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# The Relationship between Energy Inputs and Crop Yield in Greenhouse Basil Production

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## ABSTRACT

**This study was conducted to determine a relationship between energy input and yield in greenhouse basil production in Esfahan Province, Iran. Data were collected from 26 greenhouse basil producers through a face-to-face questionnaire. The data collected belonged to the production period of 2009–2010 with the following results obtained. A total energy input of 236,057 MJ ha$^{-1}$ was estimated to be required for basil production. The share of electricity (75.68% of the total energy input) was the highest form of energy required. The expense was followed by plastic cover (9.69%) and chemical fertilizer spending (7.28%), respectively. The energy ratio, productivity, specific, and net energies were found out as 0.25, 0.11 kg MJ$^{-1}$, 9 MJ kg$^{-1}$ and -177377 MJ ha$^{-1}$, respectively. A determination of the efficient allocation of energy resources was modeled through Cobb–Douglas production function. The results of econometric model estimation revealed that the impact of energies spent in the form of human labour and plastic coverings on yield was significantly positive at 1% level. Sensitivity analysis of the energy inputs revealed that the marginal physical productivity (MPP) value related to human labour was estimated as the highest.**

**Keywords**: Basil, Cobb–Douglas, Greenhouse, Input energy, Production function, Regression, Sensitivity analysis, Yield.

## INTRODUCTION

Basil (*Ocimum basilicum* L.) grows some several regions all over the world. It is a herbaceous vegetable of 20–60 cm length and white-purple flowers. The plant comes from India and Iran. Basil (*Ocimum basilicum* L.) is one of the common species used in commercial seasoning. Fresh as well as dried basil is widely used in the Mediterranean kitchen in such servings as tomato products, vegetables, salads, pizza, meat, soups and as well as marine foods. The leaves of basil are used in pharmacy for their diuretic and stimulating properties, as well as in perfume compositions (Chalchat and Ozcan, 2008; Nguyen and Kwee, 2010).

Energy demand in agriculture has been on the increase in response to increase in population, limited supply of arable land and the desire for higher standards of living. Many studies have been conducted to determine the energy efficiency in crop plant production. Examples are: wheat crop in a typical village in an arid zone (Singh *et al.,* 2002; Singh *et al.,* 2003) , soybean (Singh *et al.,* 2004), paddy (Nassiri and Singh, 2010) and wheat (Mandal *et al.,* 2002) in India, sunflower in Greece (Kallivroussis *et al.,* 2002), citrus fruits (Ozkan et al., 2004a), sweet cherry (Demircan *et al.,* 2006) plus some other field crops and vegetables (Canakci *et al.,* 2005) in Turkey, as well as onion (Moore, 2010) in the United States.

From 2002 to 2008, greenhouse production areas in Iran increased from

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3,380 to 7,000 ha (FAO, 2008), the production share of which is recorded as follows: vegetables 59.3%, flowers 39.81%, fruits 0.54%, and mushroom 0.35% (Anonymous, 2008). Greenhouse production system is one of the most intensive plant production and energy demanding systems of agriculture in which energy budgeting is of utmost importance. Energy budget is the numerical comparison of the relationship between input and output of a system in terms of energy units (Canakci and Akinci, 2006). Producers are faced with high cost of operations involved in greenhouse production processes. So, there is a great need to define all the energy inputs in greenhouse production to find the optimal combination that would make this system of production more energy efficient. Energy use for greenhouse vegetables (tomato, cucumber, eggplant and pepper) production in Turkey were investigated (Canakci and Akinci, 2006; Ozkan *et al.,* 2004b). In Iran, many studies have been conducted to determine the energy efficiency of crop plant production under greenhouse conditions. Examples are: energy use pattern for cucumber (Omid *et al.,* 2011), tomato (Heidari and Omid, 2011) and strawberry (Banaeian *et al.,* 2011). But, there is no study as yet conducted regarding the relationship between energy input *vs.* yield and neither energy sensitivity analysis in greenhouse basil production.

The objective of this study was to investigate the input-output energy balance in greenhouse basil production in Esfahan province of Iran, specifying a relationship between input energies and yield and as well as carry out sensitivity analysis for energy inputs *vs.* basil yield.

## MATERIALS AND METHODS

The study was carried out for the case of 26 greenhouse basil producers in Esfahan Province. Esfahan Province is located within 30º-42' and 34º-30' north latitude and east longitude of 49º-36' and 55º-32'. The average size of the studied greenhouses has been found to amount to 0.2 ha. The commercial greenhouses surveyed here were mainly made of galvanized steel. Steel's greatest advantage in greenhouse constructions is its proper strength. Also they are long-lasting, low cost, requiring less framework (thus less shadowing) than any other framing material, thanks to steel's natural strength. The top of the greenhouses studied was covered with UV stabilized plastic sheets of 200 µ thickness. Data were collected from the growers through a face-to-face questionnaire. The data collected belonged to a 45 day production period of plant cultivation, in 2009–2010. The size of each experimental sample was determined using Neyman technique (Zangeneh *et al.,* 2010).

The input energy (MJ $\text{ha}^{-1}$) used up through various input sources namely: human labour, chemical fertilizers, Farmyard Manure (FYM), electricity, chemicals (insecticides and fungicides), plastic cover and transportation are considered as inputs while basil yield (kg $\text{ha}^{-1}$) taken as the output. Energy equivalents shown in Table 1 were employed in making estimations. The information obtained from previous studies was used to determine the energy equivalents' coefficients (Shrestha, 1998; Nagy, 1999; Singh, 2002; Mandal *et al.,* 2002; Ozkan *et al.,* 2004b; Hatirli *et al.,* 2006; Esengun *et al.,* 2007b). The total input equivalent can be found out by adding up the energy equivalents of all the inputs, here in Mega Joule (MJ).

Equation (1) was utilized to determine the basil energy equivalent (FAO, 2008):

$$\text{Basil energy} = \frac{P.f_p + F.f_F + C.f_C}{100} \times DM \times Y \quad (1)$$

Where, $Y$= Yield (kg.$\text{ha}^{-1}$); $DM$= Dry matter (%); $P$= Protein content (%); $f_P$= Protein enclosed energy; $F$= fat content (%); $f_F$= Fat enclosed energy; $C$= Carbohydrate content (%), $f_C$= Carbohydrate enclosed energy. All the enclosed energies presented in Equation (1) were referred to in FAO (2008).

Based on the energy equivalents of the inputs and output of a crop (Table 1), the energy ratio (energy use efficiency), energy

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**Table 1.** Different inputs and output energy coefficients.

| Inputs and output | Units | Energy coefficient (MJ unit$^{-1}$) | References |
|---|---|---|---|
| A. Input | | | |
| 1. Human labour | h | 1.96 | (Esengun *et al.,* 2007) |
| 2. Chemical Fertilizers | kg | | |
| (a) Nitrogen (N) | | 66.14 | (Shrestha, 1998) |
| (b) Phosphate ($P_2O_5$) | | 12.44 | (Shrestha, 1998) |
| (c) Potassium ($K_2O$) | | 11.15 | (Shrestha, 1998) |
| (d) Sulphur (S) | | 1.12 | (Nagy, 1999) |
| (e) Micros (Fe and Mn) | | 120 | (Mandal *et al.,* 2002) |
| 3. Farmyard manure (FYM) | kg | 0.3 | (Singh, 2002) |
| 4. Chemicals | Lit. | 120 | (Singh, 2002) |
| 5. Machinery | h | 62.7 | (Singh, 2002) |
| 6. Electricity | kW h | 11.93 | (Esengun *et al.,* 2007) |
| 7. Plastic | kg | 90 | (Canakci *et al.,* 2006) |
| B. Output | | | |
| Basil | kg | 2.18 | calculated |

productivity, specific energy as well as net energy have been calculated from cucumber (Zangeneh *et al.,* 2010):

$$Energy\ use\ efficiency = \frac{Energy\ output\ (MJ\ ha^{-1})}{Energy\ input\ (MJ\ ha^{-1})} \qquad (2)$$

$$Energy\ productivity = \frac{Cucumber\ output\ (kg\ ha^{-1})}{Energy\ input\ (MJ\ ha^{-1})} \qquad (3)$$

$$Specific\ energy = \frac{Energy\ input\ (MJ\ ha^{-1})}{Cucumber\ output\ (kg\ ha^{-1})} \qquad (4)$$

$$Net\ energy = Energy\ output\ (MJ\ ha^{-1}) - Energy\ input\ (MJ\ ha^{-1}) \qquad (5)$$

For the growth and development, energy demand in agriculture can be divided into direct and indirect or renewable and non-renewable energies (Zangeneh *et al.,* 2010). Direct energy (DE) covers human labour, electricity and transportation, while indirect energy (IDE) includes energy embodied in fertilizers and chemicals used in the basil's production. Renewable energy (RE) consists of human labour and farmyard manure, whereas non-renewable energy (NRE) includes electricity, fertilizers and chemicals.

To establish a relationship between input energies and basil yield, a mathematical function needs to be identified. Several studies of production function show the effects of the choice of functional form in determining technology parameters and their economic implications (Salami and Veeman, 2000). For this purpose Cobb-Douglass production function was chosen as the most suitable function in terms of statistical significance and expected signs of parameters. The Cobb-Douglass function has been employed by several authors to investigate the relationship between input energies and yield (Singh *et al.,* 2003; Hatirli *et al.,* 2005; Heidari and Omid, 2011). The Cobb-Douglass production function is expressed as follows (Singh *et al.,* 2003):

$$Y = f(x)\exp(u) \qquad (6)$$

This function can be expressed as a linear relationship using the following expression:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2,...,n \qquad (7)$$

Where, $Y_i$, denotes the yield of the ith greenhouse, $X_{ij}$, is the vector of inputs used in the production process, $\alpha_0$, denotes a constant term, $\alpha_j$, represents coefficients of inputs estimated from the model and $e_i$, denotes the error term. The constant coefficient ($\alpha_0$) in Equation (7) is zero, because when the energy input is zero, the crop production would also be zero.

Assuming yield as a function of input energies, for an investigation of the impact of each input energy on basil yield, Equation (7) can be expanded in the following form:

$$ln\,Y_i = \alpha_1\, ln\, X_1 + \alpha_2\, ln\, X_2 + \alpha_3\, ln\, X_3 + \alpha_4\, ln\, X_4 + \alpha_5\, ln\, X_5 + \alpha_6\, ln\, X_6 + \alpha_7\, ln\, X_7 + e_i \quad (8)$$

Where, $X_i$ (i = 1,2,…,7) represents input energies from human labour ($X_1$), chemical fertilizer ($X_2$), farmyard manure ($X_3$), chemicals ($X_4$), transportation ($X_5$), electricity ($X_6$), and plastic ($X_7$).

In addition, the impacts of *DE* and *IDE* energies as well as *RE* and *NRE* energies on yield were investigated. For the purpose Cobb-Douglass function was selected and investigated in the following forms:

$$\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i \quad (9)$$

$$\ln Y_i = \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i \quad (10)$$

Please check the equations 9 and 10 because the Yi dose not exists in!!!!!!!!!!

Where, $Y_i$ is the *i*th greenhouse's yield, $\beta_i$ and $\gamma_i$ represent the coefficients of exogenous variables. *DE* and *IDE* are direct and indirect energies; while *RE* and *NRE* represent renewable and non-renewable energies.

In this study the Return To Scale (RTS) index was determined to analyze the proportional changes in output as a result of a proportional change in any of the inputs (where all inputs are increased by a constant factor). So, the RTS values for the Equations (8)-(10) were determined through obtaining the elasticities, derived in the form of regression coefficients in the Cobb-Douglas production function. If the sum exceeds, is equal to, or less than unity, it would imply that there are either increasing, constant, or decreasing returns to scale, respectively (Singh *et al.,* 2003). An either increasing, constant or decreasing value of RTS indicates that when the energy inputs are increased by an *X* value, then the yield in basil production increases by either more than, equal to or less than the *X* value, respectively.

The sensitivity of energy inputs on basil yield was also determined. For thepurpose, the Marginal Physical Productivity (MPP), based on the response coefficients of the inputs was utilized. The MPP of the various inputs was calculated using the $\alpha_j$ of the various energy inputs as follows (Singh *et al.,* 2003):

$$MPP_{xj} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \quad (11)$$

Where, $MPP_{xj}$ is Marginal Physical Productivity of *j*th input, $\alpha_j$, regression coefficient of the *j*th input, *GM (Y),* Geometric Mean of Yield, and *GM* ($X_j$), Geometric Mean of *j*th input energy on a per hectare basis. The *MPP* of a factor implies the change in the total output with a unit change in the factor input, assuming all the other factors fixed at their geometric mean levels. A positive value of *MPP* of any input variable designates that the total output is increasing with an increase in input. So, one should not stop increasing the use of variable inputs so long as the fixed resource is not fully utilized. A negative value of *MPP* of any variable input indicates that every additional unit of input starts to diminish the total output of the previous units; therefore, it is preferable to keep the variable resource in surplus rather than utilizing it as a fixed resource.

Basic information on energy inputs in basil production were inserted into Excel 2007 spreadsheets and into SPSS 17.0 software program.

## RESULTS AND DISCUSSION

### Analysis of Input–output Energy Use in Basil Production

An overview of the key characteristics of the data in the form of mean, standard deviation (SD), related maximum and minimum values is presented in Table 2.

Table 3 shows the inputs utilized in basil production and their energy equivalents along with output energy rates and their equivalents in the studied area. The results revealed that 839 h of human labour were

**Table 2**. Descriptive statistics for the 26 greenhouses

| | Human labour MJ ha$^{-1}$ | Chemical fertilizers MJ ha$^{-1}$ | FYM MJ ha$^{-1}$ | Chemicals MJ ha$^{-1}$ | Transportation MJ ha$^{-1}$ | Electricity MJ ha$^{-1}$ | Plastic MJ ha$^{-1}$ | Yield kg ha$^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Mean | 1644 | 17168 | 6737 | 314 | 8659 | 178655 | 22878 | 26917 |
| STD | 620 | 9566 | 9071 | 408 | 6369 | 112844 | 6179 | 6385 |
| Min | 575 | 1200 | 0 | 0 | 405 | 14044 | 11250 | 15000 |
| Max | 3528 | 42232 | 45000 | 1333 | 25340 | 515087 | 33300 | 40000 |

**Table 3.** Inputs, output and energy related to each in basil production.

| Inputs (unit) | Quantity per unit area (ha) | Total energy equivalent (MJ ha$^{-1}$) | Percentage |
|---|---|---|---|
| A. Inputs | | | |
| 1. Human labour (h) | 838.73 | 1643.92 | 0.70 |
| 2. Chemical fertilizers (kg) | | 17168.31 | 7.28 |
| (a) Nitrogen | 238.00 | 15741.23 | |
| (b) Phosphate ($P_2O_5$) | 46.14 | 573.92 | |
| (c) Potassium ($K_2O$) | 32.93 | 367.16 | |
| (d) Sulphur (S) | 1.71 | 1.92 | |
| (e) Micros (Fe and Mn) | 4.03 | 484.08 | |
| 3. Farmyard manure (FYM) | 22457.80 | 6737.34 | 2.85 |
| 4. Chemicals (Lit.) | 2.62 | 314.38 | 0.13 |
| 5. Transportation (h) | 138.11 | 8659.35 | 3.67 |
| 6. Electricity (kWh) | 14975.30 | 178655.29 | 75.68 |
| 7. Plastic (kg) | 254.20 | 22878.29 | 9.69 |
| Total energy input | | 236056.88 | 100 |
| B. Output | | | |
| Basil (kg) | 26917.16 | 58679.41 | |
| Total energy output | . | 58679.41 | |

required per each hectare of basil production. A majority of human labour utilized in the greenhouses was employed in the harvest operations. Additionally, 14,975 kW of electricity was consumed in pumping water up from deep wells and in running of other equipment. Approximately, 60% of the total was spent in pumping water and the remaining 40% spent in running of different types of electric equipment. To improve the greenhouse environment as well as to achieve a reduction in electricity consumption, it is strongly suggested that the pumps' efficiency be raised.

Chemical fertilizers, FYM, electricity, pest and disease control chemicals, and plastic utilized in basil growing were recorded as 323 kg ha$^{-1}$, 22,458 kg ha$^{-1}$, 14975 kW h, 3 L ha$^{-1}$ and 254 kg ha$^{-1}$, respectively. The other inputs utilized during the growing process in the surveyed area are presented in Table 3. The percentage energies of each input item out of the total energy input are presented in the last column of the table. Total mean energy used in various greenhouse stages during basil production was recorded as 236,057 MJ ha$^{-1}$ in one crop of plant cultivation during spring season. In another study (Ozkan *et al.,* 2004b), total energy inputs for greenhouse produced tomato, cucumber, eggplant and pepper in any one period of plant cultivation were reported to be 127,324.9, 134,771.3, 98,682.5 and 80,253.4 MJ ha$^{-1}$, respectively. Pashaee *et al.* (2008) estimated the total energy input for greenhouse tomato production in Kermanshah Province of Iran at 123,130 MJ ha$^{-1}$. In the present study, due to water being pumped from deep wells, need for and

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consumption of the electricity energy was very high.

The results show that the most demanding energy input for basil production in the different greenhouses investigated, was electricity energy (75.68%). A high percentage of electricity consumption in the greenhouses of the studied region could be attributed to use of pumps of low efficiency on the one hand and due to a low cost of electricity in Iran on the other. Total energy equivalent of the plastic need for the greenhouses was placed second among the energy inputs constituting 9.69% of the total energy input, followed by chemical fertilizers (7.28%) (Nitrogen with 91.69% coming in the first place followed by potassium of 3.34%, micros (Fe and Mn) 2.82%, phosphate of 2.14% and sulphur accounting for 0.01% of the chemical fertilizers). The average annual crop yield of the greenhouses was estimated as 26,917 kg ha$^{-1}$ with a calculated total equivalent energy output of 58,679 MJ ha$^{-1}$. From Table 3, it is observed that human labour and chemicals are the least energy demanding inputs for basil production (1,644 and 314 MJ ha$^{-1}$, respectively).

The energy ratio, energy productivity, specific energy as well as net energy in basil production are reflected in Table 4. Energy ratio (energy use efficiency) was estimated as 0.25, showing the inefficient use of energy in the greenhouse basil production. It is concluded that the energy ratio can be improved by raising yield and/or by lowering the level of energy input consumption. Other such results as 0.74 for cotton (Yilmaz *et al.,* 2005), 0.76 for cucumber, 0.61 for eggplant, 0.99 for pepper (Ozkan *et al.,* 2004b) and 0.99 for tomato (Pashaee *et al.,* 2008) have been reported as regards different types of crops. The average energy productivity of greenhouses was 0.11 kg MJ$^{-1}$. This means that 0.11 units of output energy was obtained per unit of input energy. Calculation of energy productivity rate is well documented in the literature for such crop as; soybean (0.18) (De *et al.,* 2001) and cherries (0.51) (Kizilaslan, 2009a). The figures for specific and net energies in basil production were recorded as 9 MJ kg$^{-1}$ and -177,377 MJ ha$^{-1}$, respectively. Net energy being negative (less than zero) makes one conclude that in basil production, energy is being lost.

Total mean energy input as direct, indirect, renewable and nonrenewable forms is given in Table 4. The total energy input expended could be classified as direct (80.05%), indirect (19.95%), renewable energy (3.55%) and non-renewable energy (96.45%). Several researchers have demonstrated that the ratio in direct energy is higher than that in indirect energy, and the rate of non-renewable energy greater than that for renewable energy consumption in various cropping systems (Kizilaslan, 2009a and b; Esengun *et al.,* 2007a; Ozkan *et al.,* 2007).

**Table 4**. Energy output–input ratio and energy forms in the course of basil production.

| Items | Unit | Quantity | % |
|---|---|---|---|
| Energy ratio | _ | 0.25 | |
| Energy productivity | kg MJ$^{-1}$ | 0.11 | |
| Specific energy | MJ kg$^{-1}$ | 9 | |
| Net energy | MJ ha$^{-1}$ | -177377 | |
| Direct energy [a] | MJ ha$^{-1}$ | 188959 | 80.05 |
| Indirect energy [b] | MJ ha$^{-1}$ | 47098 | 19.95 |
| Renewable energy [c] | MJ ha$^{-1}$ | 8381 | 3.55 |
| Non-renewable energy [d] | MJ ha$^{-1}$ | 227676 | 96.45 |
| Total energy input | MJ ha$^{-1}$ | 236057 | 100 |

[a] Human labour, electricity and transportation; [b] Fertilizers, plastic and chemicals; [c] Human labour and farmyard manure (FYM), [d] Plastic, transportation, chemical fertilizers, chemicals and electricity.

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## Econometric Model Estimation of Basil Production

Relationship between the energy input and yield was estimated using Cobb–Douglas production function for basil for different categories of greenhouses. Basil yield (endogenous variable) was assumed to be a function of human labour, chemical fertilizers, FYM, chemicals, electricity, plastic coverings as well as transportation energy (exogenous variables). In validating the Models I (Equation (8)) autocorrelation was performed using Durbin–Watson (DW) test (Hatirli *et al.,* 2005). The test revealed that *DW* value was 2.05 for Model I (Equation (8)), *i.e.* there was no autocorrelation at the 5% significance level in the estimated model. The coefficient of determination ($R^2$) was 0.99 for the model. The impact of energy inputs on yield was also investigated by estimating Equation (8). Regression results for this model are presented in Table 5. It can be seen form Table 5 that the contribution of human labour and energies related to plastic coverings are significant at the 1% level. This indicates that an additional expenditure of 1% in each of these inputs would lead, respectively, to 0.47% and 0.41% increase in yield. Hatirli *et al.* (2006) estimated an econometric model for greenhouse tomato production in Antalya province of Turkey. They concluded that among the energy inputs, human energy was found as the most effective input item influencing yield. Singh *et al.* (2004) concluded that in zone 2 of Punjab, the impact of human and electrical energies were significant to the productivity at 1% level The *MPP* values of the model variables are shown in the last column in Table 5. As can be seen the *MPP* for human labour and chemical inputs are recorded as 8.01 and -11.11, respectively. This indicates that an increase of 1 MJ in each input of either human labour or chemical energies, would lead to a change in yield by 8.01, -11.11 kg ha$^{-1}$, respectively. The value of Return To Scale (RTS) for the Model I was calculated whereby the regression coefficient was obtained as 1.15. The higher value of RTS than unity implies increasing returns to scale (IRS).

The regression coefficients of direct and indirect energies (DE and IDE) for Model II as well as renewable and non-renewable energies (RE and NRE) for Model III for yield were also investigated through Equations (9) and (10), respectively. The results appear in Table 6. As shown, the regression coefficients of direct, indirect, renewable and non-renewable energies were all statistically significant at 1% level. The impacts of *DE, IDE, RE* and *NRE* were estimated as 0.14, 0.80, 0.39 and 0.55, respectively. Similar results have been

**Table 5.** Econometric estimation results of inputs.

| Endogenous variable: | Basil yield | | |
|---|---|---|---|
| Exogenous variables | Coefficients ($\alpha_j$) | *t*-ratio | *MPP* |
| Model I: $lnY_i = \alpha_1 lnX_1 + \alpha_2 lnX_2 + \alpha_3 lnX_3 + \alpha_4 ln\, X_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + e_i$ | | | |
| 1.Human labour ($\alpha_1$) | 0.47 | 4.04* | 8.01 |
| 2. Chemical fertilizers($\alpha_2$) | 0.08 | 1.21 | 0.15 |
| 3. FYM ($\alpha_3$) | 0.02 | 0.75 | 0.18 |
| 4. Chemicals ($\alpha_4$) | -0.01 | -0.59 | -11.11 |
| 5. Transportation ($\alpha_5$) | 0.12 | 1.95 | 0.50 |
| 6. Electricity ($\alpha_6$) | 0.06 | 1.05 | 0.01 |
| 7. Plastic ($\alpha_7$) | 0.41 | 3.55* | 0.48 |
| Durbin-Watson (DW) | 2.05 | | |
| $R^2$ | 0.99 | | |
| Return to scale (RTS) | 1.15 | | |

* Significance at 1% level.

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**Table 6.** Econometric estimation results for direct and indirect energies (DE, IDE), and for renewable and non-renewable energies (RE, NRE) .

| Endogenous variable: | Basil yield | | |
|---|---|---|---|
| Exogenous variables | Coefficients ($\beta_i$, $\gamma_i$) | *t*-ratio | *MPP* |
| | Model II: $lnY_i = \beta_1 ln\ DE + \beta_2 ln\ IDE + e_i$ | | |
| DE ($\beta_1$) | 0.14 | 2.53* | 0.02 |
| IDE ($\beta_2$) | 0.80 | 13.06* | 0.46 |
| Durbin-Watson (DW) | 2.23 | | |
| $R^2$ | 0.96 | | |
| Return to scale (RTS) | 0.93 | | |
| | Model III: $lnY_i = \gamma_1 ln\ RE + \gamma_2 ln\ NRE + e_i$ | | |
| RE ($\gamma_1$) | 0.39 | 4.28* | 1.67 |
| NRE ($\gamma_2$) | 0.55 | 8.48* | 0.07 |
| Durbin-Watson (DW) | 2.15 | | |
| $R^2$ | 0.96 | | |
| Return to scale (RTS) | 0.94 | | |

* Significance at 1% level.

reported in the literature. For example, the impact of *IDE* was more than that of *DE* on yield (Hatirli *et al.,* 2009), and the impact of *NRE* was recorded as more than that for *RE* (Hatirli *et al.,* 2005). *DW* values were found out as 2.23 and 2.15 for Equations (9) and (10); indicating that there is no autocorrelation at the 1% significance level in the estimated models. $R^2$ value was found 0.96 for either of the estimated models (Models II and III). The RTS values for the Models II and III were 0.93 and 0.94, respectively, implied decreasing returns to scale (DRS).

As can be seen from Table 6 the *MPP* values of *IDE* and *RE* were 0.46 and 1.67, respectively. This indicates that an additional utilization of 1 MJ in each of the indirect and renewable energies, would lead to an additional increase in yield by 0.46 and 1.67 kg ha$^{-1}$, respectively.

Optimization is an important tool in maximizing the level of productivity which in turn can significantly have its impact on the energy consumption and production costs. Optimization of energy utilization in agricultural systems is reflected in two ways: either an increase in productivity with the existing level of energy inputs or conserving energy without the productivity being affected. In practice, a farmer has limited resources for the total cost of different inputs (chemicals, electricity, etc.).

Since each unit of basil production provides the same level of profit, then the farmer would be of the tendency to reasonably locate available resources to maximize the level of products it produces. This can be expressed in mathematical form as a linear programming. So, the present study can be extended to identify efficient farmers from inefficient ones, determine wasteful uses of energy inputs by inefficient farmers, and suggest the right and necessary quantities of various inputs out of any energy source to be utilized by a farmer from to become more efficient in his farming practices. More studies in this direction are currently underway.

## CONCLUSIONS

The energy balance between input and output as regards basil production was investigated. The total energy consumption in basil production was recorded as 236,057 MJ ha$^{-1}$. Electrical energy was the energy input item that dedicated the biggest share within all the energy inputs followed by plastic cover and chemical fertilizers, respectively. High electricity and chemical fertilizer consumption in the greenhouses of the studied region was mainly due to use of irrigation pumps of low efficiencies, low price paid for the electricity and relatively cheap chemical fertilizers in Iran. The energy equivalence for basil production was calculated as 2.18 MJ kg$^{-1}$.

On the average, 80.05% of total energy input used in basil production was direct, while the contribution of indirect energy being 19.95%. Also the shares of renewable and non-renewable energy inputs were 3.55% and 96.45%, respectively. The impact of human labour and in plastic form energy inputs was significantly positive on yield. The *MPP* value of human labour was the highest. Efficiency in energy management becomes more demanding when the required energy expenditure should be economical, sustainable and productive. Results clearly indicate that a reduction in electricity, plastic and fertilizer consumptions is indispensable for energy savings and lowering of the environmental risk problems in the area. Since the prevailing electric pumps are old, an excessively high level of electrical energy is used up and while fertilizer energy is also superfluous due to a lack of soil analysis leading to unconscious overusage of fertilizers. Reducing electricity consumption and fertilizer usage, mainly nitrogen, is important for proper energy management. A saving in electricity through an improvement of pumps' performance is possible. Use of direct and local markets can improve profitability for growers through a reduction of the level of energy used in the transport of the final products.

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# ارتباط انرژی های ورودی و عملکرد محصول برای تولید ریحان گلخانه ای

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## چکیده

هدف این مقاله تعیین رابطه بین انرژی های ورودی و عملکرد در تولید ریحان گخانه ای استان اصفهان در ایران بود. داده ها از ۲۶ تولیدکننده ی ریحان گلخانه ای به وسیله پرسشنامه به روش رو در رو در دوره ی تولید ۲۰۰۹-۲۰۱۰ جمع آوری شد. نتایجی که از این مطالعه بدست آمد این بود که: کل انرژی ورودی لازم برای تولید ریحان ۲۳۶۰۵۷ مگاژول بر هکتار بود. انرژی الکتریسیته با ۷۵.۶۸ درصد از کل انرژی ورودی بیشترین سهم را در انرژی های ورودی به خود اختصاص داد. بعد از الکتریسیته به ترتیب پوشش پلاستیک (۹.۶۹٪) و کود شیمیایی (۷.۲۸٪) بیشترین سهم انرژی های ورودی را به خود اختصاص دادند. نسبت انرژی، بهره وری انرژی ، انرژی ویژه و انرژی خالص به ترتیب برابر ۰.۲۵، ۰.۱۱ کیلوگرم بر مگاژول، ۹ مگاژول بر کیلوگرم و -۱۷۷۳۷۷ مگاژول بر هکتار محاسبه شد. تعیین اثر منابع انرژی بر عملکرد به وسیله تابع تولید کاب-داگلاس تعیین شد. نتایج نشان داد که تاثیر انرژی های نیروی کارگری و پوشش پلاستیک روی عملکرد در سطح ۱ ٪ معنی دار است. همچنین نتایج آنالیز حساسیت ورودی های انرژی نشان داد که نیروی کارگری بیشترین مقدار بهره وری فیزیکی نهائی را دارد.