Assessment of energy use pattern for tomato production in Iran: A case study from the Marand region

M.R. Jadidi[1], M.S. Sabuni[1], M. Homayounifar[2], A. Mohammadi[3]

[1]*Department of Agricultural Economics, Faculty of Agriculture, University of Zabol, Zabol, Iran*
[2]*Department of Economics, Faculty of Economic and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran*
[3]*Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran*

Abstract

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The aim of the contribution was to determine energy consumption of input and output used in tomato production and to optimize the energy inputs in the Marand region, Iran. The study also sought to analyse the effect of farm size on energy use and input costs based on tomatoes production and to reveal the relationship between energy inputs and yield by developing mathematical models. Questions about energy management present very interesting and actual topic in this time. The results revealed that tomato production consumed a total of 65,238.9 MJ/ha of which fertilizers were 50.98% followed by water for irrigation (20.67%). Output-input energy and energy productivity were found to be 0.59 and 0.74 kg/MJ, respectively. The results of energy optimization showed that using existing energy inputs, the yield of tomato can be increased by 45.2% in small farms, 43.5% in medium farms and 30% in large farms. The rate of direct, indirect, renewable and non-renewable energy forms were found to be 37.2, 62.8, 30.9 and 69.1% of total energy input, respectively. The main non-renewable inputs were chemical fertilizers and diesel fuel, management of plant nutrients and proper machinery selection to reduce diesel fuel use would increase rate of renewable energy.

Keywords: energy productivity; diesel fuel; optimization; non-renewable energy; Iran

Agriculture is a vital sector in the Iran economy. It accounted for 10.9% of gross national product in 2009 (Central Intelligence Agency 2010). But the importance of agriculture has declined in relation to the rapid increase observed in the industry and service sectors.

The tomato belongs to worldwide most widespread sort of vegetables. Tomato production is considered to be a main source of raw material for the tomato processing industry. Tomato production creates an income for many rural farmers in Iran.

Efficient use of resources is one of the major assets of sustainable production in agriculture. Also, efficient use of energy is one of the principal requirements of sustainable agriculture. Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land, and a desire for higher standards of living. Continuous demand in increasing food production resulted in intensive use of chemical fertilizers, pesticides, agricultural machinery and other natural resources. However, intensive use of energy

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

	Energy equivalent (MJ/unit)	Reference
A. Inputs		
Human labor (h)	1.96	Mohammadi et al. (2008)
Machinery (kg)	62.7	Mohammadi et al. (2008)
Chemical fertilizers (kg)		
Nitrogen (N)	66.14	Mohammadi et al. (2008)
Phosphorus (P_2O_5)	12.44	Mohammadi et al. (2008)
Potassium (K_2O)	11.15	Mohammadi et al. (2008)
Manure (t)	303.1	Mohammadi et al. (2008)
Chemicals (kg)	120	Mohammadi et al. (2008)
Seeds (kg)	1	Ozkan et al. (2004)
Diesel fuel (l)	56.31	Mohammadi et al. (2008)
Water for irrigation (m^3)	1.02	Mohammadi et al. (2008)
B. Output		
Tomato (kg)	0.8	Ozkan et al. (2004)

causes problems threatening public health and environment. Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system (Dalgaard et al. 2001).

In order to get higher productivity, the farmers, in general, use their resources in excess and inefficiently. The excess use of resources and scope to increase the productivity or conserve the energy input without affecting the productivity, thereby enhancing the efficiency of energy use, was viewed by many researchers (Kutala 1993; Refsgaard et al. 1998; Chauhan et al. 2006; Mobtaker et al. 2010; Mohammadi et al. 2011; Mousavi-Avval et al. 2011a, b). An analysis of input-output of energy is used in determining the effects of production on the use of energy in various crops. Many researchers studied energy and economic analysis to determine the energy efficiency of plant production, such as sugarcane in Morocco (Mrini et al. 2001), soybean, maize and wheat in Italy (Sartori et al. 2005), wheat, maize, sorghum in USA (Franzluebbers, Francis 1995), apple in Iran (Rafiee et al. 2010), cucumber in Iran (Mohammadi, Omid 2010), kiwifruit production in Iran (Mohammadi et al. 2010), onion in Pennsylvania (Moore 2010) and coriander, lettuce, radish and spinach in Colombia (Bojaca, Schrevens 2010). However, little study was encountered on the efficiency of energy use in tomato production and optimization of energy inputs.

The aim of the contribution was to determine energy consumption of input and output used in tomato production and to optimize the energy inputs in the Marand region, Iran. The study also sought to analyze the effect of farm size on energy use and input costs based on tomatoes production and to reveal the relationship between energy inputs and yield by developing mathematical models.

MATERIAL AND METHODS

The study was carried out in 140 tomato producer in the Marand region, Iran. It is located in the northwest of Iran, between 38°07' and 38°56' north latitude and 45°15' and 45°50' east longitude.

Data were collected from the growers by using a face-to-face questionnaire. The data collected belonged to the production period of 2008–2009. Sample farms were randomly selected from the villages in the study area by using a stratified random sampling technique. The sample size was calculated using the Neyman method (Yamane 1967) with the farms classified into three groups as small (<= 0.6 ha), medium (0.6 <= 1.5 ha) and large farms (> 1.5 ha). The permissible error in the sample size was defined to be 5% for 95% confidence and the sample size was calculated as 140 farms.

The total energy per production unit (e.g. ha) was established by the addition of the partial energies of each input referenced to the unit of production. Energy inputs were human labor, diesel fuel, machinery, farmyard manure, irrigation, chemical fertilizers consisting of nitrogen (N), phosphorous (P_2O_5) and potassium (K_2O). To estimate the energy of the inputs, expressed in MJ/ha, the energy equivalents in Table 1 were utilized.

The energy use efficiency (energy ratio) and energy productivity were calculated using the following formulae (Mohammadi et al. 2008):

$$\text{Energy ratio} = \text{Energy output (MJ/ha)}/\text{Energy input (MJ/ha)} \quad (1)$$

$$\text{Energy productivity} = \text{Tomato output (kg/ha)}/\text{Energy input (MJ/ha)} \quad (2)$$

Agriculture uses energy directly as fuel or electricity to operate machinery and equipment, to heat or cool buildings, and for lighting on the farm, and indirectly in the fertilizers and chemicals produced off the farm (Alam et al. 2005; Ozkan et al. 2004).

Optimum energy use in agriculture is reflected in two ways, i.e. an increase in productivity with the existing level of energy inputs or conserving energy without affecting the productivity. Linear programming based on the concept of one-to-one functions was used to optimize the energy inputs (assuming no change in area under the crop). Based on this concept, the linear programming problem was formulated as (Singh et al. 2004):

Table 2. Amounts of inputs and outputs in tomato production

	Farm size groups (ha)			Average
	small	medium	large	
A. Inputs				
1. Human labor (h/ha)	1,090.19	1,110.78	1,078.6	1,093.2
Land preparation	37.5	37.5	39.1	38.03
Seeding	48	50.2	49.3	49.2
Weeding	322.49	325.9	291.2	313.2
Fertilizer application	31.3	27.88	31.3	30.2
Spraying	2.7	2.1	2.7	2.5
Irrigation	225.2	217.9	216.7	219.9
Harvesting	376.8	400.9	401.2	392.9
Transporting	46.2	48.4	47.1	47.2
2. Machinery (h/ha)	46	45.8	47	46.3
Land preparation	13.2	13.1	13.4	13.2
Fertilizer application	2.8	2.8	3.2	2.9
Spraying	1.8	1.2	1.3	1.4
Transporting	28.2	28.7	29.1	28.7
3. Diesel (l/ha)	152.2	152.3	155.9	153.5
Land preparation	85.1	84.4	86.3	85.3
Fertilizer application	5.9	5.9	6.6	6.1
Spraying	3.8	2.6	2.8	3.1
Transporting	57.4	59.4	60.2	59
4. Fertilizers (kg/ha)	998.9	870.9	921.7	930.5
Phosphorus (P_2O_5)	464.5	408.4	382.6	418.5
Nitrogen (N)	411.1	366.7	441.3	406.4
Potassium (K_2O)	123.3	95.8	97.8	105.6
5. Manure (t/ha)	14.4	16	14.5	14.9
6. Chemicals (kg/ha)	2.2	2.3	2.2	2.2
7. Water (m^3/ha)	13,352.09	13,237.5	13,080.8	13,223.5
8. Seed (kg/ha)	0.3	0.3	0.3	0.3
B. Output				
Tomato (kg/ha)	47,211	48,993	48,478	48,227.3

$$\text{Maximize} \quad \sum \alpha_i Y_i \qquad (i = 1, 2, 3, \ldots, n) \qquad (3)$$

Subject to

$$\sum \alpha_i X_{ji} \leq \bar{X}_J \qquad (j = 1\text{–}10)$$
$$\sum \alpha_{i_i} = 1$$
$$\sum \alpha_i (\sum X_{ji}) \leq \sum \bar{X}_J$$
$$X_{ji} \geq 0$$
$$\alpha_i \geq 0$$

where:

$\bar{X}_j$ – weighted mean of the j^{th} energy use (j = 1–10)

$\sum X_{ji}$ – total energy use by the i^{th} farmer

Farmers who fulfilled the above constraints and contributed to the optimal solution were assigned weightage (α) according to their effectiveness of energy input use. Optimized levels of energy input use to get the existing productivity level of wheat were computed using the parametric programming by reducing the level of total energy input use ($\sum \bar{X}_j$).

RESULTS AND DISCUSSION

Analysis of input-output energy use in tomato production

Table 2 shows the amount of physical input used in tomato production in the area of survey. The results revealed that tomato is one of the highest labor demanding crops among field crops produced in region. Average labor used in tomato production was 1,093.2 h/ha and average machinery and diesel fuel were 46.3 h and 153.5 l/ha, respectively. The amount of fertilizers used and water for irrigation for tomato production were 930.5 kg/ha and 13,223.5 m^3/ha, respectively. Maximum yield of tomato production was seen in medium farms (48,993 kg/ha) with an annual average of 48,227.3 kg/ha.

As it can be seen in Table 3, the total amount of energy used for various practices in tomato production was calculated to be 65,238.9 MJ/ha that minimum energy use was seen in medium farms. The amount of fuel energy and machinery energy increased as the farm size increased with the annual average of 8,641.7 and 2,900.9 MJ/ha, respectively. The amount of fertilizers energy was 33,261.04 MJ/ha that of all chemical fertilizers, share of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) were 41.19, 7.98 and 1.80%, respectively. The amount of irrigation water energy decreased as the farm size increased and consumed the amount of 13,487.9 MJ/ha (20.67% of total energy). The rates of other inputs in the total amount of energy such as human labor, manure and chemicals

Table 3. Energy consumption and energy input-output relationship in tomato production

	Farm size groups (ha)			Average	
	small	medium	large	amount	%
A. Inputs (MJ/ha)					
1. Human labor	2,136.8	2,177.1	2,114.1	2,142.6	3.28
2. Machinery	2,884.2	2,871.7	2,946.9	2,900.9	4.45
3. Diesel fuel	8,570.4	8,576.01	8,778.7	8,641.7	13.25
4. Fertilizer	34,343.3	30,402.2	35,037.6	33,261.0	50.98
Phosphorus (P_2O_5)	5,778.4	5,080.5	4,759.5	5,206.1	7.98
Nitrogen (N)	27,190.1	24,253.5	29,187.6	26,877.1	41.19
Potassium (K_2O)	1,374.8	1,068.2	1,090.5	1,177.8	1.80
5. Manure	4,364.6	4,849.6	4,394.9	4,536.4	6.95
6. Chemicals	264	276	264	268	0.41
7. Water	13,619.1	13,502.2	13,342.4	13,487.9	20.67
8. Seed	0.3	0.3	0.3	0.3	0.00
Total energy inputs (MJ/ha)	66,182.8	62,655.1	66,878.9	65,238.9	100
Total energy outputs (MJ/ha)	37,768.8	39,194.4	38,782.4	38,581.9	–
Energy ratio	0.57	0.62	0.58	0.59	–
Energy productivity (kg/MJ)	0.71	0.78	0.72	0.74	–

Table 4. Total energy input as direct, indirect, renewable and non-renewable forms

Type of energy	Farm size groups			Average	
	small	medium	large	amount	%
Direct energy	24,326.3	24,255.3	24,235.2	24,272.2	37.2
Indirect energy	41,856.5	38,399.8	42,643.7	40,966.7	62.8
Renewable energy	20,120.9	20,529.2	19,851.7	20,167.2	30.9
Non-renewable energy	46,061.9	42,125.9	47,027.2	45,071.7	69.1
Total energy input	66,182.8	62,655.1	66,878.9	65,239.9	100

were 3.28, 6.95 and 0.41%, respectively. Total average amount of output energy was 38,581.9 MJ/ha, the maximum energy output was seen in medium farms. The rate of energy (energy ratio) and energy productivity were 0.59 and 0.74 kg/MJ, respectively. In other studies, the rate of energy in stake-tomato production in the Tokat province of Turkey (Esengun et al. 2007) and tomato production in greenhouse in Antalya, Turkey (Ozkan et al. 2004) were reported to be 0.80 and 1.26, respectively. Cetin and Vardar (2008) found that energy ratio and energy productivity in tomato production in the south Marmara region of Turkey were 0.8 and 0.99 kg/MJ, respectively. Also, in other study in Iran (Pashaee et al. 2008), energy ratio and energy productivity in tomato production in greenhouse was 0.99 and 1.2 kg/MJ, respectively. It seems that this inefficiency can be due to the conventional farming of tomato, lack of proper management of inputs especially chemical fertilizers.

Table 4 shows the distribution of total mean energy input as direct, indirect, renewable and non-renewable forms. As it can be seen from the Table 4, 37.2% of total energy input resulted from direct and 62.8% from indirect energy and 30.9% from renewable and 69.1% from non-renewable energy.

Optimization of energy inputs

The results of solving linear programming model for optimization of energy input in different levels of tomato production were given in Table 5. The results showed that the maximum attainable yield at optimal use of the existing resources was higher than the actual observed yield in all levels of pro-

Table 5. Actual use and optimum requirement of energy inputs (MJ/ha) in different levels of tomato production

	Small farms			Medium farms			Large farms		
	actual	optimum	%*	actual	optimum	%*	actual	optimum	%*
Yield (kg/ha)	4,685.7	6,806.2	+45.2	5,053.2	7,249.1	+43.5	5,226.2	6,795.5	+30
Labor	556.6	402.2	−27.7	550.2	550.2	0	519.3	519.3	0
Machinery	1,632.6	1,632.6	0	1,708.6	1,708.6	0	1,887.1	1,698.9	−10
Diesel	5,179.1	4,540.4	−12.3	5,563.2	5,559.3	−0.07	5,955.1	5,954.6	0
Seed	3,139.2	3,053.9	−2.7	2,993.4	2,940	−1.8	3,070.1	3,060.2	−0.3
Manure	11,232.5	1,856.5	−83.5	10,654.5	0	−100	5,657.9	743.6	−86.8
Phosphate	3,588.9	2,550.1	−28.9	2,667.1	1,290	−51.6	3,240.2	989.7	−69.5
Nitrogen	23,761.9	18,684.1	−21.4	17,609.5	16,535	−6.1	19,492.5	14,506.6	−25.6
Potassium	2,680.6	1,296.1	−51.6	1,475.7	1,115	−24.4	1,491.7	1,001	−32.9
Chemicals	389	313.5	−19.4	359.6	359.5	−0.03	345.4	264.5	−23.4
Water	4,944	4,390.5	−11.2	4,783.1	4,161.6	−13	4,885.9	3,991.4	−18.3
Total input energy	57,104.3	38,720	−32.2	48,365	34,220	−29.2	46,545	32,730	−29.7

*percent of change in comparison to actual use duction. The use of optimum energy revealed that there exists a greater scope to increase the productivity; as the farmers could increase average yield by 45.2, 43.5 and 30% in small, medium and large farms, respectively, by using the same level of inputs through better management of the farm.

The results revealed that the farmers in all levels of production used higher energy than the optimum. This indicated that the existing productivity level in all levels of production could be achieved even by reducing the existing energy use levels by 32.2% in small farms, 29.2% in medium farms and 29.7% in large farms. The results showed that the farmers of small farms used 19.4% chemicals, 28.9% phosphate, 21.4% nitrogen and 51.6% potassium higher than optimum. On another hand, the energy consumption can be saved by optimum use of human labor, water for irrigation and diesel fuel by 27.7, 11.2 and 12.3%, respectively. Optimal amounts in medium farms indicated that farmers in this level of production used 51.6% phosphate, 6.1% nitrogen, 24.4% potassium, 100% manure, and 13% water higher than the optimum. Also, the farmers of this level of production harvested the full potential of other resources. It can save energy consumption in large farms by 69.5% phosphate, 25.6% nitrogen, 32.9% potassium, 23.4% chemicals, 18.3% water, 86.8% manure and 10% machinery, in terms of optimum use of resources.

The energy indexes of the medium farms were higher than those of the small and large farms. On another hand, the use of optimum energy implied that the farmers in all levels of production used higher energy than the optimum. The inefficient use of chemical fertilizers and diesel fuel inputs by the tomatoes production leads to problems beyond the scope of agricultural production, increasing production costs and negative effects to environment, human health, maintaining, and sustainability. Farmers must be provided with educational opportunities in the use of efficient inputs, and this is the responsibility of policy makers in the area.

References

Alam M.S., Alam M.R., Islam K.K., 2005. Energy flow in agriculture: Bangladesh. American Journal of Environmental Sciences, *1*: 213–220.

Bojaca C.R., Schrevens E., 2010. Energy assessment of peri-urban horticulture and its uncertainty: Case study for Bogota, Colombia. Energy, *35*: 2109–2118.

Central Intelligence Agency, 2010. The World Factbook. Available at https://www.cia.gov/library/publications/the-world-factbook/geos/ir.html

Cetin B., Vardar A., 2008. An economic analysis of energy requirements and input costs for tomato production in Turkey. Renewable Energy, *33*: 428–433.

Chauhan N.S., Mohapatra P.K.J., Pandey K.P., 2006. Improving energy productivity in paddy production through benchmarking – An application of data envelopment analysis. Energy Conversion and Management, *47*: 1063–1085.

Dalgaard T., Halberg N., Porte J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agriculture, Ecosystems and Environment, *87*: 51–65.

Esengun K., Erdal G., Gunduz O., Erdal H., 2007. An economic analysis and energy use in stake-tomato production in Tokat province of Turkey. Renewable Energy, *32*: 1873–1881.

Franzluebbers A.J., Francis C.A., 1995. Energy output-input ratio of maize and sorghum management systems in Eastern Nebraska. Agriculture, Ecosystems and Environment, *53*: 271–278.

Kutala S.S., 1993. Application of frontier technology to wheat crop grown on reclaimed soils. Indian Journal of Agricultural Economics, *48*: 226–36.

Mobtaker H.G., Keyhani A., Mohammadi A., Rafiee S., Akram A., 2010. Sensitivity analysis of energy inputs for barley production in Hamedan Province of Iran. Agriculture, Ecosystems and Environment, *137*: 367–372.

Mohammadi A., Omid M., 2010. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Applied Energy, *87*: 191–196.

Mohammadi A., Tabatabaeefar A., Shahin S., Rafiee S., Keyhani A., 2008. Energy use and economical analysis of potato production in Iran a case study: Ardabil province. Energy Conversion and Management, *49*: 3566–3570.

Mohammadi A., Rafiee S., Mohtasebi S.S., Rafiee H., 2010. Energy inputs-yield relationship and cost analysis of kiwifruit production in Iran. Renewable Energy, *35*: 1071–1075.

Mohammadi A., Rafiee S.H., Mohtasebi S.S., Mousavi-Avval S.H., Rafiee H., 2011. Energy efficiency improvement and input cost saving in kiwifruit production using Data Envelopment Analysis approach. Renewable Energy, *36*: 2573–2579.

Moore S.R., 2010. Energy efficiency in small-scale biointensive organic onion production in Pennsylvania, USA. Renewable Agriculture and Food Systems, *25*: 181–188.

Mousavi-Avval S.H., Rafiee S.H., Mohammadi A., 2011a. Optimization of energy consumption and input costs for apple production in Iran using data envelopment analysis. Energy, *36*: 909–916.

Mousavi-Avval S.H., Rafiee S.H., Jafari A., Mohammadi A., 2011b. Improving energy use efficiency of canola production using data envelopment analysis (DEA) approach. Energy, *36*: 2765–2772.

Mrini M., Senhaji F., Pimentel D., 2001. Energy analysis of sugarcane production in Morocco. Environment, Development and Sustainability, *3*: 109–126.

Ozkan B., Kurklu A., Akcaoz H., 2004. An input-output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. Biomass Bioenergy, *26*: 189–195.

Pashaee F., Rahmati M.H., Pashaee P., 2008. Study and determination of energy consumption to produce tomato in the greenhouse. In: The 5th National Conference on Agricultural Machinery Engineering and Mechanization. August 27–28, 2008. Mashhad, Iran.

Rafiee S., Mousavi-Avval S.H., Mohammadi A., 2010. Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy, *35*: 3301–3306.

Refsgaard K., Halberg N., Kristensen E.S., 1998. Energy utilization in crop and dairy production in organic and conventional livestock production systems. Agricultural Systems, *57*: 599–630.

Sartori L., Basso B., Bertocco M., Oliviero G., 2005. Energy use and economic evaluation of a three year crop rotation for conservation and organic farming in NE Italy. Biosystems Engineering, *91*: 245–256.

Singh G., Singh S., Singh J., 2004. Optimization of energy inputs for wheat crop in Punjab. Energy Conversion and Management, *45*: 453–465.

Yamane T., 1967. Elementary Sampling Theory. EngleWood Cliffs. New Jersey, Prentice-Hall Inc.

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Corresponding author:

Dr. Ali Mohammadi, University of Tehran, Faculty of Agricultural Engineering and Technology, Department of Agricultural Machinery Engineering, Karaj, Iran
phone: + 98 261 280 1011, fax: + 98 261 280 8138, e-mail: mohammadia@ut.ac.ir