Iran Agricultural Research (2020) 39(1) 13-24

Shiraz
University

Tillage effects on energy use and greenhouse gas emission in wheat-cotton rotation

S. Afzalinia

Department of Agricultural Engineering Research, Fars Research and Education Center for Agriculture and Natural Resources, AREEO, Shiraz, I. R. Iran

* Corresponding Author: sja925@mail.usask.ca

DOI:10.22099/IAR.2019.33445.1350

ARTICLE INFO
***Article history*:**
Received **4 May 2019**
Accepted **22 September 2019**
Available online **29 July 2020**

***Keywords*:**
conservation tillage
cotton
energy indices
wheat

ABSTRACT- Crop production process utilizes input energy and produces some biomass energy as output. During this process, greenhouse gases (GHGs) are also emitted which can make environmental risks. In this study, input and output energies, energy indices, and GHG emissions arising from inputs were estimated for wheat-cotton rotation under different tillage practices in Fars province. The study was conducted as a randomized complete plot experimental design with three tillage treatments and four replicates. Tillage methods included conventional tillage (CT), reduced tillage (RT), and no tillage (NT). Results showed that NT and RT decreased energy consumption in wheat and cotton production by 1.53 and 1.19%, respectively as compared to the CT due to less fuel and machinery utilization. More than 72% of energy requirement for wheat and cotton production was consumed by irrigation water and electricity for pumping irrigation water in all tillage methods. Conventional tillage resulted in the highest output energy, energy ratio, and energy productivity in wheat-cotton rotation compared to RT and NT. Total GHG emissions for wheat and cotton production were estimated to be 51829, 51608, and 51529 kg CO_2e ha^{-1} in CT, RT, and NT, respectively indicating that NT and RT slightly reduced GHG emission compared to CT (0.6 and 0.4%, respectively). Results of this study indicated that irrigation showed the highest share in total energy requirement and GHG emission of wheat and cotton production in semi-arid climate condition of Fars province; therefore, total input energy and GHG emissions could be markedly reduced by using more efficient irrigation systems.

INTRODUCTION

Different types of inputs are consumed in production of agriculture crops and some output energies and greenhouse gases (GHGs) are produced in this process. Therefore, in addition to the economic aspects of agricultural products, energy balance in these products and GHG emission arising from inputs are also important. Energy use and productivity of agricultural crops may be affected by crop type. Based on the results of a research conducted in Greece, total energy requirement for cotton production was 82600 MJ ha^{-1} of which the highest share was related to the irrigation and fertilizers (Tsatsarelis, 1991). Energy efficiency, energy intensity, and average input energy for cotton production in Hatay province of Turkey were 2.36, 4.99 MJ kg^{-1}, and 19558 MJ ha^{-1}, respectively from which 40.28% was share of nitrogen fertilizer, 22.37% was share of water for irrigation, and 17.04% was share of diesel-oil (Dagistan et al., 2009). Energy ratio, energy productivity, and total energy consumption for cotton production in Antalya province of Turkey were 0.74, 0.06 kg MJ^{-1}, and 49.73 GJ ha^{-1}, respectively of which diesel fuel had the highest share (31.1%) followed by fertilizer and machinery (Yilmaz et al., 2005). Results of a research showed that energy ratio, energy productivity, and energy input in cotton production in Iran were 1.85, 0.11 kg MJ^{-1}, and 31237 MJ ha^{-1}, respectively of which fertilizer had the highest share followed by diesel fuel and machinery (Pishgar-Komleh et al., 2012).

Based on results of a research conducted by Yildiz (2016), energy use efficiency, specific energy, energy productivity, and net energy gain for wheat production in Samsun province, Turkey were 2.36, 8.96 MJ kg^{-1}, 0.112 kg MJ^{-1}, and 48690.20 MJ ha^{-1}, respectively. Shahin et al. (2008) reported values of 38.36 GJ ha^{-1}, 3.13, and 0.16 kg MJ^{-1} for total utilized energy, energy ratio, and energy productivity, respectively of wheat production in Ardabil province of Iran. The total life cycle energy inputs for soft winter wheat production in Greece ranged from 16 to 26 GJ ha^{-1} and the major energy inputs were fertilizers and fuel (Tsatsarelis, 1993). Values of 80.1 and 38 GJ ha^{-1} were calculated for total input and output energy of wheat production in Esfahan province of Iran and electricity had the highest share of the total input energy in this province (Khoshnevisan et al., 2013). Safa and Samarasinghe

(2011) estimated total energy consumption of 22,566 MJ ha^{-1} for wheat production in Canterbury, New Zealand of which fertilizer with 47% had the highest share of total energy input. Energy input and output for wheat production in New South Wales, Australia were 3028 and 27874 kWh ha^{-1}, respectively (Khan et al., 2010).

Greenhouse gas (GHG) emissions during agricultural crops production have also been evaluated in several research works. About 171 kg carbon dioxide equivalent (CO_2e) was emitted during the production and delivery of one ton of wheat in south-western Australia (Biswas et al., 2008) and N_2O emissions from the soil was the main source of GHG emissions during wheat production in Victoria, Australia (Biswas et al., 2010). Increasing N fertilizer application rate in spring wheat in the Yaqui Valley, Mexico increased N_2O emissions from soil because of low crop N use efficiency at high N fertilizer application rates (Millar et al., 2018). Cotton production in Australia emitted 275 to 1404 kg CO_2e ha^{-1} greenhouse gas to the atmosphere (Chen and Baillie, 2009). Range of 0.38 to 0.92 tons of CO_2e per bale has been reported for cotton production life cycle from farm to shipping port in Australia (Ghareei Khabbaz, 2010). Based on results of a research conducted by Chen et al. (2015), electricity used for water pumping and operating stationary systems was the highest greenhouse gas emitter in Australia. Total GHG emission from cotton production in Iran was 1195 kg CO_2e ha^{-1}, and machinery had the highest emission followed by diesel fuel and irrigation (Pishgar-Komleh et al., 2012).

Energy use and greenhouse gas emission in agricultural crops production may also be affected by tillage methods and planting systems. Chen and Baillie (2009) found that moving from conventional tillage to minimum tillage could save approximately 10% of the overall fuel used on the farm. Ghareei Khabbaz (2010) reported that zero and minimum tillage reduced energy consumption and GHG emission compared to the conventional tillage in cotton production. Chen et al. (2008) found that energy use can be reduced for 20% by using minimum tillage and controlled traffic in Queensland, Australia. Chen et al. (2015) reported that zero tillage decreased energy requirement for grain crops production compared to the conventional tillage in dryland cropping condition of Australia. Reduced and zero tillage methods saved energy for 12% and 24%, respectively compared to the conventional tillage in Northern NSW, Australia (Baillie, 2009). Maraseni and Cockfield (2011) proved that switching from conventional to zero tillage slightly reduced GHG emissions in Queensland, Australia. Zero tillage was the most environmental friendly method among the tillage methods so that it provided the minimum harmful effect on soil and environment (Busari et al., 2015). Conservation tillage practices reduced carbon dioxide emissions and increased nitrous oxide emissions from the soil (Abdalla et al., 2013). Zero tillage significantly reduced the GHG emissions from soil so that net global warming potential under zero tillage was 26-31% lower than under conventional tillage system (Mangalassery et al., 2014). Results of a research conducted in Switzerland showed that there was no significant difference between cumulative N_2O emissions from the soil in reduced and conventional tillage in the grass-clover and winter wheat cropping systems (Krauss et al., 2017). Evaluating tillage and crop rotation effects on GHG emissions in Illinois, USA showed that N_2O emission from chisel tillage in continuous corn cropping system was higher than N_2O emissions from no-tillage in continuous corn, chisel tillage in corn-soybean, and no-tillage in corn-soybean cropping system (Behnke et al., 2018).

Analyzing results of research works conducted in the area of tillage effects on energy use and GHG emissions during agricultural crops production indicated that these effects might be influenced by soil type, climate conditions, and crop type. Therefore, effects of tillage methods on greenhouse gas emissions and energy indices of wheat-cotton cropping system in semi-arid climate condition of Fars province were evaluated in this study.

MATERIALS AND METHODS

Treatments

This research was conducted at the Darab Agricultural Research Station, Fars Research and Education Center for Agriculture and Natural Resources in wheat-cotton rotation from 2010 to 2014. Three tillage methods including no tillage (NT), reduced tillage (RT), and conventional tillage (CT) were arranged as a randomized complete block design with four replications. Wheat (*Triticum aestivum* L.) standing residues (about 2000 kg ha^{-1}) were retained in the plots and loose residues were taken out of the plots. All cotton (*Gossypium arboretum* L.) residues (about 2500 kg ha^{-1}) were chopped using residue thresher and retained in the plots. Primary tillage was performed using a moldboard plow at the soil depth of 25 cm (soil moisture was 14%) followed by a secondary tillage operation using a disk harrow and a land leveler in the conventional tillage, then crop seed was planted using a seed planter. In the reduced tillage, seed bed was prepared using a tine and disc cultivator (POTTINGER, Grieskirchen, Austria) at the soil depth of 15 cm (soil moisture was 14% wet basis) able to complete the primary and secondary tillage operations simultaneously, then crop seed was planted using a seed planter. Direct grain seeder (SEMEATO, Passo Fundo, Brazil) was used to plant wheat and cotton seeds without any seed bed preparation in the no-tillage. Local wheat variety of Chamran with the seed rate of 200 kg ha^{-1} was planted in 20 by 6 m plots in November and harvested in early June of each year. Cotton local variety of Bakhtegan with the seeding rate of 25 kg ha^{-1} was planted with the row space of 0.5 m in late June and harvested in early November of each year. Surface boarder irrigation system was used to irrigate the plots. The field was under wheat-cotton cropping system with tillage treatments trial from June 2010 to June 2014 and average data of four years cropping were considered in this research.

Energy Indices

Sources of input energy for producing wheat and cotton were human labour, farm machinery, electricity for pumping irrigation water, irrigation water, seeds, agrochemicals (fertilizers, herbicides, and pesticides), transportation, and fuel. Output energy sources were crop grain and straw for wheat, and seed and lint for cotton; therefore, output energies were determined by multiplying the crop yield by the energy equivalent (energy coefficient) of produced product. Input energies were obtained by multiplying the amount of input used by the energy equivalent of that specific input shown in Table 1. Input energy related to the farm machinery used in these crops production scheme was obtained using the following equation (Kitani et al., 1999):

$$ME = \frac{M.E}{T.C_a} \tag{1}$$

where *ME* is the share of energy consumed for manufacturing the machinery used in producing crop (MJ ha^{-1}), *T* is machine lifespan (hr), C_a is the machine effective field capacity (ha hr^{-1}), *M* is the machine weight (kg), and *E* is the equivalent energy of material used in machine (MJ kg^{-1}). Energy consumption in irrigation systems included both direct energy (DE) use and indirect energy (IE) use. Direct energy was consumed to lift or pressurize the water required by crop and was calculated using the following equation (Kitani et al., 1999):

$$DE \quad \frac{Q\times\ \rho\times g\times h}{\eta_1\eta_2\times 10^6} \tag{2}$$

where DE is direct energy consumed for water supply (MJ ha^{-1}), ρ is water density (kg m^{-3}), g is gravity acceleration (m s^{-2}), Q is total water supplied to the crop during the growing season (m^3 ha^{-1}), h is pumping dynamic head (m), η_1 is pumping efficiency (0.8), and η_2 is efficiency of energy converting which was considered 0.2 for the electro-pumps. Indirect energy consumption in irrigation process included raw materials, manufacturing, and transportation of elements used in irrigation system. Since calculating this indirect energy was difficult, 18% of direct energy was considered for the surface irrigation system used in this study (Kitani et al., 1999).

After determining input and output energies for wheat and cotton production, energy indices including energy ratio (ER), net energy gain (NEG), specific energy (SE), and energy productivity (EP) were calculated for these crops using the following equations (Pishgar-Komleh et al., 2011):

$$ER = \frac{OE}{IE} \tag{3}$$

$$NEG = OE - IE \tag{4}$$

$$SE = \frac{IE}{Y} \tag{5}$$

$$EP = \frac{Y}{IE} \tag{6}$$

where *OE* is output energy (MJ ha^{-1}), *IE* is input energy (MJ ha^{-1}), and *Y* is crop yield (kg ha^{-1}). In addition to the energy indices, contribution of each input energy, direct, indirect, renewable, and non-renewable energies from the total energy consumption were also determined.

Greenhouse Gas (GHG) Emissions

The GHG emissions arising from farm inputs were estimated using the emission factors associated with each input (Maraseni et al., 2010). Emission of three greenhouse gases including CO_2, N_2O, and CH_4 were estimated in this study and all emissions data were converted into carbon dioxide equivalent (CO_2e) to facilitate the comparison between GHG emissions from different farm practices (Maraseni et al., 2010). To convert N_2O and CH_4 to CO_2e, factors of 298 and 25 were considered, respectively (Maraseni et al., 2010). Greenhouse gas emission estimations included emissions due to the production and combustion of fossil fuels, emissions from the production, packaging, storage, and transportation of agrochemicals, emissions of N_2O from soils due to N-fertilizer application, emissions due to the extraction, production, and use of electricity for crop irrigation, emissions due to the production of farm machineries (Maraseni et al., 2010).

Emissions from Fossil Fuels

Greenhouse gases are emitted from fossil fuels during production, combustion, and transportation of these fuels. Since GHG emissions during the transportation of fuels reported to be negligible (Maraseni et al., 2007), only production and combustion portions were considered in this study. The value of 3.15 kg carbon dioxide equivalent was considered suitable for the total GHG emissions during the production and combustion of 1 liter of diesel (Maraseni et al., 2010). Total diesel consumption for tillage and planting operations in wheat and cotton production were measured in the field, while fuel consumption during fertilizing, spraying and harvesting operations were estimated using data published in literature (Kitani et al., 1999). Then the total fuel consumption was used to estimate the total values of GHG emissions resulting from farm diesel usage.

Emissions from Agrochemicals

Production, packaging, storage, and transportation of agrochemicals (fertilizers and herbicides in this study) require energy; thus, they contribute to GHG emissions. Three types of fertilizers including N, P, and K fertilizers were used during wheat and cotton growing season. Carbon dioxide equivalent emissions for the production, packaging, storage, and transportation of each kg of N, P, and K fertilizers and herbicides were calculated using equivalent carbon emission factors suggested by Lal (2004) and C to CO_2e conversion factor of 3.67, which is the ratio of molecular weight of CO_2 to atomic weight of C. An additional amount of CO_2e emission (1.47 CO_2e kg^{-1}) was also considered for formulation of herbicides as suggested by Lal (2004).

Table 1. Energy equivalent of various inputs

Input	Energy equivalent	Reference	Input	Energy equivalent	Reference
Diesel	47.8 (MJ L^{-1})	(Kitani et al., 1999)	Nitrogen	78.1 (MJ kg^{-1})	(Kitani et al., 1999)
Tractor	138 (MJ kg^{-1})	(Kitani et al., 1999)	Phosphate	17.4 (MJ kg^{-1})	(Kitani et al., 1999)
Combine	116 (MJ kg^{-1})	(Kitani et al., 1999)	Potash	13.7 (MJ kg^{-1})	(Kitani et al., 1999)
Plough	180 (MJ kg^{-1})	(Kitani et al., 1999)	Chemicals	85.5 (MJ L^{-1})	(Kitani et al., 1999)
Disk harrow	149 (MJ kg^{-1})	(Kitani et al., 1999)	transportation	3.0 (MJ $t^{-1}.km^{-1}$)	(Kitani et al., 1999)
Land leveller	133.0 (MJ kg^{-1})	(Kitani et al., 1999)	Wheat grain	13.0 (MJ kg^{-1})	(Kitani et al., 1999)
Seed planter	133.0 (MJ kg^{-1})	(Kitani et al., 1999)	Wheat straw	12.5 (MJ kg^{-1})	(Kitani et al., 1999)
Sprayer	129 (MJ kg^{-1})	(Kitani et al., 1999)	Electricity	12.0 (MJ kWh^{-1})	(Kitani et al., 1999)
Thresher	148.0 (MJ kg^{-1})	(Kitani et al., 1999)	Cotton seed	44.0 (MJ kg^{-1})	(Kitani et al., 1999)
Labour	1.96 (MJ h^{-1})	(Pishgar et al, 2011)	Cotton lint	15.5 (MJ kg^{-1})	(Tsatsarelis, 1991)
Irrigation water	1.02 (MJ m^{-3})	(Shahin et al., 2008)			

Emissions of N_2O from Soil Due to N-Fertilizer Application

Nitrous oxide emission from soil related to N-fertilizer was calculated using the following equation (O'Halloran et al., 2008):

$$E = M \times EF \times C_g \tag{7}$$

where E is the annual nitrous oxide emissions from N-fertilizer (kg N_2O ha^{-1}); M is the mass of fertilizer applied to one hectare of farm (kg N ha^{-1}); EF is the emission factor which is considered 0.021 (kg N_2O-N kg^{-1} N applied) for irrigated crops as suggested by O'Halloran et al. (2008); and C_g is a factor to convert elemental mass of N_2O to molecular mass (44/28=1.57). Then, N_2O emission was multiplied by the conversion factor of 298 to convert this emission into CO_2e.

Emissions Due to Use of Electricity for Crop Irrigation

Water consumed for irrigating wheat and cotton were measured using flow meter and electric energy required for pumping irrigation water was calculated using eq.2. Since there was no data available for emission factors for generating electricity in Iran, the latest factor estimated in Australia (251 kg Co_2e GJ^{-1}) was considered (Anonymous, 2018). In addition to the CO_2e emitted due to electricity energy consumed for pumping irrigation water, emission of 34.5 kg CO_2e ha^{-1} $year^{-1}$ (9.4 kg CE ha^{-1} $year^{-1}$) was considered for installation of surface irrigation system as suggested by Lal (2004).

Emissions Due to the Production of Farm Machineries

Greenhouse gas emissions resulted from production of farm machineries were calculated using the following equation (Maraseni et al., 2007):

$$GHG_{fm} = W \times GHG_i \times F \tag{8}$$

where GHG_{fm} is total GHG emissions due to production of farm machinery (kg CO_2e ha^{-1}), W is weight of machine (kg), and F is the portion of lifespan of the machine used for a given farm activities which is defined as $F = \frac{1}{L \times Ca_e}$ [L is machine lifespan (hr) and Ca_e is machine effective field capacity ($ha\ hr^{-1}$)]. Energy required to produce one kilogram of each farm machine used in wheat-cotton cropping system was extracted from Kitani et al. (1999) in MJ kg^{-1} and then converted to kWh kg^{-1} (divided by 3.6). The resulted energy in kWh kg^{-1} was multiplied by 0.411(CO_2e GHGs emission for producing one kWh energy based on data provided by Maraseni et al. (2007)) to obtain the CO_2e GHGs emitted into the atmosphere while producing each kg of machinery (GHG_i in eq. 8). Total GHG emissions were calculated as summation of emitted GHGs from different sources and GHG emission intensity was obtained using the following equation:

$$GHGI = {}^{TGHG}/_{Y} \tag{9}$$

where $GHGI$ is greenhouse gas emission intensity (kg CO_2e kg^{-1} product), $TGHG$ is total GHG emission (kg CO_2e ha^{-1}), and Y is crop yield (kg ha^{-1}).

RESULTS AND DISCUSSION

Energy Use

The maximum energy requirement in wheat production was related to CT treatment (104776 MJ ha^{-1}) followed by RT (103014 MJ ha^{-1}) and NT (102530 MJ ha^{-1}) treatments (Table 2). No-tillage and reduced tillage decreased energy consumption in wheat production for 2.14 and 1.68%, respectively compared to the conventional tillage mostly because of less fuel and machinery utilization. Lower energy requirement of grain crops production under zero tillage compared to the conventional tillage in dryland cropping condition of Australia was also reported by Chen et al. (2015). Electricity for pumping irrigation water with more than 57% had the highest contribution in the total energy requirement for wheat production in all the tillage methods followed by agrochemicals (more than 15%). In all tillage methods, more than 65% of total energy requirement for wheat production was related to the irrigation operations including irrigation water and electricity required for pumping irrigation water, while labor had the lowest share (0.12%) in energy consumption. More than 68% of energy consumed in wheat production was direct energy which slightly decreased in RT and NT treatments compared to the CT treatment.

Table 2. Energy inputs in wheat production under different tillage methods

Inputs	CT*		RT**		NT***	
	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)
Fuel	3250.4	3.10	1912.0	1.86	1510.5	1.47
Electricity	60257.9	57.51	60257.9	58.49	60257.9	58.77
Irrigation water	8353.8	7.97	8353.8	8.11	8353.8	8.15
Machinery	11892.3	11.35	11480.3	11.14	11312.3	11.03
Agrochemicals	16619.2	15.86	16790.2	16.30	16918.4	16.50
Seeds	2600.0	2.48	2600.0	2.52	2600.0	2.54
Labour	129.4	0.12	123.5	0.12	121.5	0.12
Transportation	1673.5	1.60	1496.5	1.45	1455.3	1.42
Total input	104776.4	100.00	103014.2	100.00	102529.7	100.00
Direct energy	71991.5	68.71	70647.2	68.58	70243.7	68.51
Indirect energy	32784.9	31.29	32367.0	31.42	32286.0	31.49
Renewable energy	8483.2	8.10	8477.3	8.23	8475.3	8.27
Non-renewable energy	96293.2	91.90	94536.9	91.77	94054.4	91.73

* Conventional tillage, ** Reduced tillage, *** No tillage

More than 91% of energy required for wheat production was nonrenewable energy; however, share of renewable energy was slightly higher in the RT and NT treatments compared to the CT treatment. Shahin et al. (2008) reported a total energy consumption of 38360 MJ ha^{-1} for wheat production in Ardabil province of Iran which was much lower than what we found in this research in Fars province probably because of a big difference in climate conditions of these two provinces. Wheat production in Ardabil province with cold climate condition requires less irrigation water and consequently less input energy. Furthermore, Khoshnevisan et al. (2013) reported a total input energy of 80100 MJ ha^{-1} for Esfahan province of Iran which was closer to what we found in this study in Fars province because of similar climate condition of Esfahan and Fars provinces. Likewise what we found for Fars province in this study, electricity had the highest share of total input energy in Esfahan province (Khoshnevisan et al., 2013).

Conventional, reduced, and no-tillage had output energies of 129877, 115264, and 111877 MJ ha^{-1}, respectively in wheat production (Table 3); therefore, conventional tillage increased output energy compared to the reduced and no-tillage for 11.3 and 13.9%, respectively because of its higher grain and straw yields. Khoshnevisan et al. (2013) reported output energy of 38040 MJ ha^{-1} for wheat production in Esfahan province which was much lower than what we found in this research because of ignoring energy produced by wheat straw in that research. Net energy gain was positive for all tillage methods which showed that all tillage methods produced more energy compared to their energy consumption. Conventional tillage had the highest net energy gain followed by NT and RT due to its higher output energy. The highest energy ratio and energy productivity (1.24 and 0.098 kg MJ^{-1}, respectively) were also related to the conventional tillage followed by RT and NT. Input energy of 10.3 MJ was necessary to produce one-kilogram wheat grain and straw in conventional tillage (specific energy); while, energy consumed for producing one-kilogram wheat grain and straw in NT and RT were 12.1 and 11.5 MJ, respectively. These results showed that conservation tillage methods (NT and RT) in spite of reducing total input energy did not increase net energy gain, energy ratio, and energy productivity because of their lower crop yield and consequently lower output energy. Shahin et al. (2008) reported energy efficiency and productivity of 3.13 and 0.16 kg MJ^{-1}, respectively, for wheat production in Ardabil province which were much higher than what we obtained in this study because of lower energy requirement of wheat production in Ardabil province.

The maximum input energy requirement in cotton production (182270 MJ ha^{-1}) was related to the conventional tillage followed by reduced tillage (180607 MJ ha^{-1}) and no-tillage (180115 MJ ha^{-1}) methods (Table 4). Therefore, reduced tillage and no-tillage decreased energy consumption in cotton production by 1.0 and 1.2%, respectively, compared to the conventional tillage mostly due to reduction in fuel and machinery energies. Results of a research conducted in Australia also proved savings of 12 and 24% in input energy by adopting reduced and zero tillage, respectively, as compared to the conventional tillage in cotton production (Baillie, 2009). Energy requirements for cotton production in all tillage methods were much higher than the energy requirements of wheat production (at least 73% higher) mostly because of higher water consumption of cotton as a summer crop compared to wheat as a winter crop. Tsatsarelis (1991) reported a total energy requirement of 82600 MJ ha^{-1} for cotton production in Greece. A total input energy of 31237 MJ ha^{-1} was also reported for cotton production in Alborz province, Iran (Pishgar-Komleh *et al.*, 2012) which was much lower than what we found in this study. The reason was the very low amount of water consumption considered for cotton production in Alborz province (3450 m^2 compared to 16483 m^2 consumed in this study) and probably the difference in water supply system and source. Electricity used for pumping irrigation water had the highest share of the total input energy in all the tillage methods in this study and accounted for 66.54, 67.15, and 67.33% in CT, RT, and NT methods, respectively, followed by machineries. Irrigation and fertilizers had the highest share of input energy in cotton production in Greece (Tsatsarelis, 1991), while fertilizers with 30% of total energy had the highest share in energy requirement of cotton production in Alborz province followed by diesel fuel with 22% of total energy (Pishgar Komleh *et al.*, 2012). Share of direct energy in cotton production was more than 77.8% of total energy compared to the contribution of indirect energy which was less than 22.2% of total energy in all tillage methods. Furthermore, more than 90% of consumed energy in cotton production in all tillage methods was nonrenewable energy. Results of this study also showed that contribution of nonrenewable energy from cotton total energy consumption slightly decreased in NT and RT compared to the CT which could be considered as positive effect of conservation tillage on energy consumption in cotton.

Based on results presented in Table 5, reduced tillage had the highest output energy in cotton production (94566 MJ ha^{-1}) compared to those of CT (93503 MJ ha^{-1}) and NT (91373 MJ ha^{-1}). In addition to reducing input energy, RT increased output energy in cotton production compared to the conventional tillage by 1.12% which showed that energy use efficiency in cotton production could be improved with replacing conventional tillage by reduced tillage. Total output energy of 59165 MJ ha^{-1} has been reported for cotton production in Alborz province (Pishgar Komleh et al., 2012) which was much lower than what we found in this study. The reason was the lower energy equivalent (coefficient) considered for cotton seed (18 MJ kg^{-1}) by Pishgar Komleh *et al.* (2012) compared to the energy equivalent considered in this study (44 MJ kg^{-1}). Reduced tillage had also the maximum net energy gain, energy ratio, and energy productivity compared to CT and NT; while, the values of these indices were very close together in CT and NT. Net energy gains were negative and consequently ERs were less than one in all tillage schemes showing that energy consumption was higher than the energy generation in cotton production process; therefore, energy balance for cotton production in semi-arid climate condition of Fars province was negative. More than 66 MJ energy was required to produce one-kilogram cotton seed and lint in all tillage methods which is a huge amount of energy (Table 5). Pishgar-Komleh et al. (2012) reported values of 1.85 and 0.11 kg MJ^{-1} for energy use efficiency and energy productivity of cotton production in Alborz province which were higher than those we found in this study because of higher energy consumption of cotton found in this study. Cotton production showed lower energy efficiency and energy productivity compared to wheat production in all tillage methods because of higher energy consumption in cotton.

Table 3. Energy indices in wheat production under different tillage methods

Treatments	*IE*[1] (MJ ha^{-1})	*OE*[2] (MJ ha^{-1})	*NEG*[3] (MJ ha^{-1})	*ER*[4]	SE[5] (MJ kg^{-1})	*EP*[6] (kg MJ^{-1})
CT*	104776	129877	25101	1.24	10.3	0.098
RT**	103014	115264	12250	1.12	11.5	0.088
NT***	102530	111877	9347	1.09	12.1	0.086

* Conventional tillage, ** Reduced tillage, *** No tillage. [1]Input energy, [2]Output energy, [3]Net energy gain, [4]Energy ratio, [5] Specific energy, [6]Energy productivity.

Table 4. Energy inputs in cotton production under different tillage methods

Inputs	CT*		RT**		NT***	
	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)
Fuel	2915.8	1.60	1577.4	0.87	1175.9	0.65
Electricity	121273.7	66.54	121273.7	67.15	121273.7	67.33
Irrigation water	16812.7	9.22	16812.7	9.31	16812.7	9.33
Machinery	22580.5	12.39	22168.5	12.27	22000.5	12.21
Agrochemicals	16319.9	8.95	16319.9	9.04	16319.9	9.06
Seeds	1100.0	0.60	1100.0	0.61	1100.0	0.61
Labour	752.6	0.41	840.8	0.47	933.0	0.52
Transportation	514.9	0.28	514.4	0.28	499.7	0.28
Total input	182270.0	100.00	180607.3	100.00	180115.2	100.00
Direct energy	141754.8	77.77	140504.6	77.80	140195.2	77.84
Indirect energy	40515.3	22.23	40102.7	22.20	39920.1	22.16
Renewable energy	17565.3	9.64	17653.5	9.77	17745.6	9.85
Non-renewable energy	164704.7	90.36	162953.8	90.23	162369.6	90.15
Fuel	2915.8	1.60	1577.4	0.87	1175.9	0.65
Electricity	121273.7	66.54	121273.7	67.15	121273.7	67.33

* Conventional tillage, ** Reduced tillage, *** No tillage

Table 5. Energy indices in cotton production under different tillage methods

Treatments	*IE*^{1} (MJ ha^{-1})	*OE*^{2} (MJ ha^{-1})	*NEG*^{3} (MJ ha^{-1})	*ER*^{4}	SE^5 (MJ kg^{-1})	*EP*^{6} (kg MJ^{-1})
CT*	182270	93503	-88767	0.51	68.6	0.015
RT**	180607	94566	-86042	0.52	66.9	0.015
NT***	180115	91373	-88742	0.51	71.8	0.015

* Conventional tillage, ** Reduced tillage, *** No tillage. ^{1}Input energy, ^{2}Output energy, ^{3}Net energy gain, ^{4}Energy ratio, ^{5} Specific energy, ^{6}Energy productivity.

Total energy consumption of 287046 MJ ha^{-1} was calculated in conventional tillage, 283622 MJ ha^{-1} in reduced tillage, and 282645 MJ ha^{-1} in no-tillage for whole wheat-cotton cropping year (Table 6). Therefore, no-tillage and reduced tillage decreased energy consumption for 1.53 and 1.19%, respectively compared to the conventional tillage in whole wheat-cotton cropping year. Irrigation water and electricity for pumping irrigation water consumed more than 72% of total energy requirement for wheat and cotton production in all tillage methods; therefore, total energy requirement can be significantly reduced by using more efficient irrigation systems such as sprinkler and drip irrigation. Machineries input consumed about 12% of total energy requirement in wheat-cotton cropping system most of which was related to the irrigation facilities such as pipes, water pumps, pumping power source, and buildings. After machineries, agrichemicals (fertilizers and herbicides) consumed more than 11% of total input energy and had the third place in energy usage during whole wheat-cotton cropping year; thus, utilizing high quality fertilizers and efficient application methods are the other potential ways to reduce total energy consumption. On the other hand, renewable energy share from the total consumed energy was only 9% which showed that about 91% of energy consumed was fossil fuel-based energy. Therefore, using renewable energy sources such as solar energy (environment friendly energies) could reduce the share of nonrenewable energy (fossil fuel-based energy) from the total consumed energy.

Conventional tillage with 223380 MJ ha^{-1} had the maximum output energy in whole wheat-cotton cropping year followed by RT (209830 MJ ha^{-1}) and NT (203251 MJ ha^{-1}), consequently CT had the highest net energy gain (-63667 MJ ha^{-1}) in wheat and cotton production (Table 7). Output energy in CT was 9.0 and 6.1% higher than those of NT and RT practices due to higher wheat yield in CT. Net energy gains in all tillage methods were negative (energy ratios of less than one) indicating that generated energy was less than consumed energy in wheat-cotton cropping system due to high input energy and low output energy of cotton production. The maximum energy ratio and energy productivity was also related to the conventional tillage because of its higher yield and output energy. On the other hand, energy consumed for producing one kilogram dry matter in wheat-cotton rotation was more than 22 MJ in all tillage methods suggesting that efforts should be made to reduce specific energy (energy intensity) in wheat-cotton cropping system.

Greenhouse Gas Emissions

Total GHG emissions of 18328, 18242, and 18233 kg CO_2e ha^{-1} were calculated in wheat production for CT, RT, and NT, respectively which showed that conservation tillage methods (RT and NT) slightly reduced GHG emissions compared to the conventional tillage (Table 8). Greenhouse gas emissions in NT and RT were 0.52 and 0.47% lower than in CT mostly due to a lower fossil fuels and machineries consumption. Maraseni and Cockfield (2011) found that the net effect of switching from conventional to zero tillage on GHG emissions during grain crops production in Queensland, Australia was positive but relatively small.

Table 6. Energy inputs for whole wheat-cotton cropping year under various tillage methods

Inputs	CT*		RT**		NT***	
	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)	Energy consumed (MJ ha-1)	Share (%)
Fuel	6166.2	2.15	3489.4	1.23	2686.4	0.95
Electricity	181531.6	63.24	181531.6	64.00	181531.6	64.23
Irrigation water	25166.5	8.77	25166.5	8.87	25166.5	8.90
Machinery	34472.7	12.01	33648.7	11.86	33312.7	11.79
Agrochemicals	32939.1	11.47	33110.1	11.68	33238.3	11.76
Seeds	3700.0	1.29	3700.0	1.30	3700.0	1.31
Labour	882.0	0.31	964.3	0.34	1054.5	0.37
Transportation	2188.4	0.76	2010.9	0.71	1955.0	0.69
Total input	287046.4	100.00	283621.5	100.00	282645.0	100.00
Direct energy	213746.3	74.46	211151.8	74.45	210438.9	74.45
Indirect energy	73300.2	25.54	72469.7	25.55	72206.1	25.55
Renewable energy	26048.5	9.07	26130.8	9.21	26220.9	9.28
Non-renewable energy	260998.0	90.93	257490.7	90.79	256424.0	90.72

* Conventional tillage, ** Reduced tillage, *** No tillage

Table 7. Energy indices in whole wheat-cotton cropping year under different tillage methods

Treatments	IE^1 (MJ ha^{-1})	OE^2 (MJ ha^{-1})	NEG^3 (MJ ha^{-1})	ER^4	SE^5 (MJ kg^{-1})	EP^6 (kg MJ^{-1})
CT*	287046a	223380a	-63667a	0.78a	22.4a	0.045a
RT**	283622b	209830a	-73791b	0.74a	24.1a	0.042a
NT***	282645c	203251a	-79394c	0.72a	25.0a	0.041a

* Conventional tillage, ** Reduced tillage, *** No tillage. [1]Input energy, [2]Output energy, [3]Net energy gain, [4]Energy ratio, [5] Specific energy, [6] Energy productivity.

Table 8. Emission of GHG in wheat production under different tillage methods

Emission sources	CT*		RT**		NT***	
	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)
Fossil fuels	214.20	1.17	126.00	0.69	99.54	0.55
Agrochemicals	1044.30	5.70	1093.48	5.99	1130.36	6.20
N_2O from N-fertilizer	1807.81	9.86	1807.81	9.91	1807.81	9.91
Electricity and irrigation system installation	15142.56	82.62	15142.56	83.01	15142.56	83.05
Production of farm machineries	119.44	0.65	72.38	0.40	53.20	0.29
Total	18328.31	100.00	18242.23	100.00	18233.47	100.00
GHG emission intensity (kg CO_2e kg^{-1})	1.79		2.01		2.07	

* Conventional tillage, ** Reduced tillage, *** No tillage

More than 82% of total emitted GHGs in all tillage methods were related to electricity for water pumping and irrigation system installation; therefore, GHG emissions in wheat production could be significantly reduced by using more efficient irrigation systems such as sprinkler and drip irrigations. Results of this study also showed that 1.79, 2.01, and 2.07 kg CO_2e have been emitted for production of one kg wheat grain and straw in CT, RT, and NT, respectively. These results revealed that however conservation tillage methods slightly reduced the total GHG emission per unit area compared to the conventional tillage method, GHG emission per unit product (CO_2e kg^{-1} which is more accurate criterion compared to total GHG emission) was still higher in conservation tillage compared to the conventional tillage because of lower crop yield in conservation tillage.

Total GHG emissions for cotton production were 33501, 33365, and 33295 kg CO_2e ha^{-1} in CT, RT, and NT, respectively which were 83% higher than those of tillage methods in wheat production (Table 9). Higher GHG emissions in cotton production compared to wheat production was mostly because of higher water consumption in cotton as a summer crop. In cotton production also, conservation tillage methods slightly decreased GHG emissions compared to the conventional tillage mostly because of lower fuel consumption. Pishgar-Komleh et al. (2012) reported GHG emission of 1195 kg CO_2e ha^{-1} for cotton production in Alborz province of Iran which was significantly smaller than what we found in this study because of low water requirement of cotton in Alborz province and considering only some sources of GHG emission in that province. Based on results reported by Chen and Baillie (2009), cotton production in Australia emitted 275 to 1404 kg CO_2e ha^{-1} to atmosphere, while Ghareei Khabbaz (2010) reported the GHG emission rage of 0.38 to 0.92 tons CO_2e per bale for cotton production life cycle from farm to shipping port in Australia. Basically, comparing GHG emitted from the same crop production in different countries and even different parts of each country is difficult because of different inputs utilized, specially the amount of irrigation water requirements and irrigation systems used. Electricity for water pumping and irrigation system installation emitted more than 90% of total GHG emission during cotton production in all tillage methods showing that irrigation was the most significant source of pollution during cotton production. Electricity used for water pumping and operating stationary systems was the highest greenhouse gas emitter in Australia (Chen et al., 2015), while machinery had the highest share from the total GHG emissions in Alborz province (Pishgar-Komleh et al., 2012).

The lowest share from the total GHG emission was related to the production of farm machineries. Results of GHG emission intensity revealed that despite having higher GHG emission, conventional tillage had lower GHG intensity (12.44 kg CO_2e per kg product) compared to the no-tillage in cotton production due to higher crop yield. The lowest GHG intensity (12.26 kg CO_2e per kg product) was related to the reduced tillage. Emission of more than 12 kg CO_2e for producing one kg cotton showed that urgent efforts should be made to reduce GHG intensity during cotton production. Since the main source of this high GHG intensity is irrigation operation, the most effective action is replacing the surface irrigation with more efficient methods such as sprinkler and drip irrigation methods.The total GHG emissions of 51829, 51608, and 51529 kg CO_2e ha^{-1} were calculated for wheat and cotton production in conventional, reduced, and no tillage methods, respectively (Table 10).

Table 9. Emission of GHG in cotton production under different tillage methods

Emission sources	CT*		RT**		NT***	
	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)
Fossil fuels	192.15	0.57	103.95	0.31	77.49	0.23
Agrochemicals	958.24	2.86	958.24	2.87	958.24	2.88
N_2O from N-fertilizer	1807.81	5.40	1807.81	5.42	1807.81	5.43
Electricity and irrigation system installation	30457.07	90.91	30457.07	91.28	30431.97	91.40
Production of farm machinery	85.79	0.26	38.74	0.12	19.55	0.06
Total	33501.06	100.00	33365.81	100.00	33295.06	100.00
GHG emission intensity (kg CO_2e kg^{-1})	12.44		12.26		12.66	

* Conventional tillage, ** Reduced tillage, *** No tillage

Table 10. Emission of GHG in cotton production under different tillage methods

Emission sources	CT*		RT**		NT***	
	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)	GHG emission (kg CO_2e ha^{-1})	Share (%)
Fossil fuels	192.15	0.57	103.95	0.31	77.49	0.23
Agrochemicals	958.24	2.86	958.24	2.87	958.24	2.88
N_2O from N-fertilizer	1807.81	5.40	1807.81	5.42	1807.81	5.43
Electricity and irrigation system installation	30457.07	90.91	30457.07	91.28	30431.97	91.40
Production of farm machinery	85.79	0.26	38.74	0.12	19.55	0.06
Total	33501.06	100.00	33365.81	100.00	33295.06	100.00
GHG emission intensity (kg CO_2e kg^{-1})	12.44		12.26		12.66	

* Conventional tillage, ** Reduced tillage, *** No tillage

Electricity for water pumping and irrigation system installation with more than 88% had the highest contribution in total GHG emission in all tillage methods followed by N_2O emission from N-fertilizer. Results of Greenhouse emission intensity revealed that more than 4 kg CO_2e was emitted during producing one kg dry matter in wheat-cotton rotation which was a high GHG intensity.

CONCLUSIONS

Energy use and GHG emissions in wheat-cotton rotation under different tillage methods were evaluated in this study. The following conclusions can be drawn from results of this research:

Both wheat and cotton had the maximum energy consumption under conventional tillage in such a way that energy consumption in conservation tillage methods (NT and RT) was at least 1.2% less than that of conventional tillage because of less diesel fuel and machinery utilization. Irrigation operations including irrigation water and electricity required for pumping irrigation water consumed more than 72% of the total energy required for both crop productions in all tillage methods showing that irrigation could be the main target of energy saving strategies that should be focused on.

Conventional tillage had the highest output energy, net energy gain, energy efficiency, and energy productivity compared to NT and RT in wheat-cotton cropping system; however, NEG was negative and EUE was smaller than one in all tillage methods showing that generated energy in this process was lower than consumed energy (negative energy balance).

Despite having lower energy use compared to conventional tillage, RT and NT did not increase energy efficiency and productivity in wheat-cotton cropping system because of their lower crop yields and consequently lower output energies.

Energy requirements for cotton production in all tillage methods were higher than those of wheat production mostly because of higher water consumptions of cotton as a summer crop. On the other hand, energies generated during cotton production were lower than those generated during wheat production due to low cotton seed yield and eliminating cotton residues in output energy calculation.

In spite of reducing total GHG emissions in conservation tillage methods (NT and RT) compared to the conventional tillage method, conservation tillage methods had higher GHG emission intensities (GHG emitted per kg product) compared to the conventional tillage in wheat-cotton cropping system mostly because of lower crop yields in these tillage methods. Around 88% of total GHG were generated by irrigation operations (electricity for water pumping and irrigation system installation) in wheat-cotton cropping system which indicated that the GHG reduction strategies should be concentrated on using more efficient irrigation methods for this cropping system in semi-arid climate condition of Fars province.

Total GHG emissions for cotton production in CT, RT, and NT were about 83% higher than those for wheat production mostly because of higher water consumption of cotton as a summer crop.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support from the Agriculture Organization of Fars province and Iranian Agricultural Engineering Research Institute.

REFERENCES

Abdalla, M., Osborne, B., Lanigan, G., Forristal, D., Williams, M., Smith, P., & Jones, M. B. (2013). Conservation tillage systems: A review of its consequences for greenhouse gas emissions. *Soil Use and Management*, 29, 1-11.

Anonymous. (2018). Australian National Greenhouse Accounts: National Greenhouse Accounts Factors. Canberra: Commonwealth of Australia. Retrieved from: http://creativecommons.org/licenses/by/3.0/au.

Baillie, C. (2009). Energy and carbon accounting case study on Keytah, a project report for the Cotton Research and Development Corporation (CRDC). National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba. Retrieved from: https://eprints.usq.edu.au/23248/1/Keytah_Case_Study_Report.pdf.

Behnke, G. D., Zuber, S. M., Pittelkow, C. M., Nafziger, E. D., & Villamil, M. B. (2018). Long-term crop rotation and tillage effects on soil greenhouse gas emissions and crop production in Illinois, USA. *Agriculture, Ecosystems and Environment*, 261, 62–70.

Biswas, W. K., Barton, L., & Carter, D. (2008). Global warming potential of wheat production in Western Australia: a life cycle assessment. *Water and Environment Journal*, 22, 6-16.

Biswas, W. K., Graham, J., Kelly, K., & John, M. B. (2010). Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia: a life cycle assessment. *Journal of Cleaner Production*, 18 (14), 1386-1392.

Busaria, M. A., Kukal, S. S., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3, 119–129.

Chen, G, & Baillie, C. (2009). Development of a framework and tool to assess on-farm energy uses of cotton production. *Energy Conversion and Management*, 50(5), 1256-1263.

Chen, G., Kupke, P., & Baillie, C. (2008). Opportunities to enhance energy efficiency and minimise greenhouse gases in Queensland's intensive agricultural sector. National Centre for Engineering in Agriculture, Publication 1002801/1, USQ, Toowoomba.

Chen, G., Maraseni, T., Banhazi, T., & Bundschuh, J. (2015). Benchmarking energy use on farm. Rural Industries Research and Development Corporation (RIRDC) Publication No 15/059.

Dagistan, E., Akcaoz, H., Demirtas, B., & Yilmaz, Y. (2009). Energy usage and benefit-cost analysis of cotton production in Turkey. *African Journal of Agricultural Research*, 4 (7), 599-604.

Ghareei Khabbaz, B. (2010). Life cycle energy use and greenhouse gas emissions of Australian cotton: impact of farming systems. M.Sc. thesis, University of Southern Queensland, Australaia.

Khan, S., Khan, M. A., & Latif, N. (2010). Energy requirements and economic analysis of wheat, rice and barley production in Australia. *Soil and Environment*, 29(1), 61-68.

Khoshnevisan, B., Rafiee, Sh., Omid, M., Yousefi, M., & Movahedi, M. (2013). Modelling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. *Energy*, 52, 333-338.

Kitani, O., Jungbluth, T., Peart, R. M., & Ramdani, A. (1999). *CIGR Handbook of Agricultural Engineers, vol. V: Energy and Biomass Engineering* (1st ed.). MI.: American Society of Agricultural Engineers (ASAE) Publication.

Krauss, M., Ruser, R., Müllerb, T., Hansen, S., Mädera, P., & Gattinger, A. (2017). Impact of reduced tillage on greenhouse gas emissions and soil carbon stocks in an organic grass-clover ley-winter wheat cropping sequence. *Agriculture, Ecosystems and Environment*, 239, 324-333.

Lal, R. (2004). Carbon emission from farm operation. *Environment International*, 30: 981-990.

Mangalassery, Sh., Sofie Sjögersten, S., Sparkes, D. L., Sturrock, C. J., Craigon, J., & Mooney, S. J. (2014). To what extent can zero tillage lead to a reduction in greenhouse gas emissions from temperate soils? *Scientific Reports*, 4, 1-8.

Maraseni, T. N, & Cockfield, G. (2011). Does the adoption of zero tillage reduce greenhouse gas emissions? An assessment for the grains industry in Australia. *Agriculture Systems*, 104, 451-458.

Maraseni, T. N, Cockfield, G., and Apan, A. (2007). A comparison of greenhouse gas emissions from inputs into farm enterprises in Southeast Queensland, Australia. *Journal of Environmental Science and Health, Part A*, 42, 11-19.

Maraseni, T. N, Cockfield, G., & Maroulis, J. (2010). An assessment of greenhouse gas emissions: implications for the Australian cotton industry. *Journal of Agricultural Science*, 148, 501-510.

Millar, N., Urrea, A., Kahmark, K., Shcherbak, I., Robertson, G. P., & Ortiz-Monasterio, I. (2018). Nitrous oxide (N_2O) flux responds exponentially to nitrogen fertilizer in irrigated wheat in the Yaqui Valley, Mexico. *Agriculture, Ecosystems and Environment*, 261, 125–132.

O'Halloran, N. J., Fisher, P. D., & Rab, M. A. 2008. Vegetable industry carbon footprint scoping study preliminary estimation of the carbon footprint of the Australian vegetable industry. Discussion Paper 4. Sydney: Horticulture Australia Ltd.

Pishgar-Komleh, S. H., Keyhani, A., Rafiee, Sh., & Sefeedpary, P. (2011). Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran. *Energy,* 36, 3335-3341.

Pishgar-Komleh, S. H., Sefeedpari, P., & Ghahderijani, M. (2012). Exploring energy consumption and CO_2 emission of cotton production in Iran. *Journal of Renewable and Sustainable Energy*, 4, 1-14.

Safa, M., & Samarasinghe, S. (2011). Determination and modelling of energy consumption in wheat production using neural networks: A case study in Canterbury province, New Zealand. *Energy*, 36 (8), 5140-5147.

Shahin, S., Jafari, A., Mobli, H., Rafiee, S., & Karimi M. (2008). Effect of farm size on energy ratio for wheat production: A case study from Ardabil province of Iran. *American-Eurasian Journal of Agricultural and Environmental Science,* 3 (4), 604-608.

Tsatsarelis, C. A. (1991). Energy requirements for cotton production in central Greece. *Journal of Agricultural Engineering Research*, 50, 239-246.

Tsatsarelis, C. A. (1993). Energy inputs and outputs for soft winter wheat production in Greece. *Agriculture, Ecosystems and Environment*, 43(2), 109-118.

Yilmaz, I., Akcaoz, H., & Ozkan, B. (2005). An analysis of energy use and input costs for cotton production in Turkey. *Renewable Energy*, 30, 145–155.

Yildiz, T. (2016). An input-output energy analysis of wheat production in Çarşamba district of Samsun province. *Journal of Agricultural Faculty of Gaziosmanpasa University*, 33(3), 10-20.

تحقیقات کشاورزی ایران (۱۳۹۹) ۳۹(۱) ۱۳-۲۴

اثر خاک ورزی بر مصرف انرژی و انتشار گازهای گلخانه ای در تناوب گندم-پنبه

صادق افضلی نیا

بخش تحقیقات فنی و مهندسی کشاورزی، مرکز تحقیقات و آموزش کشاورزی و منابع طبیعی فارس،
سازمان تحقیقات، آموزش و ترویج کشاورزی شیراز، شیراز، ج. ا. ایران

---

*نویسنده مسئول

اطلاعات مقاله

تاریخچه مقاله:
تاریخ دریافت: ۱۳۹۸/۲/۱۴
تاریخ پذیرش: ۱۳۹۸/۷/۳۰
تاریخ دسترسی: ۱۳۹۹/ ۵/۸

واژه‌های کلیدی:
خاک ورزی حفاظتی
پنبه
شاخص های انرژی
گندم

چکیده- فرایند تولید محصولات کشاورزی با مصرف انرژی و تولید انرژی زیست توده به عنوان انرژی خروجی همراه است. در طی این فرایند، مقداری گاز گلخانه‌ای هم تولید می شود که محیط زیست را تهدید می کند. در این تحقیق، انرژی مصرفی و تولیدی، شاخص‌های انرژی و گازهای گلخانه‌ای متصاعد شده از مصرف انرژی‌های ورودی در تناوب گندم-پنبه تحت تأثیر روش‌های مختلف خاک‌ورزی در استان فارس تعیین گردید. تحقیق در قالب طرح بلوک‌های کامل تصادفی با سه تیمار (روش‌های خاک‌ورزی) و چهار تکرار انجام شد. روش‌های خاک‌ورزی شامل خاک‌ورزی مرسوم (CT)، کم‌خاک‌ورزی (RT) و بی‌خاک‌ورزی (NT) بودند. نتایج نشان داد که روش‌های بی‌خاک‌ورزی و کم‌خاک‌ورزی انرژی مصرفی در تولید گندم و پنبه را نسبت به خاک‌ورزی مرسوم به ترتیب ۱/۵۳ و ۱/۱۹ درصد کاهش دادند که دلیل آن کاهش مصرف سوخت و ماشین‌های کشاورزی در این دو روش بود. بیش از ۷۲ درصد از مصرف انرژی در تولید گندم و پنبه در تمام روش‌های خاک‌ورزی مربوط به آب آبیاری و برق مصرفی برای استحصال آب آبیاری بود. خاک‌ورزی مرسوم بیشترین انرژی تولیدی، راندمان انرژی و بهره‌وری انرژی را در تناوب گندم-پنبه به خود اختصاص داد. گازهای گلخانه‌ای متصاعد شده در تولید گندم و پنبه در روش‌های خاک‌ورزی مرسوم، کم‌خاک‌ورزی و بی‌خاک‌ورزی به ترتیب معادل ۵۱۸۲۹، ۵۱۶۰۸ و ۵۱۵۲۹ کیلوگرم گاز دی اکسید کربن در هکتار تخمین زده شد که نشان داد روش‌های بی‌خاک‌ورزی و کم‌خاک‌ورزی در مقایسه با روش خاک‌ورزی مرسوم تولید گازهای گلخانه‌ای را اندکی (به ترتیب ۰/۶ و ۰/۴ درصد) کاهش داده اند. همچنین، نتایج این تحقیق نشان داد که آبیاری بیشترین سهم را در انرژی مصرفی و گازهای گلخانه‌ای تولیدی در فرایند تولید گندم و پنبه در اقلیم نیمه خشک استان فارس داشت. بنابراین، استفاده از روش های آبیاری با راندمان بالا می تواند مصرف انرژی و تولید گازهای گلخانه ای را به مقدار قابل توجهی کاهش دهد.