A source-wise and operation-wise energy use analysis for corn silage production, a case study of Tehran province, Iran

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Abstract

This study aims at finding the input–output energy use and the relationship between energy input levels on yield in southern part of Tehran province, Iran. Besides, the energy analysis was carried out based on different farm operations. Data were collected from 40 corn silage (as animal feed) farms, using face to face questionnaire method. The total energy input consumption was 36.5 GJ ha−1, in which chemical fertilizers with 11.8 GJ ha−1 (with 32.3%), followed by diesel fuel and water for irrigation (with 26.5% and 24.9%, respectively) were highly contributed to the total energy use. Energy ratio, energy productivity, specific energy and net energy indices were 3.49, 1.45 kg MJ−1, 0.69 MJ kg−1 and 90563.3, respectively. The operation-wise analysis showed that land preparation and plant protection operations had significantly high energy consumption (4224.6 and 2446.0 MJ ha−1, respectively). The econometric results revealed that chemical fertilizers, fuel, water, human labor had a positive impact on output level. Moreover, as a result of this study, corn silage production has experienced a substantial increase in non-renewable energy use. Additionally, land preparation, planting and post-harvest operations were used in excess.

Keywords: Corn silage; Sensitivity analysis; Energy ratio; Farm size levels; Plant protection

1. Introduction

Silage can be made from many different crops. Corn silage (including grain) is a widely used crop and popular forage for ruminant animals because of the following reasons: (1) High yields of high-energy feed per acre, (2) High digestibility, (3) Palatable, consistent feed, (4) storable directly at the time of cutting when plant characteristics for storage are near ideal, (5) Rapid harvest, and (6) Low-cost storage (Wheaton et al., 1993; Schroede, 2004). The world production of corn silage in 2008 was 9.2 million tonnes with an average yield of 8.8 ton per hectare.
(Anonymous, 2007). The Iranian cultivated land area, annual production and the average yield of forage crops (expect alfalfa and clover) were about 280,381 ha, 9411 tons (wet matter basis) and 36 tons (wet matter basis), respectively in 2008.

In agriculture, the maximization of crop yield per unit of cultivated area and minimization of energy inputs require the formulation of the interaction between them in the form of pre-harvest energy, fertilizer, irrigation, etc. (Singh et al. 1994). The relation between agriculture and energy is very close. Agriculture itself is an energy user and energy supplier in the form of bioenergy (Ghasemi Mobtaker et al., 2010; Alam et al., 2005). Energy use in agriculture has developed in response to increasing populations, limited supply of arable land and desire for an improved standard of living (Esengun et al., 2007). Effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resource preservation and air pollution reduction (Uhlin, 1998). Energy budgets for agricultural production can be used as building blocks for life-cycle assessments that include agricultural products, and can also serve as a first step towards identifying crop production processes that benefit most from increased efficiency (Piringer and Steinberg, 2006). The use of renewable resources such as sunlight, water flow, wind and biomass have been always considered as sources of energy, since they are renowned as environmentally friendly resources (Hakala et al., 2009).

Energy requirements in agriculture are divided into four groups: direct and indirect, non-renewable and renewable. Direct energy is the form of energy used to perform various tasks related to crop production processes such as land preparation, irrigation, plant protection, threshing, harvesting and transportation of agricultural inputs and farm produce (Singh, 2000). Direct energy consumption in Iranian agriculture amounts to around 204.37 PJ yr\(^{-1}\) (Peta Joule = 1015 J) which makes up 3.5% of the national consumption of fuel and electricity (Anonymous, 2006). However, a large part of the energy consumption in agriculture is in indirect form. Indirect energy consists of the energy used in the manufacture, packaging and transport of fertilizers, biocides and farm machinery (Mohammadi et al., 2008). Non-renewable energy is mentioned as diesel, chemicals, fertilizers and machinery; whereas renewable energy consists of human labor, seeds and manure (Ozkan et al., 2004). Energy analysis of agricultural ecosystems seems to be a promising approach to investigate and assess the energy use efficiency, environmental problems and their relation to sustainability ( Giampietro et al., 1992). There has been increasing use of fertilizers, chemical pesticides and new crop varieties, and this is the main reason for the increase in the yield per hectare. In the meanwhile the energy consumption in the agriculture sector has also increased (Pishgar-Komleh et al., 2011b).

In the literature review, Pishgar Komleh et al. (2011a) examined the energy input and output of corn silage production. The total energy input was found to be 68,928 MJ ha\(^{-1}\) and the energy ratio and energy productivity were 2.27 and 0.28 kg MJ\(^{-1}\), respectively. According to their results larger farms consume less input energy and corn silage production is significantly related to seed and chemical fertilizer inputs. Heichel (1982) studied energy use for forage production systems (corn silage, alfalfa and oat). Phipps et al. (1976) compared the energy output-input ratio for forage maize and grass leys (a rotational grass which is sown every few years as part of an arable crop rotation). The results indicated 4.8 and 2.7 for forage maize and grass energy ratio, respectively. With respect to the fact that, however, several studies have been carried out on the use of energy in various crops (Yadav et al., 1991;

**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>required sample size</td>
</tr>
<tr>
<td>( N_i )</td>
<td>number of holdings in target population</td>
</tr>
<tr>
<td>( S )</td>
<td>standard deviation</td>
</tr>
<tr>
<td>( S_h )</td>
<td>number of the population in the ( h ) stratification</td>
</tr>
<tr>
<td>( S_h )</td>
<td>variance of ( h ) stratification</td>
</tr>
<tr>
<td>( D )</td>
<td>precision (( \bar{x} - \bar{X} ))</td>
</tr>
<tr>
<td>( Z )</td>
<td>reliability coefficient (1.96 in the case of 95% reliability)</td>
</tr>
<tr>
<td>( D^2 )</td>
<td>( d^2 / Z^2 )</td>
</tr>
<tr>
<td>( Y_i )</td>
<td>yield level of the ( i )th farmer</td>
</tr>
<tr>
<td>( X_1 )</td>
<td>diesel fuel energy</td>
</tr>
<tr>
<td>( X_2 )</td>
<td>labor energy</td>
</tr>
<tr>
<td>( X_3 )</td>
<td>machinery energy</td>
</tr>
<tr>
<td>( X_4 )</td>
<td>seed energy</td>
</tr>
<tr>
<td>( X_5 )</td>
<td>chemical fertilizer energy</td>
</tr>
<tr>
<td>( X_6 )</td>
<td>irrigation energy</td>
</tr>
<tr>
<td>( X_7 )</td>
<td>biocide energy</td>
</tr>
<tr>
<td>( e_i )</td>
<td>error term</td>
</tr>
<tr>
<td>( z_i )</td>
<td>coefficients of the exogenous variables</td>
</tr>
<tr>
<td>( \beta_i )</td>
<td>coefficients of the exogenous variables</td>
</tr>
<tr>
<td>( \gamma_i )</td>
<td>coefficients of the exogenous variables</td>
</tr>
<tr>
<td>( DE )</td>
<td>direct energy</td>
</tr>
<tr>
<td>( IDE )</td>
<td>indirect energy</td>
</tr>
<tr>
<td>( RE )</td>
<td>renewable energy</td>
</tr>
<tr>
<td>( NRE )</td>
<td>non-renewable energy</td>
</tr>
<tr>
<td>( MPP_{xj} )</td>
<td>marginal physical productivity of ( j )th input</td>
</tr>
<tr>
<td>( x_i )</td>
<td>regression coefficient of ( j )th input</td>
</tr>
<tr>
<td>( GM(Y) )</td>
<td>geometric mean of yield (the ( 'i' )th root product of ( 'i' ) yields)</td>
</tr>
<tr>
<td>( GM(X_j) )</td>
<td>geometric mean of ( j )th input energy (the ( 'j' )th root product of ( 'j' ) energy inputs)</td>
</tr>
</tbody>
</table>
Yaldiz et al., 1993; Singh et al., 1998; Franzluebbers and Francis 1995; Safa and Tabatabaeeefar, 2002; Heidari and Omid, 2011), relatively little attention has been paid to the analysis of energy use in corn silage production, mainly in the specified region. In some other similar studies the following results were revealed. Mohammadi et al. (2008) evaluated energy use in potato crop and reported that potato production consumes 81,624.96 MJ ha\(^{-1}\) energy. In the study carried out by Ghasemi Mobtaker et al. (2010) on barely crop energy use, the energy input was calculated as 25,027 MJ ha\(^{-1}\) in which total fertilizer had the highest energy consumption. Canakci et al. (2005) reported the specific energy and energy ratio of maize crop as 3.88 and 3.8 MJ kg\(^{-1}\), respectively.

The present article has concentrated on corn silage production scenario from an energy use viewpoint in southern regions of Tehran province in Iran. The objectives of the current study were to evaluate (a) energy use pattern of corn silage crop and its efficiency, (b) the relationship between energy inputs and corn silage yield by econometric estimation and sensitivity analysis and (c) energy consumption of various mechanized farming operations. The mechanized operations include land preparation operations (done by mold-board plow, disk harrows and land leveler), planting (by row crop planter), plant protection (by cultivator, sprayer and fertilizer), harvesting (chopper harvester) and post-harvest operation (transportation). Moreover, the Cobb-Douglas production function was utilized to study the sensitivity and the relationship between energy inputs and corn silage yield. It is worth mentioning that all the comparisons were done with regard to the four economic regions. The total energy of inputs and output per hectare (MJ ha\(^{-1}\)) were calculated by multiplying the amounts of each input by its corresponding coefficient of energy equivalents (Table 1).

Using energy equivalents of the inputs and output calculation, energy ratio (Eq. (2)), energy productivity (Eq. (3)), specific energy (Eq. (4)) and net energy (Eq. (5)) were calculated using the following equations (Mandal et al., 2002):

\[
\text{Energy Ratio} = \frac{\text{Energy Output} (\text{MJ ha}^{-1})}{\text{Energy Input} (\text{MJ ha}^{-1})} \tag{2}
\]

\[
\text{Energy Productivity} (\text{kg MJ}^{-1}) = \frac{\text{Corn silage Output} (\text{kg ha}^{-1})}{\text{Energy Input} (\text{MJ ha}^{-1})} \tag{3}
\]

\[
\text{Specific Energy} (\text{MJ kg}^{-1}) = \frac{\text{Energy Input} (\text{MJ ha}^{-1})}{\text{Corn silage Output} (\text{kg ha}^{-1})} \tag{4}
\]

\[
\text{Net Energy} (\text{MJ ha}^{-1}) = \frac{\text{Energy Output} (\text{MJ ha}^{-1})}{\text{Energy Input} (\text{MJ ha}^{-1})} \tag{5}
\]

Energy ratio is the ratio between the energy output and the total energy inputs. It gives an indication of how much energy was produced per unit of energy utilized. The energy productivity provides quantitative data on how much corn silage is obtained per unit of energy input. Net energy is defined as the difference between the gross energy output and the total energy used (Mohammadi et al., 2008).

All energy indices (Eq. (2) – Eq. (5)) were calculated for corn silage production in various farm size groups, which were classified into four categories as small (<10 ha), med-
ium (between 10 and 20 ha), large farms (between 20 and 30 ha) and very large farms (>30 ha).

Realizing that output is a function of inputs, production function can be expressed as \( Y = f(X_{ij}) \) where \( Y \) is output level, \( X_{ij} \) is a vector of input variables that affect output such as fertilizer, seed and diesel and \( t \) is a time subscript.

In order to estimate this relationship, a mathematical function needs to be specified. For this purpose, several functions were tried, and the Cobb-Douglas production function was chosen since it produced better results among the others in terms of statistical significance and expected signs of parameters. Several authors have used this function in order to find the functional relationship between inputs and output parameters (Ghasemi Mobtaker et al., 2011a; Heidari and Omid, 2011; Hatirli et al., 2005; Mohammadi et al., 2010). The Cobb-Douglas production function is expressed in general form as follows:

\[
\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i = 1, 2, \ldots, n
\]  

(6)

where \( Y_i \) denotes the yield of the \( i \)th farmer, \( X_{ij} \) the vector of inputs used in the production process, \( \alpha \) the constant term, \( \alpha_j \) represents coefficients of inputs which are estimated from the model and \( e_i \) is the error term. While \( \alpha \) implies the output derived when the input is zero and assuming that, when no energy input is consumed, the crop yield would also be zero, Eq. (6) changed to Eq. (7):

\[
\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i = 1, 2, \ldots, n
\]  

(7)

With assumptions that yield is a function of input energy, Eq. (7) can be expanded to Eq. (8):

\[
\ln Y_i = \alpha_1 \ln(X_1) + \alpha_2 \ln(X_2) + \alpha_3 \ln(X_3) + \alpha_4 \ln(X_4) + \alpha_5 \ln(X_5) + \alpha_7 \ln(X_7) + e_i
\]  

(8)

where \( X_1 \) is diesel fuel energy, \( X_2 \) is labor energy, \( X_3 \) machinery energy, \( X_4 \) seed energy, \( X_5 \) fertilizer energy, \( X_6 \) irrigation energy and \( X_7 \) is biocides. With respect to these equations, the effect of each farm energy input and output was investigated. Then, the impact of DE and IDE energies on the output was studied. For these purposes, Cobb-Douglas function was utilized as following:

\[
\ln Y_i = \beta_1 \ln(\text{DE}) + \beta_1 \ln(\text{IDE}) + e_i
\]  

(9)

\[
\ln Y_i = \gamma_1 \ln(\text{RE}) + \gamma_1 \ln(\text{NRE}) + e_i
\]  

(10)

where \( Y_i \) indicates the yield of the \( i \)th farmer, DE, IDE, RE and NRE are direct, indirect, renewable and non-renewable energies that are used for corn silage production respectively, \( \beta_i \) and \( \gamma_j \) are the coefficients of variables and \( e_i \) is the error term. The effect of various mechanized farming operations on the yield was investigated as following:

\[
\ln Y_i = \alpha_1 \ln(X_1) + \alpha_2 \ln(X_2) + \alpha_3 \ln(X_3) + \alpha_4 \ln(X_4) + \alpha_5 + e_i
\]  

(11)

where \( Y_i \) indicates the yield of the \( i \)th farmer, \( X_1 \) is land preparation energy, \( X_2 \) is planting operation energy, \( X_3 \) plant protection, \( X_4 \) harvesting energy and \( X_5 \) is post-harvest energy, respectively that are used for corn silage production. \( \beta_i \) and \( \gamma_i \) are the coefficients of variables and \( e_i \) is the error term. With respect to these equations, the effect of each farm operation energy use on output was investigated. By using ordinary least square (OLS) technique, coefficients of Eqs. (8) – (11) were estimated.

For the purpose of sensitivity analysis, the marginal physical productivity (MPP) technique, based on the response coefficients of the inputs, was used to determine the sensitivity of a particular energy input on production. The MPP of a factor indicates the change in the output with a unit change in the factor input in question, keeping all other factors constant at their geometric mean level. The MPP of the various inputs was computed using the \( \alpha_j \) of the various energy inputs as (Singh et al., 2004):

\[
\text{MPP}_{ij} = \left( \frac{GM(Y)}{GM(X_{ij})} \right) \times \alpha_j
\]  

(12)

where \( \text{MPP}_{ij} \) is marginal physical productivity of \( j \)th input, \( \alpha_j \) regression coefficient of \( j \)th input, \( GM(Y) \) geometric mean of corn silage yield and \( GM(X_{ij}) \) geometric mean of \( j \)th input energy. Return to scale is indicated by the sum of the elasticities (\( \sum \beta_{ij} \)) derived in the form of regression coefficients in the Cobb-Douglas production function. If the sum is less than, or equal to, or greater than unity, the decreasing, constant or increasing return to scale is indicated, respectively. The concept of return to scale

<table>
<thead>
<tr>
<th>Inputs and outputs (unit)</th>
<th>Energy equivalent (MJ unit(^{-1}))</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Labor (h)</td>
<td>1.96</td>
<td>Shrestha (2002)</td>
</tr>
<tr>
<td>3. Diesel fuel (L)</td>
<td>47.8</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>4. Fertilizer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N (kg)</td>
<td>66.14</td>
<td>Shrestha (2002)</td>
</tr>
<tr>
<td>P(_2)O(_5) (kg)</td>
<td>12.44</td>
<td>Shrestha (2002)</td>
</tr>
<tr>
<td>K(_2)O (kg)</td>
<td>11.15</td>
<td>Shrestha (2002)</td>
</tr>
<tr>
<td>5. Seed (kg)</td>
<td>100</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>6. Water for irrigation (m(^3))</td>
<td>1.02</td>
<td>Acaroglu (1998)</td>
</tr>
<tr>
<td>7. Biocides (kg)</td>
<td>120</td>
<td>Singh (2000)</td>
</tr>
</tbody>
</table>

* Economic life of machine (year).
emphasizes the proportionate change in output due to an equi-proportionate change in all the inputs.

In the last part of study, the effect of different farm size levels on various mechanized farm operations including machinery equipment was investigated. They were land preparation, planting and plant protection, harvesting and post-harvest operations. The culled data on various input consumptions and corn silage yield were entered into Excel Spreadsheet 2007 and SPSS19. Shazam9 software program was utilized to find the relationship between energy inputs and yield, as well.

3. Results and Discussion

3.1. Analysis of input–output energy use in 4 levels of corn silage farm size

The collected data from 40 farms during a face to face interview method in the selected region, were analyzed via the methods which were stated prior to this section. It is reminded that 4 different levels of farm size were as follows: small (<10 ha), medium (between 10 and 20 ha), large farms (between 20 and 30 ha) and very large farms (>30 ha). The average corn silage yield was about 52,711 kg ha⁻¹ in the studied region. The average total energy during corn silage production was 36,513 MJ ha⁻¹, since the average total energy output was 127,077 MJ ha⁻¹. In the literature, Pishgar Komleh et al. (2011a) examined the energy use and economic analysis of corn silage production and the results showed that total energy input and output were 68,928 MJ ha⁻¹ and 148,380 MJ ha⁻¹, respectively at the similar region to our studied zone. Table 2 represents the average energy consumption in four groups of different farm sizes. The results asserted that, the quantity of chemical fertilizer energy (11,778 MJ ha⁻¹) in corn silage production had the highest share (32%) (Fig. 1). The second place belonged to diesel fuel with the amount of 9685 MJ ha⁻¹ (26.5%) followed by water for irrigation with the amount of 9075 MJ ha⁻¹ (25%). The results were similar to Phipps et al. (1976) where fertilizer and diesel fuel were major energy inputs for forage maize and grass leys. Amanlou et al. (2010) found chemical fertilizer and electricity as the highest energy consumers that were followed by diesel fuel for corn silage production in Zanjan province of Iran. With lack of studies in corn silage production energy analysis, similar results have been reported from Pervanchon et al. (2002) who noted that the shares for other inputs in the total amount of energy such as machinery, fertilizer application, seeds, chemicals, and other inputs in potato production were 48%, 33%, 6%, 3%, 10%, respectively. Ghasemi Mobtaker et al. (2010) reported fertilizer as the most energy consuming input followed by diesel fuel for barley production. Kizilaslan (2009) deduced that with a share of 42%, chemical fertilizer was the highest energy consumer input used in cherry production. Among three common sorts of chemical fertilizers, nitrogen had the most significant share as 27.9%. This is in agreement with the results of study done by Ghorbani et al. (2011) on irrigated wheat production systems (33.27%) for nitrogen consumption share.

Human labor was the least energy consumer input among others with 44.6 MJ ha⁻¹ because of high mechanization level applied in corn silage production in the studied area. The research results suggested that fertilizer (especially N), diesel fuel and water inputs seemed to be the most significant areas for improving energy efficiency. Machinery management to reduce direct use of diesel fuel energy, precise utilization of chemicals and fertilizer, optimized exploitation of water sources, and using new electricity pumps for water pumping can be employed to improve the energy use without any yield or profitability reduction.

In order to compare the energy consumption based on different farm size levels, ANOVA and Duncan compare mean test were applied. Results noted that farmers with

<table>
<thead>
<tr>
<th>Inputs and output</th>
<th>Farm size groups (ha)</th>
<th>Average (MJ ha⁻¹)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Inputs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td>2285.7</td>
<td>2163.2</td>
<td>2085.1</td>
</tr>
<tr>
<td>Labor</td>
<td>46.3</td>
<td>44.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>9301.4a</td>
<td>9972.5b</td>
<td>9259.9c</td>
</tr>
<tr>
<td>Chemical fertilizer</td>
<td>12232.3a</td>
<td>12023.8a</td>
<td>11419.7b</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>10281.7a</td>
<td>9722.6b</td>
<td>9039.2b</td>
</tr>
<tr>
<td>Phosphate (P₂O₅)</td>
<td>1187.5a</td>
<td>1586.1b</td>
<td>1382.2c</td>
</tr>
<tr>
<td>Potassium (K₂O)</td>
<td>962.9a</td>
<td>808.3b</td>
<td>650.7c</td>
</tr>
<tr>
<td>Water for irrigation</td>
<td>10632.2a</td>
<td>8188.7b</td>
<td>9407.9b</td>
</tr>
<tr>
<td>Seed</td>
<td>3590.9a</td>
<td>3000.0b</td>
<td>2722.2c</td>
</tr>
<tr>
<td>Biocides</td>
<td>752.7</td>
<td>748.0</td>
<td>720.0</td>
</tr>
<tr>
<td>Total energy input</td>
<td>38841.5</td>
<td>36140.3</td>
<td>35861.1</td>
</tr>
<tr>
<td>B. Output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn silage (based on dry matter)</td>
<td>120654.5</td>
<td>125520.00</td>
<td>127733.3</td>
</tr>
</tbody>
</table>

Note: a,b,c,d Different letters show significant difference of means at 5% level.
more than 30 ha used the least amount of machinery energy (2061 MJ ha$^{-1}$) by using wider farm machinery in the larger farms. This is proved by Table 2. The comparison of chemical fertilizer energy usage in farm groups specified more amount of chemical fertilizer was used in very large farms (Table 2) that was related to inattention in management of chemical fertilizer use in small and very large farms. It can be concluded that with increasing of farm size the value of corn silage yield intensifies, as well. Some studies have been conducted for dry apricot (Esengun et al., 2007), cotton (Yilmaz et al., 2005) to evaluate the farm size effect. Esengun et al. (2007) confirmed that by increasing farm size the amount of human labor and fertilizer application energy have decreased. Yilmaz et al. (2005) reported machinery energy use in small farms was higher in cotton production. In the survey carried out by Nassiri and Singh (2009) an increasing trend of total energy input was observed with the increase in the size of the land holding.

Different energy indices and the direct, indirect, renewable and non-renewable forms of energy according to four sizes of crop farms are given in Table 3. It is seen that the energy ratio was calculated as 3.49, indicating that energy consumption in corn silage production in surveyed region is efficient, i.e. energy production was greater than energy utilization; but it was lower than Heichel’s research result on corn silage crop (Heichel, 1982), because of high consumption in chemical fertilizer energy. By growing farm size, energy ratio increased where it was found to be 3.82 in large sized farms. Energy productivity, specific energy and net energy of corn silage production were 1.45 kg MJ$^{-1}$, 0.69 MJ kg$^{-1}$, and 90.563 MJ ha$^{-1}$ respectively. It is obvious that large farmers had better results in energy indices. Different energy input forms as direct, indirect, renewable and non-renewable are also shown in Table 3 where the share of direct and indirect forms was 52% and 48%, respectively which are nearly equally utilized while the share of renewable energy group (33%) was fairly different from non-renewable form (67%). Several researchers have found same results that the ratios of direct and indirect energy were similar and non-renewable energy was greater than that of renewable energy consumption (Esengun et al., 2007; Giampietro et al., 1992).

Energy usage of various mechanized operations under four cultivated area levels was presented in Table 4. Total energy used in various farm operations during corn silage production was 10,947.1 MJ ha$^{-1}$. Mohammadi et al. (2008) calculated the total energy use of different farm operations such as 81,624.96 MJ ha$^{-1}$ for potato crop. The results showed that the most significant energy consumer operation was land preparation (38.6%) and the second rank belonged to plant protection operation (22.3%). The shares for other operations like harvesting, post-harvest and planting operations were 18.6%, 13.8% and 6.6%, respectively. De et al. (2007) provided an analysis of energy use pattern. This study revealed that total direct energy consumption rate increases with an increase in productivity, mainly due to increased consumption rate in tillage, harvesting, threshing and transportation. Esengun et al. (2007) research results revealed that land preparation energy use increased with farm size heightening. This high energy share of land preparation in corn silage production can be attributed to high energy demand of tillage equipment particularly primary tillage machinery. In order to

![Figure 1. The share of energy inputs in corn silage production.](image)
reduce this amount, it is suggested to substitute the conventional tillage machinery with conservation tillage equipment to omit some high energy demand machinery like mold-broad plow.

3.2. Econometric model estimation of corn silage production

For investigating the relationship between the energy inputs and corn silage yield, Cobb-Douglas production function was chosen. It was assumed that the corn silage yield (endogenous variable) to be a function of human labor, machinery, diesel fuel, seed, chemical fertilizer, water for irrigation and biocides (exogenous variables). For the validation of the models in this study, autocorrelation was performed using the Durbin-Watson statistic test (Mohammadi et al., 2008). This test result revealed that Durbin-Watson value was as 1.87 for Eq. (8), indicating that there is no autocorrelation at the 1% significance level in the estimated model. The $R^2$ (coefficient of determination) was 0.98 for this linear regression model. The regression results of Eq. (8) (Table 4) revealed that, the impacts of human labor, diesel fuel, water and fertilizer energies were 0.84, 0.04, 0.04, and 0.03, respectively. Human labor had the highest impact between the other inputs in corn silage production indicating that by increase in the energy obtained from human labor input, the amount of yield improves in present condition. With respect to the assessed results, increasing 10% in the energy of human labor would lead to 8.4% increase in corn silage output. This can be approved by the results presented in this study. Human labor had the least amount of energy consumption; namely, the increase in energy use terminates in yield addition. This was in agreement with results reported by Pishgar Komleh et al. (2011a) who concluded that seed and fertilizer are respectively in relation with yield. While there were few researches in econometric analysis of corn silage crop, results were compared with some other crops including grains and fruits. Hatrili et al. (2005) developed an econometric model in the Antalya Province of Turkey and reported that human labor, chemical fertilizers, biocides, machinery and water energy were important inputs significantly contributing to yield. Mohammadi et al. (2010) calculated the human labor energy had the highest impact (0.17) among the other inputs in kiwi fruit production. The MPP values of model variables are shown in the last column of Table 5. As can be seen the MPP of human labor, water, diesel fuel and fertilizer inputs were found to be 2.59, 0.06, 0.05 and 0.04, respectively. This indicates that an increase of 1 MJ in each input of human labor, water, diesel fuel and chemical fertilizer energy would result in an additional increase of yield by 2.59, 0.06, 0.05, and 0.04 kg ha$^{-1}$, respectively. Vice versa the MPP value of machinery, seed and biocides ($-1.53$, $-0.39$, and $-0.21$) pointed out that increasing a unit value of machinery, seed and biocides energy will lead to decrease 1.53, 0.39, and 0.21 MJ in yield of corn silage production.

The study was also aimed at investigating the relationship between output and different energy input forms. More specifically, we considered different energy forms as renewable or non-renewable, direct or indirect. As a functional form, the Cobb-Douglas production function was selected and specified in the following forms (Table 6). The MPP of direct, indirect, renewable and non-renewable energy were found to be 1.1, $-0.05$, $-0.06$, and 0.14, respectively. This indicated that with an additional use of 1 MJ of each of the direct and non-renewable energy would lead to an additional increase in yield by 1.1 and $0.14$ kg ha$^{-1}$, respectively. Also, the MPP of indirect and renewable energy was calculated to be $-0.05$ and $-0.06$ implying that the use of indirect and renewable energy is in excess for corn silage production. Durbin-Watson value for both model 2 and 3 was calculated to be 1.65. The estimated $R^2$ value for models 2 and 3 was 0.95 and 0.91, respectively.

The sum of the regression coefficients of energy inputs (return to scale) was calculated less than unity as 0.88 in model 2 and 0.07 in model 3 for Eqs. (9)–(10), respectively. This implied that 1% increase in the total energy input utilization would lead to 0.88% and 0.07% decrease in the specified crop yield for these equations. Thus, they brought about a decreasing return to scale for the estimated models.

The econometric estimation and sensitivity analysis of operation-wise energy use can be seen in Table 7. Results were in agreement with the energy share calculation of farming operations in the previous sections. Among all the explanatory variables included in the regression equation, plant protection and harvesting operations had contributed to the production of corn silage production by 95%. Land preparation, planting and post-harvest operations were used in excess. The MPP value of plant
5. Fertilizer 0.03 2.17b 0.04
Plant protection 0.069 0.394a 0.1

4. Seed

2. Non-renewable 0.12 4.71a 0.14

Model 3: \[ \ln Y_i = \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \beta_4 \ln(X_4) + \beta_5 \ln(X_5) + \epsilon_i \]

1. Diesel fuel 0.04 1.24c 0.05
2. Human labor 0.84 6.82a 2.59
3. Machinery
4. Seed
5. Fertilizer 0.03 2.17b 0.04
6. Water for irrigation 0.04 5.21a 0.06

Inconsistent with output.

4. Conclusions

The aim of this study was to analyze the energy use pattern of corn silage production on the farms of Shahr-e-Rey city of Tehran province, Iran. Based on the obtained results, following conclusions and approaches were drawn:

1. Chemical fertilizer had a significant share among other energy inputs. Improving farm management strategies from the view point of chemical fertilizer consumption is essential. The key to develop plant nutrient recommendations is to do soil test.

2. Energy ratio and energy productivity were 3.44 and 1.43 kg MJ⁻¹ respectively. The share of direct was nearly as equal as indirect energy; meanwhile the value of non-renewable energy was greater than that of renewable energy consumption.

3. Human labor energy had the highest impact on corn silage production. Plant protection and harvesting operations were significantly effective on yield. Moreover, non-renewable and direct energy forms were in relation with crop yield.

4. Energy use in corn silage farms of studied area is high especially for non-renewable energy sources. This has brought some environmental concerns such as global warming and increase in CO₂ emissions. Therefore, policy makers should take the necessary measurements to ensure more environmentally friendly energy use patterns in the Iranian agriculture.

5. It is concluded that planting in larger farms will result in lower total energy input and vice versa higher total energy output. This can be achieved through land unification policy and farmers’ cooperative companies which cause them to use lands in joint ventures.

6. Since GHGs (greenhouse gas) are emitted from fossil fuel burning during machinery application in land and processes of input manufacturing, improving energy efficiency is the key policy category for reducing it.

7. Study of the socio-cultural and economic aspects of the group of most efficient farmers and comparing them with those of the relatively inefficient farmers can be incorporated in future studies.

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References


