presented in Table 2. Mean Technical Efficiency (TE), Pure Technical Efficiency (PTE), and Scale Efficiency (STE) were 0.86, 0.93, and 0.80, respectively. In CCR and BCC modes 13 and 22 units were efficient, respectively. Vazquez-Rowe *et al.* (2012)'s report on grape production in Spain revealed that 60% of the producers were working efficiently, while efficiency degree of inefficient farmers ranged from 36 to 71%. Nabavi-Pelesaraei *et al.* (2014) reported the means of technical, pure and scale efficiency for orange production to be 0.894, 0.925 and 0.922, respectively. Moreover, mean *STE*, *PTE* and *TE* were 97, 97 and 94%, respectively for mushroom production in Iran (Ebrahimi and Salehi, 2015). Khoshnevisan *et al.* (2015) calculated mean technical efficiency for inefficient watermelon producers as to be 80%. They revealed that similar yields could have been obtained by 20% savings in resources. The *PTE* analysis showed that 22 farms were efficient and could be used as benchmarks establishing inefficient farms. For example, for F11 (Farm numbered 11), the composite farm, representing the best practice; or reference composite benchmark farm could be formed by a combination of F4, F9, F15 and F21. This means the F11 is close to the efficient frontier segment formed by these efficient farms. Hence, a farm which appears more than others in the referent set is selected as the most efficient unit. F38, in this study appeared in the benchmark referent set for 12 times, so it is given the top ranking followed by F10, F9 and F20.

Ecological Footprint

Table 3 shows the results for EF_{CO2} of each input under current and optimum production conditions. The CO_2 ecological footprints were 0.95 and 0.83 gha under current and optimum production conditions, respectively, showing 13.42% reduction in EF_{CO2} under optimum use of resources by farmers (Table 3). Results of EF_{CO2} under optimum condition revealed that although manure was the least important contributor, its EF_{CO2} would have decreased by 61% when the resources were used efficiently. Electricity and fertilizer had the most reduction of EF_{CO2} by 0.5 and 0.3 gha, respectively.

Electricity and then fertilizer formed the highest share of EF_{CO2} (Figure 3). As the EF_{CO2} is known to be directly related to greenhouse gas emissions, the results indicated that both electricity and fertilizer were important sources of greenhouse gas emissions in silage corn production of the region. Mohammadi *et al.* (2014) found similar results and reported electricity and diesel as the main sources of greenhouse gases in silage corn and soybean production. In another study (Nikkhah *et al.,* 2015), electricity was reported as the main source of greenhouse gases in kiwifruit production in Northern Iran. The highest emissions in wheat and corn productions were reported to be related to electricity (Khoshnevisan *et al.,* 2013; Yousefi *et al.,* 2014a). Yousefi *et al.* (2014b) stated that electricity was the most important contributor to greenhouse gas emissions in sugar beet production accounting for 73% of total emission, followed by urea (15%) and diesel fuel (7%).

The yield-based ecological footprints were 0.084 and 0.081 gha ton^{-1} under current and optimum conditions, respectively. The bio-productive land required to earn $ 1,000

Table 2. Efficiency scores of silage corn farms.

Farms	TE	PTE	SE	Frequents in referent set	Benchmarks
F1	1.00	1.00	1.00	0	
F2	0.52	1.00	0.52	3	
F3	0.81	1.00	0.81	0	
F4	0.92	1.00	0.92	1	
F5	0.80	0.96	0.84		9 (0.45) 14 (0.46) 20 (0.05) 23 (0.04)
F6	0.74	0.81	0.91		9 (0.66) 10 (0.03) 15 (0.13) 20 (0.18) 30 (0.01) 38 (0.00)
F7	0.69	1.00	0.69	1	
F8	0.80	0.95	0.84		9 (0.50) 13 (0.12) 15 (0.21) 20 (0.06) 34 (0.11)
F9	1.00	1.00	1.00	10	
F10	0.71	1.00	0.71	10	
F11	0.70	0.81	0.86		4 (0.20) 9 (0.44) 15 (0.10) 21 (0.26)
F12	1.00	1.00	1.00	3	
F13	1.00	1.00	1.00	5	
F14	1.00	1.00	1.00	6	
F15	0.60	1.00	0.60	7	
F16	0.37	0.71	0.52		9 (0.40) 10 (0.31) 12 (0.20) 23 (0.09)
F17	0.33	0.93	0.36		7 (0.17) 9 (0.38) 12 (0.07) 15 (0.38)
F18	0.61	0.64	0.96		9 (0.62) 12 (0.36) 21 (0.02)
F19	1.00	1.00	1.00	3	
F20	1.00	1.00	1.00	10	
F21	1.00	1.00	1.00	4	
F22	0.69	1.00	0.69	4	
F23	1.00	1.00	1.00	2	
F24	0.91	0.94	0.97		19 (0.05) 34 (0.50) 36 (0.10) 38 (0.25) 42 (0.09)
F25	0.80	0.92	0.87		10 (0.11) 14 (0.12) 15 (0.07) 22 (0.10) 34 (0.09) 38 (0.52)
F26	0.83	0.83	0.99		9 (0.12) 10 (0.02) 13 (0.02) 14 (0.08) 20 (0.13) 38 (0.62)
F27	0.96	1.00	0.96	0	
F28	0.81	0.84	0.96		2 (0.11) 34 (0.42) 38 (0.47)
F29	0.71	0.91	0.79		2 (0.36) 10 (0.16) 34 (0.41) 38 (0.07)
F30	0.88	1.00	0.88	2	
F31	0.61	0.73	0.84		2 (0.01) 9 (0.28) 10 (0.12) 15 (0.09) 34 (0.22) 38 (0.29)
F32	0.65	0.86	0.76		9 (0.23) 10 (0.03) 15 (0.11) 20 (0.29) 30 (0.34)
F33	0.95	0.95	1.00		13 (0.03) 19 (0.07) 21 (0.12) 34 (0.31) 38 (0.47)
F34	1.00	1.00	1.00	9	
F35	0.41	0.91	0.45		10 (0.25) 14 (0.01) 20 (0.45) 22 (0.09) 38 (0.20)
F36	1.00	1.00	1.00	2	2
F37	0.39	0.93	0.42		10 (0.37) 14 (0.13) 20 (0.03) 22 (0.05) 38 (0.43)
F38	1.00	1.00	1.00	12	
F39	0.73	0.73	1.00		13 (0.04) 19 (0.23) 20 (0.07) 34 (0.13) 36 (0.01) 38 (0.52)
F40	0.74	0.78	0.95		10 (0.06) 14 (0.02) 20 (0.05) 22 (0.05) 38 (0.81)
F41	0.74	0.75	0.99		13 (0.22) 20 (0.41) 21 (0.23) 34 (0.13)
F42	1.00	1.00	1.00	1	
Mean	0.80	0.93	0.86	--	
SD	0.20	0.10	0.18		

Table3. EF_{CO2} under current and optimum conditions for silage corn production.

Inputs	EF_{CO2} under current condition(gha)	EF_{CO2} under optimum condition(gha)	Difference (%)
Manure	0.03	0.02	61.54
Diesel	0.15	0.13	13.37
Electricity	0.55	0.50	10.32
Fertilizer	0.21	0.18	16.47
Total	0.95	0.83	13.42

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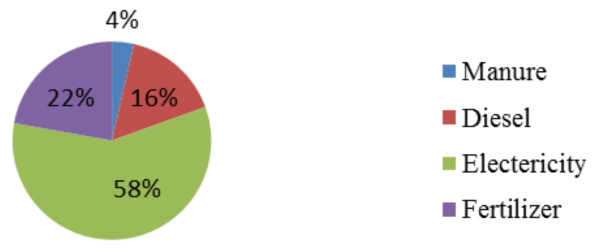

Figure3. The share of each input of $EFco_2$ for corn silage production.

from silage corn production in Sarayan County was 1.62 gha, which could be reduced to 1.57 gha when resources were consumed efficiently (Table 4). *EF* based land was estimated to be 1.38 and 1.33 gha $gha^{-1}{}_{farm}$ for silage corn production under current and optimum conditions, respectively.

Since the footprint measure is a relatively novel concept in research on sustainability, no similar studies were found on silage corn in order to compare results of the assessment, putting them in perspective. Thus, findings of the present study were to be compared with studies on other crops. Naderi Mahdei *et al.* (2015) estimated *EF* of wheat production in Hamedan Province, Iran to be 2.84 and 2.96 gha under conservative and conventional culture practices, respectively. Lustigová and Kušková (2006) reported *EF* of winter wheat production as 1.309 and 1.134 gha for organic and conventional farms, correspondingly. Cerutti *et al.* (2010) reported *EF* for production of one ton of nectarine as 1.34 gha in Italy. According to Cerutti *et al.* (2013), *EF* was estimated as to be 1.57, 1.61 and 3.05 gha for production of one ton of apple, apricot and kiwifruit, while 4.9, 1.66 and 6.77 gha for $ 1,000 in their earnings, respectively. It seems that relatively higher yield of silage corn per ha could be the main reason for lower *EF* measure in the present study compared to other studies. In fact, mean yield of silage corn was 41 tons in Sarayan, whilst mean yield of apple, apricot and kiwifruit were 30, 23 and 12 tons; respectively, in the report by Cerutti *et al.* (2013). In addition, optimum use of production inputs allowed reducing *EF* measure by 3.35% while producing one ton of silage corn.

CONCLUSIONS

Today, one of the most important agricultural challenges is sustainability of production systems. In order to provide policy-makers with practical guidelines facing current challenges of sustainable agriculture, quantitative and objective indices are preferred over the qualitative and subjective concepts. In other words, development of quantitative measures for sustainability could be an important prerequisite for development of new applicable policies towards sustainable

Table 4. Multi-functional ecological footprint under current and optimum conditions.

	EF of yield (gha ton^{-1})	*EF* of land (gha $gha^{-1}{}_{land}$)	*EF* of revenue (gha 1000 $\$^{-1}$)
Current conditions	0.084	1.377	1.628
Optimum conditions	0.081	1.332	1.575

agriculture (Sands and Podmore, 2000). Environmental impact assessment of agricultural systems is the first phase of an overall assessment of agricultural sustainability. From an environmental viewpoint, a farm is regarded as sustainable only when its emissions and use of natural resources could be supported by the surrounding natural environment in the long run (Payraudeau *et al.*, 2005). Farm is the most important managerial unit of an agricultural system, and its environmental impact depends on farmers' production practices (Van der Werf *et al.*, 2009). Of course, farmers need a guideline enabling them to change their current production practice. Sustainability index is a tool that can be used by farmers at farm level to assess effects of their actions (Payraudeau *et al.,* 2005).

The ecological footprint is an important and efficient planning tool helping sustainability to be realized. Despite its simplicity, the concept is scientifically robust in addressing environmental issues (Cerutti *et al.,* 2013). It could enlighten not only awareness and decision-making, but also assessing sustainability of current human activities (Kharrazi *et al.,* 2014). In this regard, efficiency analysis at farm level has been prioritized in the agenda of many countries in response to increasing concerns about conventional agriculture and growing interests towards environmental issues and improvement of farmers' performances (Halberg *et al.,* 2005).

The present study combined ecological footprint with data envelopment analysis to provide more comprehensive and interpretable data of silage corn production in the studied region. Calculations for technical efficiency indicated that if inefficient farms used inputs efficiently, $EFco_2$ and ecological footprint would be improved by 13.42 and 3.35%, respectively. Electricity, fertilizers and diesel fuel had the highest share in $EFco_2$, whose optimum use could reduce ecological footprint. Electricity in silage corn planting is mainly consumed for water pumping. The use of modern irrigation systems like drip or sprinkler irrigation and increasing efficiency of water pumps could help reduce the ecological footprint. Furthermore, results showed that manure and fertilizer were used inefficiently. Other studies confirmed inefficient consumption of fertilizers in Iran and recommended use of green fertilizer to reduce environmental impacts (Mobtaker *et al.,* 2012; Soltani *et al.,* 2013) .Green fertilizers are used as N source in most agricultural systems because they can fix atmospheric nitrogen (Mohammadi *et al.,* 2015). Comparison of findings of this study with other studies, carried out in Iranian agriculture, indicated that *PTE* was in an acceptable level, while the TE and SE were

Appendix. Greenhouse gas emission coefficients of agriculture inputs

Inputs	Unit	GHG coefficients (kg CO2 eq. unit1)	References
Off farm emission (Emission embodied in input)			
N fertilizer (N)	kg	3	(Nguyen and Hermansen, 2012)
P fertilizer (P_2O_5)	kg	1	(Snyder *et al.,* 2009)
Diesel for farm traction and transportation	L	0.016 kg CO2eq. MJ^{-1} diesel×36.4 MJ L^{-1} Diesel	(Nguyen and Hermansen, 2012)
Electricity credite	KW	0.8	(Nguyen and Hermansen, 2012)
On farm emission			
N fertilizer (N)	kg	4.7(0.01 kg N2O-N kg^{-1} N)	(Nguyen and Hermansen, 2012)
Farmyard manure	kg	0.097 kg CO2eq. MJ^{-1} FMY×0.3 MJ Kg^{-1} FMY	(Houshyaret al., 2014)
Diesel for farm traction and transportation	L	0.074 kg CO2eq. MJ^{-1} diesel×36.4 MJ L^{-1} diesel	(Nguyen and Hermansen, 2012)

[DOR: 20.1001.1.16807073.2017.19.7.7.4]

low. Considering the relationship amongst the *PTE*, *PT* and *SE*, it seems that the farms' size could be blamed for. Therefore, it is recommended that increasing the farm size is necessary to improve efficiency. Encouraging farmers to integrate their farms could effectively help strengthen the efficiency and sustainability of their production. Finally, it should be noted that analysis of environmental impact is the first phase of an effective environmental management system. At this stage, environmental impact at farm level should be measured. The most important inputs and environmental impacts should be defined in order to take appropriate action to develop a sustainable farmer production in the region (Galan *et al.,* 2007). However, a study on how to implement the recommendations of this study can complete the sustainability assessment chain.

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[DOR: 20.1001.1.16807073.2017.19.7.7.4]

کارایی و پایداری تولید ذرت علوفه ای با استفاده از تحلیل فراگیر داده ها و ردپای اکولوژیک چند کارکردی: مثالی از منطقه سرایان، ایران

س. م. ج. اصفهانی، ک. نادری مهدیی، ح. سعدی، و آ. دوراندیش

چکیده

شاخص رد پا اکولوژیک ابزار محاسباتی است که برای فهم ارتباط میان فعالیت‌های انسان و فشار بر زمین و منابع آن به کار می-رود. در این مطالعه با ترکیب شاخص جای پای اکولوژیک چند کارکردی و تحلیل فراگیر داده‌ها اثرات زیست محیطی استفاده ناکارآمد از منابع در تولید ذرت علوفه ای درشهرستان سرایان سنجیده شده است. اطلاعات مورد نیاز از طریق پرسشنامه و مصاحبه رودرو با ۴۲ کشاورز جمع آوری شد(N=48). اعتبار پرسشنامه با استفاده از نظر کارشناسان و روایی آن با روش پیش آزمون- پس آزمون تایید شد. نتایج مطالعه نشان داد که میانگین کارایی فنی و کارایی خالص فنی و کارایی مقیاس به ترتیب ۰.۸۶، ۰.۹۳ و ۰.۸۰است. شاخص ردپای co2 در شرایط جاری و بهینه تولید به ترتیب معادل ۰.۸۳ و ۰.۹۵ هکتار جهانی (gha)که الکتریسته و کودحیوانی به ترتیب بیشترین و کمترین مقدار را در آن داشتند. شاخص ردپای اکولوژیک بر مبنای زمین(gha/ghafarm)، محصول (gha/ton)و درآمد (gha/1000$)در شرایط جاری تولید به ترتیب معادل ۱.۶، ۰.۸۴ و ۱.۴ و در شرایط بهینه تولید معادل ۱.۵۷، ۰.۰۸۱ و ۱.۳۳ بود. در صورت استفاده بهینه از منابع ردپای اکولوژیک و ردپای CO2به ترتیب۳.۳۵و ۱۳.۴۲٪بهبود مییابد که از نظر مقدار الکتریسته و از نظر درصد کودحیوانی و کود شیمیایی بیشترین بودند. با استفاده از نتایج این مطالعه میتوان دریافت که مصرف بهینه الکتریسته و کودهای شیمیایی سهم زیادی در کاهش اثرات زیست محیطی تولید ذرت علوفه ای در خراسان جنوبی دارد. لذا استفاده از روشهای نوین آبیاری به منظور صرفه جویی در مصرف آب و کاهش مصرف الکتریسته لازم برای پمپ آبهای زیر زمینی و افزایش آگاهی کشاورزان جهت کاربرد موثرتر کودهای شیمیایی توصیه میشود. همچنین با توجه به نتایج کارایی، افزایش اندازه مزرعه جهت بهبود کارایی توصیه می‌شود.

[DOR: 20.1001.1.16807073.2017.19.7.7.4]