Renewable Energy 36 (2011) 3217–3221

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Technical Note

Energy inputs and crop yield relationships in greenhouse winter crop tomato production

Burhan Ozkan*, R. Figen Ceylan, Hatice Kizilay

Faculty of Agriculture, Department of Agricultural Economics, Akdeniz University, Antalya 07070, Turkey

ARTICLE INFO

Article history:
Received 20 September 2010
Accepted 31 March 2011
Available online 29 April 2011

Keywords:
Greenhouse tomatoes
Energy analysis
Output–input ratio
Antalya

ABSTRACT

In this study, energy use patterns and the relationship between energy inputs and yield for single crop (winter) greenhouse tomato production were examined in Antalya province, one of the most important greenhouse centres in Turkey. Data were collected using face-to-face surveys from 85 farms producing winter greenhouse tomatoes. The results indicated that the bulk of energy was consumed in fertilizer (38.22%), electricity (27.09%), manure (17.33%) and diesel-oil (13.65%). Average yield and energy consumption were calculated as 57,905.1 kg/ha and 61,434.5 MJ/ha, respectively. Results also determined an output–input ratio of 0.8 and a respective energy productivity and specific energy of 1.061 MJ/t and 0.94 kg/MJ. In addition, the Cobb Douglas production function was applied to test the relationship among different forms of energy consumption. The findings suggested that single crop tomato producers must optimize their use of indirect energy resources. Single crop producers applied an excess use of chemicals, resulting in an inverse effect on yield as well as imposing risks to natural resources and human health. This research suggested an expansion in energy use training opportunities to greenhouse farmers in the region.

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1. Introduction

In the agricultural industry, efficient use of available energy resources is crucial to meet intensifying competition, increase productivity and aggregate production, and sustain rural lifestyles. One widely applied approach to characterize energy efficiency and the environmental impacts of agricultural production is through energy auditing. This method provides researchers with data derived from energy use samples, resulting in the opportunity to calculate input–output ratios [1].

Increased energy requirements in agriculture have resulted from continued growth in the human population, limited supply of arable lands, and the desire for an overall improved standard of living. Consequently, these factors have lead to increased demands for energy inputs to maximize yield, minimize labor-intensive practices, or both [2].

Energy plays a key role in economic and social development, but rural energy development policies that focus on agriculture have not been initiated. Agriculture serves a dual role as an energy user, but also energy supplier in the form of bio-energy. Agriculture offers important rural development opportunities as well as one means of climate change mitigation by substituting bio-energy for fossil fuels [3].

Energy is one of the most important elements in agricultural production. It is invested in various forms, including mechanical (farm machines, human power, and draft animals), electrical, and chemical fertilizer, pesticide and herbicide applications. The amount of energy used in agricultural production, processing and distribution must be adequate to feed the expanding population and meet other social and economic goals. A sufficient amount of energy and its effective and efficient use are prerequisites for improved agricultural production. Stout [4] reported that crop yields and food supplies are directly related to energy. In developed countries, a rise in crop yields was primarily attributed to an increased use of improved commercial energy, in addition to enhanced crop varieties [5].

The agricultural industry has become increasingly dependent on energy resources, such as electricity, fossil fuels, chemicals and fertilizers, largely due to relatively low energy prices. Energy use in agricultural production differs from energy use in non-agricultural production in terms of seasonality and the need for uninterrupted services. Due to the biological nature of agriculture, hydrocarbon cost fluctuation between seasons has less impact than an interruption of service in one season [6].

Turkey's agricultural energy consumption has increased in recent years and consequently associated energy issues have

* Corresponding author. Tel.: +90 242 3102475; fax: +90 242 2274564.
E-mail addresses: bozkan@akdeniz.edu.tr (B. Ozkan), ceylan.figen@gmail.com (R.F. Ceylan), hkizilay@akdeniz.edu.tr (H. Kizilay).

0960-1481/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.renene.2011.03.042

become more problematic. Currently, producers find their only choice is to use more energy to increase yield. Turkey has no additional arable lands available for agriculture and producers are not knowledgeable on more efficient forms of energy for agricultural production. Under these circumstances, an input–output energy analysis provides researchers, planners and policy makers an opportunity to evaluate economic interactions of energy use [7].

A number of studies have been conducted on agricultural energy use and energy input–output analysis in Turkey and other countries [7–16]. In all of these related studies, energy ratio (energy use, efficiency) and energy productivity were measured. However, none of these studies report energy input and output in greenhouse tomato production in Turkey.

The main objective of the present study was to develop an econometric model for greenhouse tomato production in Antalya province, Turkey. Prior to model development the main indicators of energy equivalent inputs and amounts produced were calculated through an energy auditing study. The preliminary calculations were designed to reveal the input–output relationships for the 85-sample greenhouse tomato farms. After the productive relationship based on energy equivalents was estimated, the model was expected to show the relationship between energy inputs and yield, providing yield energy input elasticity. Subsequently, the effects of indirect and direct energy consumption on yield using functional form were analyzed. In addition, the study served to calculate output–input ratios, energy productivity, and specific energy used in greenhouse tomato production in Antalya province, Turkey.

2. Materials and methods

Data were collected from 85-greenhouse single crop tomato production enterprises in the towns of Kumluca, Serik and Central of Antalya province via face-to-face surveys. The questionnaires were implemented in June 2007. The questionnaire was structured using our research objectives, and the views of experts in the international and national literature.

The enterprises that were registered under a specific production system were clustered into three samples/groups with respect to greenhouse area (size). The clustering enabled homogenization of enterprises by grouping businesses by size. Stratified sampling was used to determine sample size applying the "Neyman Method" in the framework list [17]. The following formulas (1-2-3) were used in a consecutive order with a 95% confidence interval, a 5% margin of error and a sample size of $n = 85$.

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

n denotes the sample size
N denotes the number of holdings in the target population
N_h denotes the population number h stratified
S_h denotes the variance of h stratified

$$D^2 = \frac{d^2}{Z^2} \tag{2}$$

d denotes the precision where (x–X)
Z denotes the reliability coefficient (1.96 which represents 95% reliability)

The following equity was used in sample size distribution into layers (n_h)

$$n_h = \frac{N_h S_h}{\sum N_h S_h} n \tag{3}$$

Table 1
Energy equivalents of inputs and outputs in agricultural production.

Input (Unit)	Energy equivalent (MJ unit^{-1})	Reference
Chemicals (kg)	101.20	[21]
Human power (h)	2.30	[21]
Machinery (h)	64.80	[8]
Nitrogen fertilizer (kg)	66.14	[11]
Phosphorus (kg)	12.44	[11]
Potassium (kg)	11.15	[11]
Manure (tons)	303.10	[21]
Diesel-oil (l)	56.31	[8]
Electricity (kWh)	3.60	
Water for irrigation (m^3)	0.63	[21]
Tomato	0.80	

The amount of energy input used in chemicals, fertilizers, fuel, electricity, irrigation water, human power, and machine power for greenhouse single crop tomato production were determined to calculate energy equivalents. The input amounts were calculated using the units indicated in Table 1. The energy input amounts per hectare were determined and multiplied by the energy equivalent quotient. Energy equivalent quotients were applied as shown in Table 1. The energy equivalents of all inputs were reported in mega joule (MJ) units. Total input equivalents were calculated by summation of energy equivalents.

Input energy can be examined in four classes as follows: direct, indirect, renewable and non renewable [2,8,18,19]. Indirect energy include pesticides and fertilizers used during the production phase; direct energy refers to electricity, fuel and human power; non-renewable energy resources include fuel, electricity, chemicals and fertilizers; and renewable energy sources include but are not limited to human and animal power [18,19].

$$\begin{aligned}
\text{Output} - \text{input ratio} &= \frac{\text{Energy output}(MJ/ha)}{\text{Energy input}(MJ/ha)} \\
\text{Specific energy} &= \frac{\text{Energy input}(MJ/ha)}{\text{Tomato output}(t/ha)} \\
\text{Energy productivity} &= \frac{\text{Tomato output}(kg/ha)}{\text{Energy input}(MJ/ha)}
\end{aligned} \tag{4}$$

Following the calculation of energy input and output equivalents, and interpretation of formulas derived by Faidly [5], the relationship between energy input and output was investigated using *a priori* production relationships. The energy equivalencies suggested the appropriate functional form was the Cobb Douglas production function. The main objective to estimate this production function was to search for the elasticity relationships and return to the production scale in the greenhouse single crop tomato setting. This methodology has been applied to investigate theoretical assumptions for signs of energy input in determining the optimal output levels [8,12,20].

Table 2
Socioeconomic characteristics of greenhouse tomato farms.

Features	Means	%
Land (ha)	0.31	
Farmers' age	40.5	
Farmers' agricultural experience (year)	15.3	
Family size	3.9	
Farmers' educational level (per person)	85	100.0
-Illiterate	–	–
-Literate	–	–
-Primary school	52	61.2
-Middle school	10	11.8
-High school	15	17.6
-University	8	9.4

Table 3
Energy inputs, outputs and output–input ratio in greenhouse tomato production.

Input (Unit)	Quantity used per unit area (ha)	Total energy equivalent (MJ ha^{-1})
Chemicals (kg)	10.7	1083.5
Human power (h)	212.8	489.5
Machinery (h)	8.2	530.3
Total fertilizer (kg)	866.6	23,483.0
Nitrogen fertilizer (kg)	245.3	16,225.7
Phosphorus (kg)	255.3	3176.4
Potassium (kg)	366.0	4080.9
Manure (tons)	35.1	10,643.6
Diesel-oil (l)	148.9	8385.6
Electricity (kWh)	4623.7	16,645.4
Water for irrigation (m^3)	275.5	173.6
Total energy input (MJ/ha)		61,434.5
Yield (kg/ha)	57,905.1	46,324.1
Energy output–input ratio		0.8
Energy productivity (kg MJ^{-1})		0.94
Specific energy (MJ t^{-1})		1061.0

Accordingly, the functional representation of the energy equivalent relationship is as follows [5]:

$$Y = \beta_0 * \Pi X_{ji}^{\beta j} e^{ui}, (i: 1, \ldots 85; j: 1, \ldots, 10) \quad (5)$$

or in linear Cobb Douglas form

$$Y = \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_5 \ln X_{5i} + \beta_6 \ln X_{6i} + \beta_7 \ln X_{7i} + \beta_8 \ln X_{8i} + \beta_9 \ln X_{9i} + \beta_{10} \ln X_{10i} + u_i$$

where

Y_i: Yield at farm i (kg/ha)
X_{1i}: Energy equivalent of machinery per hectare at farm i
X_{2i}: Energy equivalent of electricity per hectare at farm i
X_{3i}: Energy equivalent of human power per hectare at farm i
X_{4i}: Energy equivalent of manure per hectare at farm i
X_{5i}: Energy equivalent of irrigation per hectare at farm i
X_{6i}: Energy equivalent of fuel per hectare at farm i
X_{7i}: Energy equivalent of nitrogen per hectare at farm i
X_{8i}: Energy equivalent of potassium per hectare at farm i
X_{9i}: Energy equivalent of phosphorus per hectare at farm i
X_{10i}: Energy equivalent of chemicals (herbicides, pesticides) per hectare at farm i

The contribution of input energy equivalents into the yield levels, including comparisons of signs of coefficients was interpreted in the results. The analysis was performed using the SPSS statistical package.

3. Results and discussion

3.1. Socio-economic characteristics of the greenhouse tomato farms

Results found that small family farms carry out greenhouse production enterprises and the number of large greenhouse holdings using modern technology is limited. The average farm size was 0.31 ha. The average farm family size was 3.9 people. The average farmer age and average years of agricultural experience were 40.5 and 15.3 years respectively. Results indicated that 61.2% of the farmers were primary school graduates, 11.8% were middle school graduates, 17.6% had a high school education and 9.4% were university graduates (Table 2). The source of farm labor was primarily from family members and the major component of the family income was greenhouse tomato production.

3.2. Energy input and output in greenhouse tomato production

Energy sources and consumption for greenhouse tomato production are presented in Table 3 and Fig. 1. Energy sources were reported as direct-indirect and renewable-non-renewable forms. Total physical energy input consisted of diesel, fertilizer, electricity, chemicals, human power, machinery and water irrigation.

The conversion factors given in Table 1 were used to determine energy inputs and outputs (Table 3). Greenhouse tomato production used 10.7 kg of chemicals and 866.6 kg of chemical fertilizers per hectare. The respective chemical use was 28.3%, 29.5% and 42.2% for nitrogen, phosphorus and potassium (Fig. 1).

The total energy used in producing greenhouse tomatoes was 61,434.5 MJ ha^{-1}. The most energy consumed by all farm operations producing greenhouse tomatoes was total fertilizer (38.22%), followed by electricity (27.09%). Diesel energy was mainly utilized for operating tractors to perform various farm operations. Chemicals, human power, machinery, farmyard manure, diesel and water for irrigation consumed, respectively 1.76%, 0.80%, 0.86%, 17.33%, 13.65% and 0.28% (Fig. 1). The average tomato yield was around 58 tonnes ha^{-1} and its energy equivalent was calculated at 46,324.1 MJ ha^{-1}.

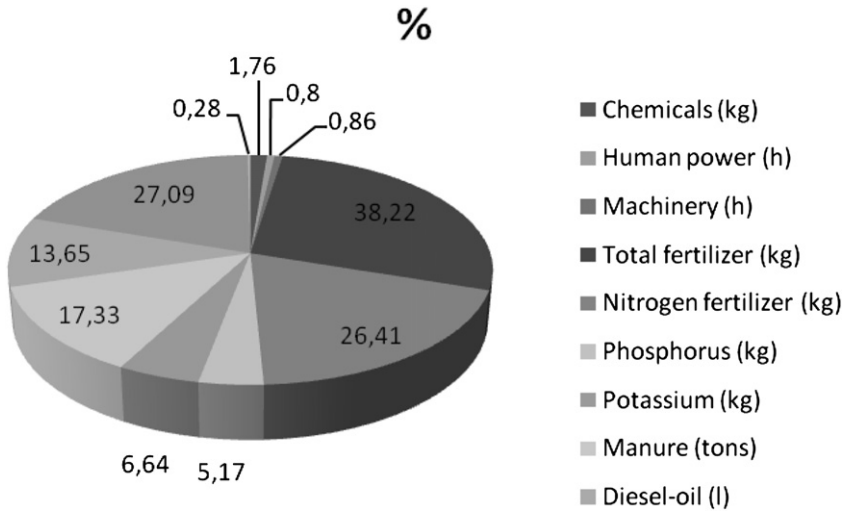


Fig. 1. Percentage distribution of energy inputs in greenhouse tomato production.

Table 4
Energy consumption under different energy sources in tomato production.

Energy forms	MJha^{-1}	Percentage of total energy input[a] (%)	Inputs
Direct energy	25,520.5	41.54	Human, diesel, electricity
Indirect energy	35,740.4	58.18	Fertilizers, farmyard manure, chemicals, machinery
Renewable energy	11,133.1	18.12	Human, farmyard manure
Non-renewable energy	50,127.8	81.60	Diesel, electricity, chemicals, fertilizers, machinery
Commercial energy	50,127.8	81.60	Diesel, electricity, chemicals, fertilizers, machinery
Non-commercial energy	11,133,1	18.12	Human, farmyard manure
Total energy input	61,434.5		

[a] Energy equivalent of water for irrigation is not included.

Output–input ratio is one of the important indicators to maintain efficiency in greenhouse production. The energy output/input ratio was 0.8 in greenhouse single crop tomato production. The energy efficiency quotient refers to the output obtained in response to the energy used per unit area and was 0.94 kg/MJ with a specific energy of 1.061 MJ/t.

The input classification used for greenhouse tomato production as direct, indirect, renewable and non-renewable energy groups are provided in Table 4. Results indicated that the direct and indirect energy resource ratios were not significantly different; however significant differences were observed between renewable and non-renewable energy resource ratios. The rate of renewable energy from human power and farm manure was considerably low (18.12%). The highest percentage (81.60%) of resources used in greenhouse tomato production was non-renewable resources (Fig. 2).

In addition, following disaggregation of the impact of energy on relevant inputs, the production function was estimated by using the input energy equivalent measures against yield per farm.

The relationship (energy input and yield) produced unexpected outcomes in terms of the signs of input energy equivalents. Therefore, prior to data interpretation, direct function implementation was tested in terms of heteroscedastic variance and autocorrelation of error terms because the data exhibited cross sectional characteristics. The Breusch-Pagan-Godfrey test results indicated no structural breaks in the data. Furthermore, visual inspection of error terms confirmed these results. Therefore, the data required no adjustment for heteroscedasticity.

Subsequently, the relationship was tested for autocorrelation. The Durbin-Watson statistic generated a value of 1.694 (indecisive relationship). The non-parametric and Breusch Godfrey tests revealed a series autocorrelation indicating transfer within decision units i.e. greenhouse farms. The d-statistic approximated a value close to unity; therefore the first difference of the explanatory and explained variables was accepted. The first difference estimates of the relationship provided us with explanations similar to the energy audit results. The exogenous variables, which were the first differences of input energy equivalents, explained 76.8% of the variation in yield for the first coefficient. The respective coefficients are provided in Table 5.

The estimate outcomes revealed unexpected results; energy equivalents for farm machinery, farm electricity, farm manure and nitrogen showed negative impacts in single crop tomato yield. These results are likely related to the limited share of farm machinery in production and excessive use of remaining energy inputs. The increased use of electricity, manure and nitrogen can also be used to explain the low output–input ratio. The coefficients which were significant when interpreted together (i.e. the F-statistic did not indicate an autocorrelation), can be applied to interpret the energy relationship of single crop production in the surveyed area.

The coefficients also indicated inefficient characteristics regarding production practices. In addition, significance and near unity values for human power coefficients indicated the weight of labor in production. Therefore, the most important input in terms of elasticity of production is human power (1.009), which was followed by energy used for irrigation (0.159). However, nitrogen was the most widely applied chemical fertilizer and resulted in yield decline. The overall elasticity of inputs was close to unity (1.187), suggesting an almost constant return to scale relationship between the energy equivalents of inputs and yield. Subsequently, considering the bulk of energy consumed was non-renewable, transfer of some of the energy to renewable sources may lead to a rise in production efficiency. In other words, direct

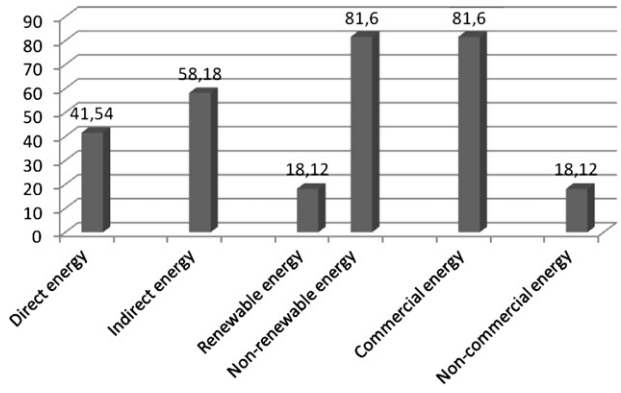


Fig. 2. Percentage of total energy input for tomato production.

Table 5
Results for the first difference Cobb Douglas Equation.

Exogenous variable	Coefficient	*t*-value
Constant	0.012	0.378
DMACH	−0.068	−1.294
DELT	−0.011	−0.666
DLAB	1.009	9.439[a]
DMAN	−0.007	−0.517
DIRR	0.159	1.644
DFUEL	0.018	0.500
DN	−0.022	−0.469
DP	0.024	0.704
DK	0.014	0.476
DCHEM	0.059	1.432
D-W statistic	2.458	
F-statistic	28.807[a]	

[a] Significant at 1%.

energy contributes more to increase in productivity in greenhouse farms.

4. Conclusions

The main objective of this study was to calculate energy use per hectare of greenhouse single crop tomato production in the towns of Kumluca and Serik of central Antalya province, Turkey. An energy audit was conducted to examine data as total mean energy inputs from direct-indirect and renewable-non-renewable energy forms.

Results indicated that the total energy use in greenhouse single crop tomato production were chemical fertilizer (38.22%), electricity (27.09%), manure (17.33%) and diesel fuel (13.65%). The energy consumed from chemicals, machinery, labor and irrigation exhibited lower values of 1.76%, 0.86%, 0.80% and 0.28%, respectively.

The average energy expended for an average yield of 57,905.1 kg/ha was 61,434.5 MJ/ha. In addition, the specific energy used and energy efficiency were 1.061 MJ/t and 0.94 kg/MJ respectively. Additionally, the output–input ratio, which is the ratio of the equivalent produced amount of energy to *t* equivalent consumed input energy, was calculated as 0.8. On average, non-renewable forms of energy were 81.60% of the total energy input in greenhouse tomato production.

The less than unit output–input ratio indicated inefficient use of inputs during the production process.

The inefficient use of inputs leads to problems beyond the scope of agricultural production. Specifically, unconscious use of chemicals and fertilizers can result in damage to human health, the environment and energy waste.

In addition, the regression analysis revealed an excess use of chemicals and machinery resulting in a decline in single crop tomato yield. In contrast, energy inputs that contributed most to productivity were human power and energy used for irrigation. These inputs must be considered carefully when optimizing for the cost of production and reducing any negative impacts to human health and the environment. Accordingly, a shift in focus from indirect to direct energy sources is expected to contribute to rising yields and reduce resource damage. Furthermore, returns to scale are anticipated as the relationship demonstrated nearly constant returns to expended inputs.

However, producers must be provided educational opportunities in the use of efficient inputs, and this is the responsibility of local and regional policy planning and implementation by decision making authorities. Finally, this research suggested the expansion of training opportunities to greenhouse farmers to increase production efficiency in the region, and can serve as a foundation to improve yield via input efficiency to greenhouse enterprises worldwide.

Acknowledgments

This research was supported by TUBITAK (The Scientific and Technological Research Council of Turkey), Project number: TOVAG 106O026

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