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Sensitivity analysis of energy consumption of durum wheat production

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Abstract

In this study, energy use pattern for durum wheat production in three provinces of Iran, (Khuzestan, Fars and Kerman) was analysed and compared. Data were obtained from 90 farmers using a face to face questionnaire based on random sampling method. Sensitivity analysis of durum wheat operations was carried out using the marginal physical productivity (MPP) technique and partial regression coefficients on output energy. The collected data belonged to the production period of 2012-2013 with the following results obtained. The energy use efficiency varied from 1.64 for Khuzestan to 2.08 for Fars provinces. The results revealed the main difference between the energy consumption in these provinces comes from electricity and chemical fertilizers. The econometric model evaluation showed that the impact of sowing operation in Khuzestan and Fars and impact of fertilization operation in Kerman was significantly positive on output energy. The sensitivity analysis of energy consumption indicated that among the significant operations, sowing and fertilization had the highest MPP values in Khuzestan, Fars and Kerman provinces, respectively. Using renewable energy sources for electricity production, irrigation scheduling, improving the efficiency of water use and using manure instead of chemical fertilizer are some practices to obtain more energy efficiency.

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Introduction

Durum wheat (*Triticum durum* Desf.) is the desired raw material for the worldwide pasta production (DuCros, 1987). Durum wheat denotes 10% of the wheat grown globally, occupying about 11 million hectare in the countries around the Mediterranean Basin. Durum wheat in Iran is cultivated across various environments, ranging from tropical area to cold highlands, but mostly in tropical areas. The success of durum wheat in Iran, as a food security crop, is largely because of its good ability and capacity to yield well under drought-prone and poor management conditions where other crops would fail (Mohammadi *et al.,* 2010).

Agriculture is a process of energy conversion; the conversion of solar energy into food, feed and fiber through photosynthesis (Stout, 1990). The need to increase food production has resulted in the increased energy consumption and natural resources depletion because farmers usually don't use energy in efficient ways (Esengun *et al.,* 2007). Efficient use of energy in agricultural sector is one of the main requirements for sustainable agricultural production. Improving energy use efficiency is becoming more and more important for combating rising energy costs, depletion of natural resources and environmental deterioration (Dovi *et al.,* 2009). Analysis of energy input-output of products allows the energy cost of existing process operations to be compared with that of new or modified production lines (Jekayinfa, 2007). Energy auditing is the numerical comparison of the relationship between input-output of a system or agricultural business in terms of energy units (Gezer *et al.,* 2003). The marginal physical productivity (MPP) technique is one the techniques which is used to evaluate the efficiency of production systems and to determine the sensitivity of a particular energy input on agricultural and food production (Singh *et al.,* 2004). Several researches have been conducted on energy use in wheat production (Singh *et al.,* 2007; Tabatabaeefar *et al.,* 2009; Ali *et al.,* 2013; Rahman and Hasan, 2014).

The main goal of this study was to determine the energy use efficiency per one hectare of durum wheat for three provinces of Iran. Accordingly, this study will provide an opportunity for having a reliable database concerning consumption of various types of energy by different operations and farmers in durum production farms.

Material and methods

Goal and scope

In this study, the data were collected from 90 durum wheat farms in the south and south-west of Iran, Khuzestan (24% of national production), Fars (30%), and Kerman (16%) provinces. Data were collected during the growing period 2012–2013 using face-to-face questionnaires from durum wheat farmers. These studied farms account for 2% of the total durum production of Iran. Farms were randomly selected in the area of study. Average yield of surveyed farms was 5680 kg.ha^{-1}. Table 1 shows statistical information about yield and area of each province farms.

Energy equivalents of inputs and outputs

The energy use efficiency of the durum wheat production has been evaluated by energy indices based on output and input sources. Seeds, herbicides, pesticides, chemical fertilizers, electricity, fuel (diesel and gasoline), human labor, machinery and transportation (from input suppliers to farms) and output yield and straw values of durum wheat have been used for assessing the energy indices. Table 2 summarizes the energy equivalents used for estimation of energy inputs and outputs.

The fuel energy was computed on the basis of total diesel and gasoline consumption (l.ha^{-1}) in different operations such as seedbed preparation, fertilization, spraying irrigation and harvesting. Based on the energy equivalents of inputs and outputs (Table 2), energy indicators such as the energy ratio (ER), energy productivity (EP) and net energy gain (NEG) were calculated as follows (Eq. 1-3) (Heidari and Omid, 2011):

$$\text{Energy use efficiency} = \frac{\text{Energy Output (MJ.ha}^{-1})}{\text{Energy Input (MJ.ha}^{-1})} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield (kg.ha}^{-1})}{\text{Energy Input (MJ.ha}^{-1})} \quad (2)$$

$$\text{Net energy} = \text{Energy Output (MJ.ha}^{-1}) - \text{Energy Input (MJ.ha}^{-1}) \quad (3)$$

In order to estimate and analyze technical efficiencies and productivity of the durum wheat farms, the collected data were analyzed using descriptive statistics and stochastic frontier production (STP) function. The STP was used to estimate the coefficients of the parameters of the production function and also to predict the technical efficiencies (TE) of the durum wheat farms. We selected the Cobb-Douglas (CD) for relation between outputs and various energy inputs as the best function in terms of statistical significance and expected signs of parameters. The CD function has been used in several studies to investigate the relationship between input energies and production yield (Heidari and Omid, 2011, Banaeian *et al.*, 2011).

Accordingly, in this study, the production technology of the farmer was assumed to be specified by the CD production function which is used by (Banaeian *et al.*, 2011). With the assumption that the output energy is a function of energy consumption of operations, linear form of CD production function for durum wheat operations can be expressed as (Eq. 4):

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + \alpha_8 \ln X_8 + e_i \quad (4)$$

where X_j (j= 1, 2, ..., 8) indicated energy consumption of durum wheat operations included seedbed preparation (X_1), sowing (X_2), fertilization (X_3), weed control (X_4), plant protection (X_5), irrigation (X_6), harvesting (X_7) and transportation (X_8). The constant coefficient (α_0) in Eq. (4) is almost zero, because when the operational energy is zero, the durum wheat production is also zero.

Since the marginal product governs the law of production, the marginal physical productivity (MPP) technique, based on the response coefficients of the operations, was used to determine the sensitivity of a particular energy consumption of operations on output energy.

The MPP of various operations were computed using regression coefficients (α_i) of various energy consumptions of operations as given by Eq. (5) (Manes and Singh, 2005):

$$MPP_{xj} = \frac{GM(P)}{GM(E_j)} \times \alpha_j = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \quad (5)$$

where MPP_{xj} marginal physical productivity of j_{th} operation, α_j regression coefficient of j_{th} operation, $GM(P)$ geometric mean of production, $GM(E_j)$ geometric mean of j_{th} operation on farm ($E_{ji} = X_{ij}A_i$), $GM(Y)$ geometric mean of productivity, and $GM(X_j)$ geometric mean of j_{th} input on one hectare basis.

The MPP of a factor input 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 (Manes and Singh, 2005). Negative value of MPP states that it is better to keep it in surplus rather than using it as a fixed resource. A positive value of MPP of any factor indicates that with an increase in operation energy, production is increasing, so, one should not stop increasing the use of variable inputs so long as the fixed resource is not fully utilized (Singh *et al.*, 2004).

Return to scale (RTS) refers to the character of change of the output, when all inputs are changed in equal proportion (Singh *et al.*, 2007). In this study, the RTS values of Eq. (4) were determined by gathering the elasticities, derived in the form of regression coefficients in the CD production function (Singh *et al.*, 2004).

Basic information on energy inputs and energy indices of durum wheat production were entered into Excel 2013 spreadsheets and SPSS 19.0 software program was used for data modelling.

Results and discussion

Analysis of input–output energy use in durum wheat production

Table 3 shows the amount of input and output energy, energy ratio and energy productivity of each province farms. The share of energy inputs for durum wheat production indicated second column of the province.

The most energy consuming inputs for durum wheat production in the different studied farms of Khuzestan, Fars and Kerman were electricity (40.12%), chemical fertilizers (43.94%) and electricity (49.99%), respectively. Energy use efficiency (energy ratio) was calculated as 1.57-2.08, showing the efficiency use of energy in the durum wheat production. Similar results can be seen in studies by Tabatabaeefar *et al.* (2009) and Zangeneh *et al.* (2010).

Table 1. Statistical information of area and province-specific yield.

	Area (ha)			Yield (kg.ha^{-1})		
	Khuzestan	Fars	Kerman	Khuzestan	Fars	Kerman
Min	1	2	1.5	3500	6150	4000
Max	50	16	150	5500	7300	8500
Mean	11.77	8.03	27.07	4653.33	6713.33	5673.33
Standard Deviation	10.70	3.58	34.00	509.04	337.83	1143.10

Energy consumption in different operations per each province has been shown in Table 4 and Fig. 1 to 3. In Fig. 1-3, the center of each box equals the median, the edges of each box represents the 25th and 75th percentiles while the whiskers show the 5th and 95th percentiles.

Table 2. Energy equivalents of inputs and outputs in durum wheat production.

Inputs	Unit	Energy equivalent (MJ.Unit^{-1})	Reference
A. Inputs			
Seed	kg	13	(Kitani, 1999)
Herbicide	kg	238	(Kitani, 1999)
Pesticide	kg	120	(Banaeian and Namdari, 2011)
Chemical fertilizers			
N	kg	78.1	(Kitani, 1999)
P_2O_5	kg	17.4	(Kitani, 1999)
K_2O	kg	13.7	(Kitani, 1999)
Electricity	kWh	11.21	(Pishgar-Komleh *et al.*, 2013)
Fuel	L	47.8	(Kitani, 1999)
Labor	ha	1.96	(Heidari and Omid, 2011)
Equipment	h	129-180	(Kitani, 1999)
Tractor	ha	138	(Kitani, 1999)
Combine	h	116	(Kitani, 1999)
Transportation	t.km	3.6	(Kitani, 1999)
B. Outputs			

Durum Wheat	kg	13	(Kitani, 1999)
Straw	kg	9.25	(Tabatabaeefar *et al.*, 2009)

In Khuzestan province, irrigation was the main source of energy consumption among other operations. The irrigation had also the most variability. Its variability comes from different water sources among studied farms. Most farms in this province (> 67%) used groundwater and others used water from canals. Zangeneh *et al.* (2010) also showed in potato production, irrigation is the main source of energy consumption.

Table 3. Energy inputs and outputs per province.

Production Inputs	Khuzestan		Fars		Kerman	
	Used (MJ.ha^{-1})	Share (%)	Used (MJ.ha^{-1})	Share (%)	Used (MJ.ha^{-1})	Share (%)
Seed	3434.17	8.04	4996.33	9.96	3806.83	6.71
Herbicide	344.03	0.81	379.69	0.76	323.68	0.57
Pesticide	49.00	0.11	84.40	0.17	217.12	0.38
Chemical fertilizers		33.64		43.49		25.69
N	13537.33	31.68	20554.62	40.98	13466.26	23.73
P_2O_5	792.28	1.85	1259.76	2.51	1003.40	1.77
K_2O	43.38	0.10	0.00	0.00	109.60	0.19
Electricity	17141.96	40.12	13835.01	27.58	28370.64	49.99
Fuel	6374.25	14.92	6949.25	13.86	7580.27	13.36
Labor	88.74	0.21	285.38	0.57	165.10	0.29
Equipment	213.98	0.50	245.72	0.49	326.13	0.57
Tractor	215.45	0.50	238.80	0.48	528.72	0.93
Combine	85.98	0.20	182.30	0.36	86.65	0.15
Transportation	407.02	0.95	1144.88	2.28	770.40	1.36
Durum Wheat	60493.33	98.44	87273.33	83.90	73753.33	85.21
Straw	955.83	1.56	16742.50	16.10	12802.00	14.79
Input Energy (MJ.ha^{-1})	42727.59		50156.13		56754.81	
Output Energy (MJ.ha^{-1})	61449.17		104015.83		86555.33	
ER	1.64		2.08		1.57	
EP (Kg.MJ^{-1})	9.22		7.48		10.36	
NEG (MJ.ha^{-1})	18721.58		53859.70		29800.52	

In Fars province, fertilization was the most energy consuming operation (44.16%), followed by irrigation (28.11%). The variability of fertilization operation at this province comes from different rate of nitrogen application after sowing and before harvesting. In the study of Singh *et al.,* (2007) fertilizers had the biggest share among energy inputs.

Table 4. Energy used in different operation of durum wheat production.

Operation	Khuzestan		Fars		Kerman	
	Used (MJ.ha^{-1})	Share (%)	Used (MJ.ha^{-1})	Share (%)	Used (MJ.ha^{-1})	Share (%)
Seedbed preparation	3523.85	8.25	3252.95	6.49	4342.94	7.65
Sowing	3975.72	9.30	5494.67	10.96	4202.83	7.41
Fertilization	14677.30	34.35	22148.27	44.16	14754.33	26.00
Weed control	744.96	1.74	776.19	1.55	752.80	1.33
Plant protection	217.89	0.51	745.85	1.49	947.65	1.67
Irrigation	17208.27	40.27	14100.65	28.11	28501.70	50.22
Harvesting	1809.92	4.24	2110.42	4.21	2109.32	3.72
Transportation	569.67	1.33	1527.12	3.04	1143.23	2.01
Total	42727.59	100.00	50156.13	100.00	56754.81	100.00

In Kerman province farms, irrigation (50.22%) consumed the most energy of total energy input and also was more than other provinces. Because of tropical condition, all studied farms at this province used groundwater from deep wells. The variability of the irrigation operation in this province comes from different irrigation scheduling by farmers.

Econometric model estimation of durum wheat production

At this study Cobb-Douglas (CD) production function was applied to estimate the relationship between energy consumption in different operations and the output energy using Ordinary Least Square (OLS) estimation technique. For this goal it was assumed that the output energy of durum wheat production (endogenous variable) is a function of seedbed preparation, sowing, fertilization, weed control, plant protection, irrigation, harvesting and transportation (exogenous variables). The OLS results for this model is shown in Table 5.

Table 5. Econometric estimation of durum wheat production operations energy consumption.

	Khuzestan			Fars			Kerman		
	α	t-Ratio	MPP	α	t-Ratio	MPP	α	t-Ratio	MPP
Seedbed preparation	0.02	0.18ns	0.37	0.05	0.71ns	1.73	0.40	1.41ns	7.75
Sowing	0.30	3.59*	4.64	0.42	2.68*	7.94	0.47	1.36ns	9.45
Fertilization	0.28	2.46**	1.21	0.43	5.83ns	2.03	0.45	2.65**	2.66
Weed control	0.00	-0.35ns	-0.56	0.08	1.22ns	11.33	-0.06	-0.30ns	-6.38
Plant protection	0.00	0.40ns	1.45	0.02	3.43*	2.73	0.02	0.81ns	7.37
Irrigation	0.00	0.28 ns	0.08	0.40	3.22ns	2.94	-0.16	-1.14ns	-0.51
Harvesting	0.17	0.76 ns	5.77	0.11	8.46*	5.61	0.18	0.61ns	7.43
Transportation	0.07	1.71 ns	9.85	0.06	1.18ns	4.44	0.05	1.37ns	6.52
Durbin-Watson (DW)	1.73			1.89			2.01		
R^2	0.97			0.99			0.96		
Return to scale ($\sum_{n}^{i=1} \alpha_i$)	0.84			1.57			1.35		

ns: not-significant.

* Significant at 1% level.

** Significant at 5% level.

In Khuzestan province, the contributions of sowing and fertilization operations were significant at 1% and 5% levels, respectively. Other operations were not significant at 10% level for durum wheat production. Among significant exogenous variables, sowing had the highest impact (0.30).

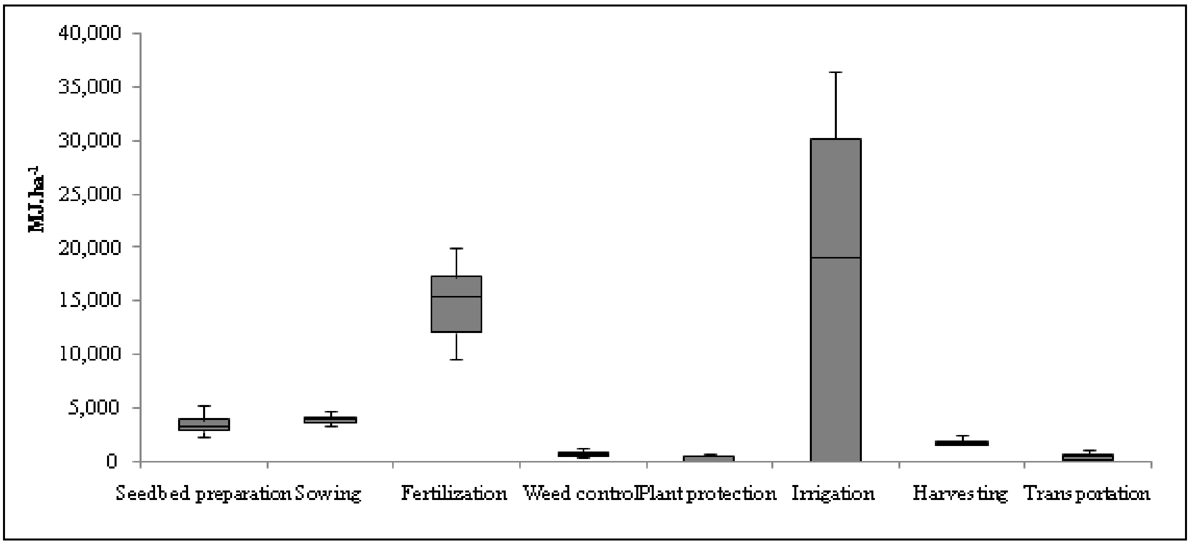

Fig. 1. Variability of energy consumption per each operation for Khuzestan province.

This revealed that 1% additional use of this operation energy would lead to 0.30% increase in output energy. For validating the model, autocorrelation was performed by using Durbin–Watson (DW) test (Hatirli *et al.,* 2005) and the value of this test (1.73) indicated that there was no autocorrelation existing at the 5% significance level in the estimated model. The return to scale (RTS) value was calculated less than unity as 0.84 that implied a 1% increase in the total energy consumption of operations would lead in 0.84 increases in output energy. RTS value less than unity indicate a decreasing RTS for the estimated model. The third column of Table 5 for each province shows the MPP value for all operations. Based on these results, the highest MPP values of significant operations belonged to sowing with MPP values of 4.64.

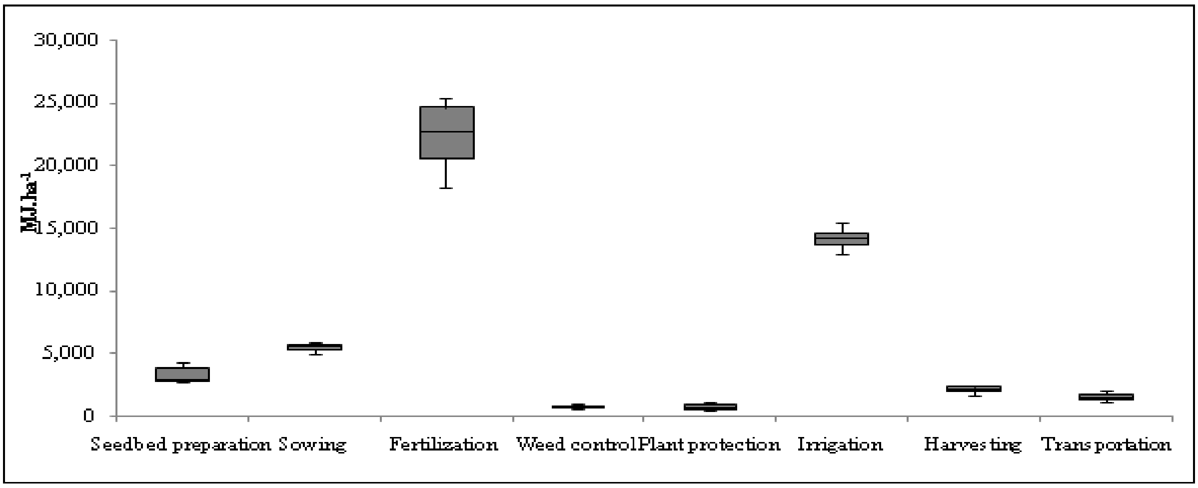

Fig. 2. Variability of energy consumption per each operation for Fars province.

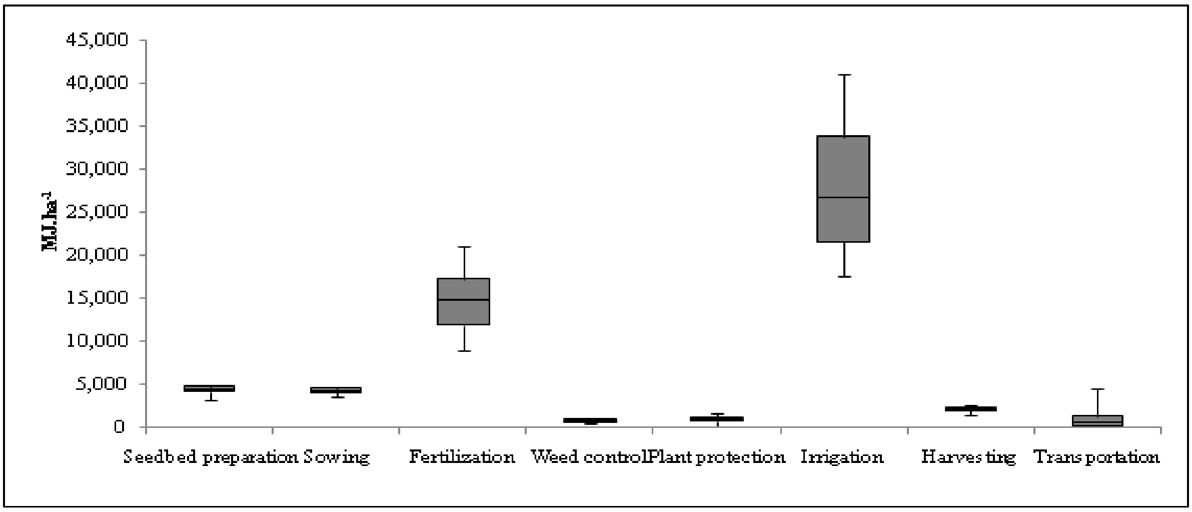

Fig. 3. Variability of energy consumption per each operation for Kerman province.

In Fars province, the contributions of sowing, plant protection and harvesting were significant at 1% level. Among significant exogenous variables sowing had the highest impact (0.42). The value of DW test (1.89) indicated that there was no autocorrelation existing at the 5% significance level in the estimated model. The RTS value was calculated more than unity as 1.57. The highest MPP values of significant operations belonged to sowing and harvesting operations at this province.

In Kerman province, only the contribution of fertilization was significant at 5% level and its impact was 0.45. The value of DW test (2.01) indicated that there was no autocorrelation existing at the 5%

significance level in the estimated model. The RTS value was calculated more than unity as 1.35.

Conclusion

In this study, sensitivity of a particular input energy level on farm output energy of durum wheat production for three provinces of Iran was analyzed. For this purpose, the marginal physical productivity technique, based on the response coefficients of the operations was implemented. Based on the results of the investigations, the following conclusions were drawn:

Khuzestan province

The total energy consumption in durum wheat production was 42728 MJ.ha^{-1}. Among operations, irrigation had the biggest contribution in total energy consumption. Irrigation energy comes from electricity consumption for pumping water from ground wells. The impact of sowing and fertilization operations was significantly positive on output energy. The MPP values of sowing and fertilization were 4.64 and 1.21, respectively.

Fars province: The total energy consumption in durum wheat production was 50156 MJ.ha^{-1}. Chemical fertilizers had the biggest energy consumption among other energy sources with 43.5%. Most of energy consumption of this province came from urea application as additional fertilizer after before and along with irrigation. The impact of sowing, plant protection and harvesting operations were significantly positive on the output energy. The MPP values of these operations were 7.94, 2.73 and 5.61, respectively.

Kerman province: The total energy consumption in durum wheat production was 56755 MJ.ha^{-1}. Among operations, irrigation had the biggest contribution in total energy consumption. Irrigation energy comes from electricity consumption for pumping water from ground wells. The impact of sowing and fertilization operations was significantly positive on output energy. The MPP value of fertilization was 2.66.

Modern and well established scientific practices should be used to obtain more energy efficiency (especially in irrigation and fertilization operations) from durum wheat farming like:

Irrigation scheduling can minimize the total volume of water applied to the durum wheat farm. Irrigation scheduling mostly depends on farmer's decision. Soil moisture content is the irrigation criterion, can help farmers to start the irrigation. For example, when soil water content falls under 70% of the total available soil moisture, irrigation should start.

Improving the efficiency of water use is a second way to save irrigation energy. Water use efficiency is a comparison between the depth of water pumped and the depth stored in the soil where it is available to the plant. Irrigation systems (canals between water pumps and farms) usually lose water to evaporation in the air or directly off plant foliage. One of the suggestions that have used in several provinces of Iran and can be used in studied farms is use of pipe water instead of water canals.

Chemical fertilizers, especially nitrogen, were one the main sources of energy consumption in studied farms. There are some approaches to increasing nitrogen use efficiency: using manure instead of chemical fertilizers, precision application of fertilizer and organic or similar farming methods. Precision farming efforts on matching the nitrogen supplied from chemical fertilizers to the crop need, avoiding the excesses that contribute to nitrogen pollution. Organic farming focuses on building soil quality and soil organic matter, which provides multiple aids including reduced nitrogen loss from the farm. All of these recommendations should be strongly pursued and supported *via* government.

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