Effect of conservation tillage senarios on energy consumption in soybean production in Iran: case study (Golestan province)

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Abstract: A study was conducted to determine the effect of four tillage methods on the energy efficiency indices in soybean cultivation in northern Iran, Golestan province. Four tillage methods including conventional tillage (CT) (Disk harrow+planting with planter), minimum tillage (MT) (Chisel packer+planting with planter), no-tillage with no-till planter (NT-Planter) and no tillage with no-till grain drill (NT-Grain drill) were used in this study. Experimental design was a randomized complete block design with four replications. Energy efficiency indices consisted of energy ratio (ER), energy productivity (EP), energy intensity (EI) and net energy gain (NEG) were then calculated. The results indicated that NT-Grain drill had the highest energy ratio of 4.5 and yield of 3612 kg ha^{-1} more than the other treatments. The energy efficiency is higher in NT-Grain drill and equals to 0.7777, 108.3%, followed by the NT-Planter (0.7531, 104.8%), MT (0.7183, 100%) and CT (0.7183, 100%). The high values of energy productivity in NT-Grain drill (0.19 kg MJ^{-1}) and in NT-Planter (0.17 kg MJ^{-1}) compared to the CT (0.15 kg MJ^{-1}), showed that NT systems had higher energy efficiencies. Although minimum tillage had the lowest consumption of energy with the amount of 2030.2 MJ ha^{-1} among the treatments but due to reduction of soybean yield with the amount of 2794 kg had the lowest amount of net energy gain. The consumed energy of conventional tillage method was also obtained 2840.6 MJ ha^{-1}. Using of conservation tillage methods would lead to less energy consumption and proper management and optimum use of inputs.

Keywords: conservation tillage, energy productivity, energy ratio, net energy gain, soybean

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1 Introduction

Soybean is the major crop cultivated in the summer season from June to October covering about 76% of the total soybean planted areas of Iran located in the north, Golestan province. Average yield of soybean in that province is approximately 2079.3 kg ha^{-1}. Golestan province produces 74% of soybean in Iran (Iranian Ministry of Jihad-e-Ariculture, 2011). Agricultural technologies are looking for economic, ecological and bio-environmental aims in which they chase agricultural crops production with respect to save and maintain the environment. Thus, there is necessity to develop sustainable agricultural technologies like conservation agriculture. One of the elements could be regarded to conservation agriculture is “conservation tillage” which is a type of tillage that maintains crop residues on the soil surface or mixes/does not mix it with soil using conservation

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tillage machinery. Conservation tillage could be studied regarding for required energy consumption of producing one kilogram crop. Several researchers have been conducted studies on the consumed energy for production of various crops such as wheat (Hussain et al., 2010; Singh et al., 2002; Shahan et al., 2008; Tabatabaeifar et al., 2009; Najafabadi, 2017), sunflower (Mousavi-Avval et al., 2011a), sugarbeet (Younesi Alamouti et al., 2024), corn (Afzalinia, 2022), Grape (Kamari et al., 2021) and Rice (Vahedi, 2021). Also, energy efficiencies of soybean production under different tillage systems have been studied in the recent years by a number of researchers (Rusu, 2014; Gelfand et al., 2010). They suggested that conservation tillage methods can enhance energy efficiency of agricultural crops production. The relationship between soybean yield and energy inputs was estimated in Iran by Mousavi-Avval et al. (2011b). De et al. (2001) also reported the adoption of more energy-efficient cultivation systems would help in energy conservation and better resource allocation. Therefore, the objective of this research was to study the effect of four tillage methods on the energy efficiency indices in soybean cultivation in northern Iran.

2 Materials and methods

2.1 Specification of research station

The study was conducted in Gorgan Agricultural Research Station, Golestan province, located in the northern areas of Iran (20' 54° East Longitude and 36' 55° North Latitude, 6 m above sea level and annual precipitation of 450 mm). The area has a temperate climate. The soil texture was silt clay loam. Soil physical properties of experimental filed are given in Table 1.

Table 1 Soil physical properties of experimental field

Depth (cm)	Soil particles			Texture	Field capacity (%)	Wilting point (%)	Bulk density (g cm^{-3})
	Clay	Silt	Sand				
0-30	33	49	18	Silt clay loam	27.4	12.7	1.43

2.2 Treatments and experimental design

Four tillage methods including conventional tillage (CT) (Disk harrow+planting with planter), minimum tillage (MT) (Chisel packer+planting with planter), no tillage with no-till planter (NT-Planter) and no tillage with no-till grain drill (NT-Grain drill) were used in the experiment. Experimental design was a randomized complete block design (RCBD) with four treatments and four replications. The size of plots was 8m×20m. The study was carried out in 2012. Technical specifications of used machines in the study are presented in Table 2.

Table 2 Technical specifications of used machines in the study

Machine type	Specifications	Weight (kg)	Hitch type	Working width (cm)
No-till planter	Six planter unit, seed hopper capacity of 25 liter, fertilizer hopper capacity 450 liter, required power of 70-80 hp, pneumatic seed meter, equipped with disc, fluted coulters, plastic press wheel	1235	Three point hitch	250
No-Till grain drill	Fifteen planter unit with 17 cm row space, fluted feed seed meter, feed Roll type fertilizer meter, double disc openers, ripple disc coulter, plastic press wheel	3500	Pull	255
Chisel packer	Five sweep tines at front with steel roller at rear	350	Three point hitch	140
Disk harrow	Twenty eight disc, tandem, notched discs at front and ordinary discs at rear, hydraulic jack	610	Pull	250
Row crop planter	Four planter unit, drum hopper, horizontal plate seed meter, hoe furrow opener, wide rubber press wheel	600	Three point hitch	210

2.3 Farm operations

A soybean variety called DPX with 60 kg ha^{-1} was planted in this study. Weeds were controlled in the middle of summer by spraying of one liter Persuit herbicide (100 g lit^{-1}). There was a need to spray with a mix of Supergalant and Bentazon herbicides due to the high density of weeds. Pests were also controlled by spraying of 2 lit ha^{-1}. The amount of 100 kg ha^{-1} fertilizer (with a proportion of 15% K, 8% P, and 15% N) during planting below seed in no-till planter, within seed in no-till grain drill and along with disk harrow in other treatments were used. During the growing season, the field irrigated three times by sprinkler method and two times raining happened.

2.4 Measured parameters

Input and output energy were calculated using the value of energy equivalents for crop production inputs and outputs (Table 3). Inputs included human, machine, irrigation, electricity, fuel, fertilizer, herbicide, pesticide and seed energy. Output was obtained from multiplying equivalent energy of produced crops by the amount of production.

Table 3 Energy equivalents for crop production inputs and outputs

Source of energy	Unit	Energy equivalent	Reference
Human	MJ hr^{-1}	1.95	(Laguë and Khelifi, 2001)
Operator	MJ hr^{-1}	1.05	(Pimentel and Burgess, 1980)
Fuel	MJ L^{-1}	47.8	(Kitani, 1999)
Nitrogen	MJ Kg^{-1}	78.1	(Kitani, 1999)
Phosphate	MJ Kg^{-1}	17.4	(Kitani, 1999)
Potassium	MJ Kg^{-1}	13.7	(Kitani, 1999)
Herbicide	MJ L^{-1}	347.8	
Pesticide	MJ L^{-1}	326	
Soybean seed	MJ Kg^{-1}	23.8	(Rathke et al., 2007)
Tractor	MJ Kg^{-1}	138	(Kitani, 1999)
Combine	MJ Kg^{-1}	116	(Kitani, 1999)
Planter	MJ Kg^{-1}	133	(Kitani, 1999)
Disc	MJ Kg^{-1}	149	(Kitani, 1999)
Spreader	MJ Kg^{-1}	129	(Kitani, 1999)
Sprayer	MJ Kg^{-1}	127	(Kitani, 1999)

2.4.1 Energy of machine

Energy of using machine was computed by Equation 1 (Kaltsas et al., 2007).

$$E_m = [(E \times W)/L_t] \times t \quad (1)$$

Where, E_m energy of using machine in MJ ha^{-1}, E is is energy of manufacturing, repair and maintenance and transporting of machine in MJ Kg^{-1}, W is weight of machine in Kg, L_t is useful life of machine in hr and t is working hours of machine in hr.

2.4.2 Energy of irrigation

The required energy for pumping and pressurizing of water, raw material and manufacturing of irrigation equipments can be calculated by both direct and indirect energy. The amount of required direct energy of irrigation was calculated using Equation 2

$$DE = (\delta \times g \times H \times Q) / (\eta_1 \times \eta_0) \quad (2)$$

Where, DE is direct energy in J ha^{-1}, δ is water density, g is gravity, H is dynamic head of well, Q is consumed volume of water in m^{-3}, η_0 is electromotor efficiency and η_1 is pump efficiency. The consumed volume of water was calculated on the base of 25 lit sec^{-1}, in three irrigation stages with 6 hr working hours. The dynamic head of well, electromotor efficiency and pump efficiency were 80 m, 20% and 70%, respectively. Indirect energy of pressurized irrigation systems was considered 18% of direct energy (Ju et al., 2006).

Energy efficiency indices including energy ratio, energy productivity, energy intensity and net energy gain were calculated and measured in the experiment according to the Equations 3 to 7 given below. (Tabatabaeifar et al., 2009)

2.4.3 Energy efficiency

The efficiency of energy is calculated by Equation 3:

$$e = (ER-1)/ER \quad (3)$$

where *ER* is the energy ratio. The energy ratio is calculated by Equation 4:

$$ER=OE/IE \quad (4)$$

where, *OE* is output energy in MJ and *IE* is input energy in MJ.

2.4.4 Energy productivity

The index of energy productivity can be calculated by Equation 5:

$$EP=Y_i/IE \quad (5)$$

where Y_i is grain yield in kg ha^{-1} and *IE* is input energy in MJ.

2.4.5 Energy intensity

The intensity of energy is calculated by below Equation 6:

$$EI=IE/Y_i \quad (6)$$

2.4.6 Net energy gain

This index is calculated by Equation 7:

$$NEG=OE-IE \quad (7)$$

3 Results and discussion

As it can be observed in Table 4, the consumed energy of machine for NT methods is higher than that of CT method due to their heavy weight while MT has consumed lower energy. Consequently, the consumed energy of human in MT is the lowest than the other tillage methods with the amount of 1.72 MJ ha^{-1}. The reason for that is because of the higher field capacity and higher forward speed for the chisel packer machine which could lead to decrease the total energy consumption in MT. The energy consumed for fuel in NT methods with the amount of 478 MJ ha^{-1} is less than those of CT and MT. The energy consumption of fuel in CT and MT is 1912 and 1195 MJ ha^{-1}, respectively. The same results have been suggested by other researchers (Kiani and Houshyar, 2012; Razzaghi et al., 2012). The consumed energy of CT and MT is 714 MJ and that of NT-Planter and NT-Grain drill is 1428 MJ. The reason for lower energy of CT and MT methods was that the seed consumption was less than of NT methods. The amount of energy of machine consumed in NT-Grain drill was 548 MJ ha^{-1} which is the highest consumption followed by NT-Planter, CT and MT with 233 MJ ha^{-1}, 207.7 MJ ha^{-1} and 119.4 MJ ha^{-1}. The high value of NT methods is for heavier machinery has been used in the experiment (Table 2).

Table 4 Consumed energy of tillage methods (MJ ha^{-1})

Energy type	Disk harrow+planter (CT)	Chisel packer+planter (MT)	No-Till Planter (NT-Planter)	No-Till Grain Drill (NT-Grain drill)
Input	714	714	1428	1428
Fuel	1912	1195	478	478
Machine	207.7	119.4	233	548
Human	6.87	1.72	4.25	3.95
Total	2840.6	2030.2	2143.3	2458

The amounts of input and output energy depend upon the cultivation of soybean especially on the energy produced from soybean. It also depends on the tillage methods and is highest for NT-Grain drill method (Tables 5 and 6). The tillage methods affect on energy efficiency. The energy efficiency is the highest in NT-Grain drill and equals to 0.7777, 108.3%, followed by the NT-Planter (0.7531, 100.1%), MT and CT (0.7183, 100%). The same results for no-tillage method reported in wheat production (Najafabadi, 2017; Afzalinia, 2022). NT-Grain drill had the highest amount of yield of 3612 kg which was more than the other treatments. The energy ratio of that treatment was also the highest one with the value o f 4.5. The high values of energy productivity and in NT0-Grain drill (0.19 kg MJ^{-1}) and in NT-Planter (0.17 kg MJ^{-1}) compared to the CT (0.15 kg MJ^{-1}), indicates that NT systems had higher energy efficiencies. NT-Grain drill has produced 0.19 kg crop for consumption of 1 MJ energy and consumed the lowest energy with 5.3 MJ for production of 1 kg soybean. It also had the highest net energy gain than the others.

The amount of output energy in soybean cultivation under conservation tillage methods was highest for the no-till methods. Moreover, the energy efficiency verifies the suitability of no-tillage methods, in terms of energy consumption reduction in cultivation of soybean.

The energy required for CT in soybean cultivation is 19512.1 MJ ha^{-1}. This amount of energy drops to 96.4% and 98% for no-till methods and also reduces to 95.9% in MT (Table 5).The amounts of energy intensity for CT, MT, NT-Planter and NT-Grain drill were obtained 6.71 MJ kg^{-1}, 6.71 MJ kg^{-1}, 5.87 MJ kg^{-1} and 5.30 MJ kg^{-1}, respectively. These results of no-tillage methods approve promising respond of soybean to the conservation tillage methods. Our results confirm previously data in this regard (Rusu, 2014; De et al., 2001; Gelfand et al., 2010). Although MT had the lowest energy consumption with the value of 2030.2 MJ ha^{-1}, but it also had the lowest net energy gain of 47771.7 MJ. It can be due to reduced yield of soybean of 2794 kg ha^{-1} in this method. The consumed energy of conventional tillage method was also obtained equal to 2840.6 MJ ha^{-1}.

The results of this study indicated that using new technologies and implements is the most important necessities for the optimal use of time, energy and reducing production costs. New methods of irrigation, proper consumption of inputs, reduction of fuel consumption and the application of MT and NT methods could decrease energy consumption. The results of the works of other researchers also confirms this issue (Zentner et al., 2004; Razzaghi et al., 2012; Gelfand et al., 2010).

Table 5 Energy efficiency (*e*) indices in soybean cultivation under different tillage methods

Treatment	IE (MJ)		OE (MJ)	ER	e	
	Value	Percent of CT			Value	Percent of CT
Disk harrow+planter (CT)	19512.1	100	69234.2	3.55	0.7183	100
Chisel packer+planter (MT)	18701.7	95.9	66473.4	3.55	0.7183	100
No-Till Planter (NT-Planter)	18814.8	96.4	76231.4	4.05	0.7531	104.8
No-Till Grain Drill(NT-Grain drill)	19129.5	98.0	85965.6	4.50	0.7777	108.3

Table 6 Energy efficiency (e) indices in soybean cultivation under different tillage methods

Treatment	*EI* (MJ kg^{-1})	*NEG* (MJ)	*EP* (kg MJ^{-1})	Crop yield (kg ha^{-1})
Disk harrow+planter (CT)	6.71	49722.1	0.15	2909
Chisel packer+planter (MT)	6.71	47771.7	0.15	2794
No-Till Planter (NT-Planter)	5.87	57416.6	0.17	3203
No-Till Grain Drill (NT-Grain drill)	5.30	66836.1	0.19	3612

In overall, using of conservation tillage methods would lead to less energy consumption. Proper management and optimum use of inputs could also increase output energy and consequently increases energy ratio. The results showed that efficient use of energy resources in the production management will increase energy efficiency. This will then be directed to sustainable agriculture through reducing energy consumption.

4 Conclusions

Energy efficiency is attributed to decrease in energy savings. It is also attributed to the effect of the no tillage methods on the cultivated soybean. The energy efficiency was higher in NT-Grain drill with the value of 0.7777 and 108.3%, followed by the NT-Planter with 0.7531 and 100.1%), MT and CT with 0.7183 and 100%. The high values of energy productivity in NT-Grain drill with 0.19 kg MJ^{-1} and in NT-Planter with 0.17 kg MJ^{-1} compared to the CT with 0.15 kg MJ^{-1} showed that NT systems had higher energy productivity. No-till-Grain drill has produced 0.19 kg crop for consumption of 1 MJ energy and consumed the lowest energy of 5.3 MJ for production of 1 kg soybean. Nt-Grain drill had the highest net energy gain of 66836.1 MJ than the others.

According to the improvement of consumed energy for production of agricultural crops, it can be concluded that among those tillage methods, no-till implements had the best indices regarding planting operations considering the limitation of time and reducing energy consumption. Although the size of no-till grain drill will increase the weight and energy consumption of machine, but it well penetrates on the soil. However, the existing planters could be modified for row crops and increasing of planting accuracy indices along with correct management of no-till methods at crop protection stages. It could also help to localize conservation tillage implements and speeding up new methods for reaching to sustainable energy and production resources.

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