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Tillage Effects on Energy Use Efficiency in Safflower Production in Middle Anatolia

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ABSTRACT

In this study conducted in province of Konya, the effect on grain yield and energy productivity of three different tillage methods (conventional tillage, reduced tillage and direct seeding) in safflower production were investigated. Yield values obtained were 921 kg ha^{-1} for conventional tillage, 903 kg ha^{-1} for reduced tillage, and 822 kg ha^{-1} for direct seeding. In growing of safflower, it was found that the highest share in total input energy is fertilizer energy, followed by fuel-oil, seed, herbicide, and machine energy respectively. In conventional tillage, reduced tillage and direct seeding, the share of fuel-oil energy in total input were 22.86%, 14.40%, 6.20% respectively. The highest value 5.67 of the energy output-input rate was obtained from direct seeding. This rate was 5.45 for reduced tillage, and 4.97 for conventional tillage. Of all these methods, direct seeding had the least energy consumption per safflower plant produced, which was found as 3.44 MJ kg^{-1}. The highest value was also obtained in conventional tillage as 3.95 MJ kg^{-1}.

1. Introduction

Energy, economics, and environment are mutually dependent. There is a close relationship between agriculture and energy. While agriculture uses energy, it also supplies it in the form of bio-energy. At present time, the productivity and profitability of agriculture depends upon energy consumption. Tillage is one of the highest power-required processes of the agricultural production. In addition, today, the high cost of energy forces the_farmers to find alternative economic tillage methods. Therefor, it is necessary to apply reduced tillage or no-tillage (Pimentel et al., 1994; Alam et al., 2005; Marakoglu and Çarman, 2008).

In intensive tillage (conventional tillage including inversion of soil), one of the main disadvantages is the loss in the topsoil from 0-20cm especially where agricultural land is exposed to water and wind erosion. The average wind erosion rate dropped 31 percent with protective farming practices in the world. Almost 1 billion tons of soil savings have occurred per year due to these changes in management. However, erosion is still occurring at a rate of 1.9 billion tons per year, and 108 million acres (29 percent of cropland) is still eroding at excessive rates (USDA- ARS, 1997).

Conservation of agriculture is a multi-dimensional approach the level of both energy usage and cost is minimized; and which involves the leaving of crop residues on surface to decompose in situ to protect water and soil. Direct seeding makes production profitable by decreasing the water and wind erosion. Although protecting of the soil is the main goal, soil moisture, energy usage, labor, and protection of machineries are also important (Köller, 2003).

Effective use of energy in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction. Energy efficiency can be increased by decreasing the energy use from inputs such as fertilizer or tillage operations or by increasing the outputs such as crop yield. Aykas and Önal (1999) studied on how different tillage methods may affect both the yield of wheat and the amount of weed. According to results of the study, the highest yield value was 420 kg da^{-1} for reduced tillage, and the lowest was 350 kg da^{-1} for direct seeding.

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When compared with conventional tillage, direct seeding has less water consumption. In years when winter rains were too little, in lands with no weed, and without even any seedbed preparation, robust oilseed crops with deep root system such as safflower and flax can be grown (Mandal et al., 1994). Bayhan et al., (2001) reported that the lowest fuel consumption among different practices belong to direct seeding, and the highest yield value belong to combined tillage. In a similar study carried out by Yalçın and Çakır (2006), it was found that fuel consumption was measured as 60 L ha^{-1} in conventional tillage, and in direct seeding; it was obtained as 7.5 L ha^{-1}.

Çarman and Marakoğlu (2007) reported the highest total fuel consumption (5.202 L da^{-1}) was belonged to conventional tillage whereas the lowest (0.972 L da^{-1}) was belonged to direct seeding. Additionally, seedling emergence degrees were obtained as 73.02% at conventional tillage, 64.29% at reduced tillage and 62.7% at direct seeding.

Many researchers have studied energy and economic analyst is to determine the energy efficiency of plant production such as sugarcane in Morocco (Mrini, et al., 2001), wheat, maize, soybean, sugarbeet, sunflower, barley, oat in Italy (Sartori et al., 2005), cotton crops in Turkey (Dagistan, et al., 2009), sunflower in Greece (Kallivroussis et al., 2002), winter oilseed rape in Germany (Rathke and Diepenbrock, 2006) and wheat in Iran (Safa and Tabatabaeefar, 2002).

Due to the wide adaptation limits of the safflower plant, it can be grown in different ecologies. In addition, the roots can go into deep layers within the soil. Prickly plant growth increases the resistance to drought and heat (Dajue and Mundel 1996). With these properties, safflower is gaining importance as an oil plant which can be located in the cultivation of fallow land in dry land (Machado 2004). The most important advantage of safflower is that it is drought resistant and its agriculture is suitable for mechanization (Pinarkara 2007). In this study, the feasibility of safflower cultivation with wheat-safflower rotation was investigated in the fallow lands in Central Anatolia and especially in Konya which has a fallow area of 5.6 million decares. In addition, the effects of two different conservation tillage on the seedling emergence degree and grain yield values after seeding, and the energy balance of the safflower production have been determined.

2. Materials and Methods

Experiments were conducted in 2016 at Agricultural Research and Education Center of Selcuk University in the province of Konya (Seeding: 20th February 2016, Harvest: 2nd August 2016). The average monthly temperature and rainfall values in the experiment area are given in Table 1. Some of the important physical properties of the experiment field soils are given in Table 2.

Table 1
The meteorological data taken during the vegetation at the experiments

Month	Temperature °C			Rain (mm)	Wind Speed (m s^{-1})
	Maximum	Minimum	Mean		
February	20.6	-8.3	6.6	3.4	1.0
March	25.6	7.8	-5.6	37.2	1.3
April	27.9	4.4	0.7	10.2	1.3
May	30.3	5.2	15.7	31.2	1.4
June	33.7	7.5	21.9	36.4	1.6
July	36.6	11.5	24.3	2.8	1.4
Mean/Total	29.1	4.6	10.6	121.2	1.3

Table 2
Some of the important physical properties of the experiment field soils

Textural class	33.2 % Salt; 31.5 % Silt; 35.3 % Clay Clay-Loam		
Method	Conventional tillage	Reduced tillage	Direct seeding
Volumetric weight (g cm^{-3}) (0-20 cm)	1.11	1.25	1.40
Gravimetrical soil moisture (%) (0-20 cm)	39.7	40.1	43.9
Porosity (%)	54	51	43
pH	7.52	7.52	7.52
Organic substance (%)	1.35	1.35	1.35

Conventional and two conservation tillage treatments were performed on February. The treatments included:

- (CT) Conventional tillage (plough + Cultivator – float (2 times) + Seeding
- (RT) Reduced tillage: Vertical rotary tiller + Seeding
- (DS) No tillage: Direct Seeding

The equipments used in this study were operated with the standard tractor (Erkunt-Haşmet 110) of 80 kW. Some of the machine's technical properties are given in Table 3. Safflower seeds (Dinçer) of 47.4 g.1000^{-1} seeds were used in this study. Safflower seeds were sown for the experiment with 40 kg ha^{-1} seed rate and at 40 mm sown depth. Row spacing was 12.5 cm, seeding machine had a variable rate speed transmission system and toothed metering rollers that were used for seeding of different seeds. The speeds of the metering rollers of the seed drill were set at 10 rpm at travelling speed of 1.75 m s^{-1}. The direct seeder has a press wheel of 400x75 on the back of each seeder disc.

In order to determine the pulling force requirements of the machines, the draw pin of 30,000 N has been attached to three-point link arms of the tractor. The data logger that collects 20 data per seconds was used. In trials, nitrogen of 86.8 kg ha^{-1} and phosphorus of 59.8 kg ha^{-1} were applied together with seeding. In addition, 2.5 kg ha^{-1} herbicide was applied for weed control.

Table 3
Some technical specifications of used machines

Machine	Number of tide or body	Working width (cm)	Working depth (cm)	Travel speed (km/h)	Type
Plough	5	170	30	5.8	3 pt hitch
Cultivator + Float	13/2	310	20	6.7	3 pt hitch
Vertical Rotary Tiller	10	250	25	2.7	3 pt hitch
Combined Seeder	21	262	4	6.3	3 pt hitch
Direct Seeder	20	284	4	6.3	Pull-type
Spraying machine	-	1000	-	6.5	3 pt hitch

To measure the fuel consumption, measurement device brand Rudolf Schmitt (0.5% - accuracy) was used.

Surface relief was measured by using surface profile meter. This consisted of a set of vertical rods, spaced at 2.5 cm intervals, sliding through an iron bar of 100 cm length. The soil surface roughness was calculated by using the Kuipers equation; (Abo–Habaga 1990)

$$R = 100 \log_{10} S$$

Where R is the surface roughness (%) and S is the standard deviation (mm).

The standard deviation was estimated by measuring the distance between a constant horizontal surface and the soil surface over a set of 100 cm.

In order to determine the penetration resistance, an Eijkelkamp analog penetrometer with 60° cone angle was used. Measurements were made at the depth of 20 cm in 5 cm increments with five replications in each plot before and after soil tillage.

The soil shear testing device was used in order to determine the soil shearing strength which has a 10 cm diameter (D) and 12 cm height (h). Torque arm having a measuring range of 0-80 Nm was impaled on shear vane. The maximum torque (T) was obtained via soil shear testing device as shear stress (τ) was obtained by the following equation (Okello 1991):

$$\tau = \frac{T}{\pi D^2\left(\frac{h}{2} + \frac{D}{6}\right)}$$

In order to determine seedling emergence, the experiment field was observed throughout the emergence time and along with the beginning of the emergences, emergence counts were taken at two days intervals at the distance of 300 cm from three separate rows. The values of average emergence day (MED), emergence rate index (ERI), and seedling emergence degree (PE) were calculated by using the values obtained from the counts in the equations given in Bilbro and Wanjura, (1982):

$$MED = \frac{N_1 D_1 + N_2 D_2 + ... + N_n D_n}{N_1 + N_2 + ... + N_n}$$

$$ERI = \frac{Total\ emergence\ in\ 1\ meter\ long\ band}{MED}$$

$$PE = \frac{Total\ emergence\ in\ 1\ meter\ long\ band}{Number\ of\ seeds\ sowed\ in\ 1\ meter\ long\ band} \times 100$$

Where MED is mean emergence day; ERI is emergence rate index, seedlings $day^{-1}m^{-1}$; PE is percentage of emergence, %; N_1…n is number of seedlings emerging since the time of previous count; D_1…n is number of days after the seeding.

In order to determine the number of seeds sown in a 1 meter line length, the machines were set to give 40 kg ha^{-1} seed rate. The number of seeds dropped from different furrow opener was determined as 5 replications. The average seed number dropped from a furrow opener to the 1m line length was found to be 11.

The safflower seed and biomass energy equivalent were measured by a calorimeter. For this EN 61010, EN 50082, EN 55014 and EN 60555 standards are taken into account.

Randomized Complete-Block Design with three replicates has been performed in this study. Human labor, machinery, chemical fertilizers, diesel fuel and seed energy have been computed inputs. In order to evaluate energy efficiency of agricultural production, energy equivalents of the inputs and outputs used in the safflower production are given in Table 4. Energy parameters are given in Table 5.

Table 4
Equivalent energies

Properties	Unit	Equivalent energy Mj/unit	Reference
Inputs			
Labor	h	2.3	Kızılaslan (2009), Barut et al. (2011)
Tractor	h	158.3	Doering (1980), Barut et al. (2011)
Machine	h	121.3	Doering (1980), Barut et al. (2011)
Fuel-Oil	L	41	(Reinhardt., 1993)
Herbicide	kg	120	(Çanakçı et al., 2005)(Mandal et al ., 2002) (Singh,2002)
Fertilizer (N)	kg	60.6	(Bojaca and Shrevens.,2010) (Öztürk.,2011)
Fertilizer (P)	kg	15.7	(Kaltschmitt and Reinhardt., 1997)
Seed	kg	24.37	
Outputs			
Yield	kg	23.99	
Biomass	kg	17.18	

Table 5
Energy parameters (Tabata baeefar, et al., 2009; Zangeneh, et al., 2010; Mousavi-Avval et al., 2011; Öztürk, 2011)

Parameter	Unit	Definitions
Total energy input	MJ/ha	EI
Total energy output	MJ/ha	EO
Yield of net energy	MJ/ha	Total energy output - Total energy input
The rate of output / input	%	Total energy output / Total energy input
The rate of net energy	%	Net energy efficiency / Total energy input
Energy efficiency	kg/MJ	Grain and biomass yield / Total energy input
Energy required for the unit product	kg/MJ	Total energy input / Grain and biomass yield

3. Results and Discussion

Before the trial, the amount of stubble was 885-920 m^2 in the plots. The weed coating rate was found to be between 1-1.3% in the field, and this rate will not affect the efficiency negatively, thus weed struggle has not been done directly before planting, while not economical to fight with chemical methods was thought.

When the applications were evaluated in terms of the effect of penetration resistance in 0-20 cm depth region of soil, the greatest penetration resistance was seen in direct seeding as expected, while the lowest value was observed in reduced tillage application (Figure 1). The penetration resistance of the soil varied between 0.91 MPa and 1.07 MPa depending on the application of soil tillage.

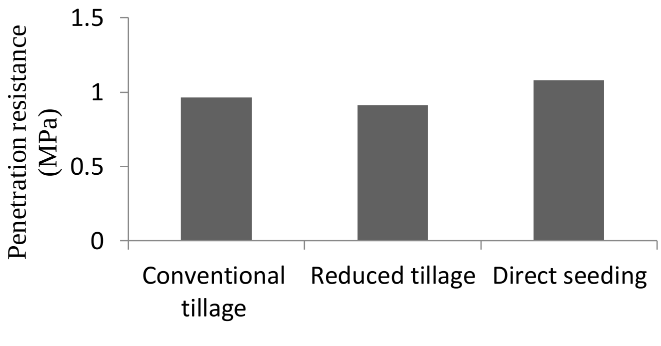

Figure 1
The effects on penetration resistance of different applications.

The values of soil cut resistance ranged from 1.11 to 1.99 Ncm^{-2}. The soil cut resistance values obtained from the applications are given in Figure 2.

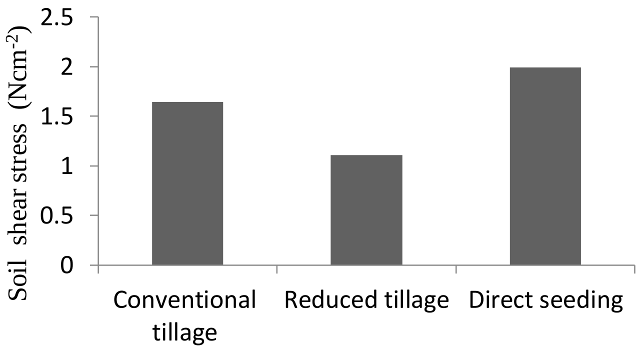

Figure 2
The effects on soil shear stress of different applications

Surface roughness's values of the application soil ranged from 7.78% to 25%. (Figure 3). In conventional application, according to the surface roughnessü, values were 221.3% higher than reduced tillage. In addition to this, these were 138.6% higher than direct seeding.

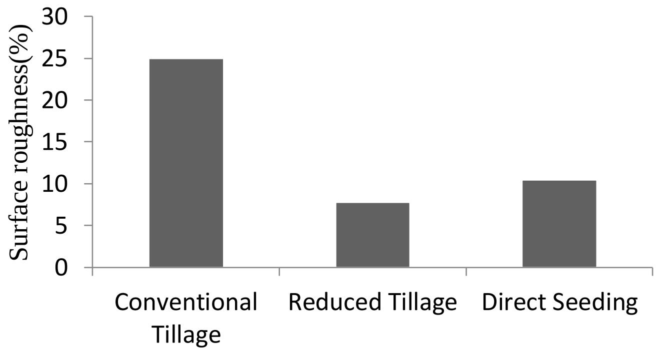

Figure 3
The effects on surface roughness values of different applications

The specific draw force requirements of the machines used in the three different applications of safflower production is given in Figure 4. The highest value in terms of specific draw force is obtained in the plough, while the lowest value is obtained in the classic combined seed drill.

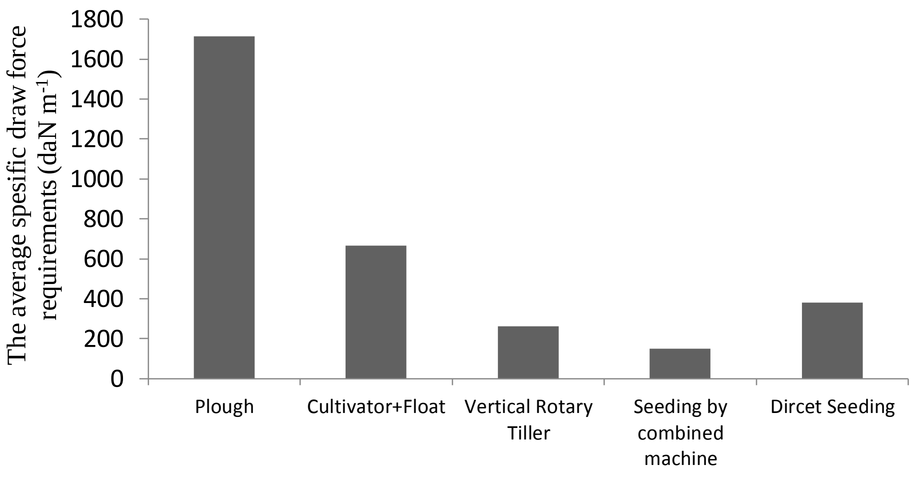

Figure 4
The average specific draw force of equipments

According to Marakoğlu and Çarman (2008), because of the two years of studies on reduced tillage and direct seeding applications in wheat production, the highest specific draw force value of the machines used was reported on the plow and the lowest value was obtained from the classic combined grain seeding machine.

The fuel consumption values of the tractor in working with different equipments are given in Table 6. The highest fuel consumption was obtained with 20.8 L ha^{-1}

application in vertical rotary tiller and the lowest consumption was obtained with 3 L ha^{-1} application from spraying machine. By using the direct seeding machine, the fuel consumption of the tractor was 11.76% higher than the classic seeding machine. Marakoğlu and Çarman (2008) reported that in a two-year study of reduced tillage and direct seeding applications in wheat production, the highest fuel consumption was 19.9 L ha^{-1} from vertical rotary tiller machine, the lowest fuel consumption was 8.1 L ha^{-1} from a minimum combined seeding machine and the fuel consumption of the direct seeding machine was higher than 12.3% to the classic seeding machine.

Table 6
Total fuel consumption values of used equipment and applications

Equipment	Conservational Tillage L ha^{-1}	Reduced Tillage L ha^{-1}	Direct Seeding L/ha^{-1}
Moldboard plought	20,7	-	-
Cultivator + Float (two times)	12.3 x 2	-	-
Vertical Rotary Tiller	-	20.8	-
Combined Seed Drill	8.5	8.5	-
Direct Seed Machine	-	-	9.5
Spraying machine	3	3	3
Total	56.8	32.3	12.5

When the applications were evaluated in terms of total fuel consumption, the highest fuel consumption was seen in the conventional application and the lowest was in the direct seeding application. In conventional application, the total fuel consumption was 4.54 times higher than direct seeding. According to *Akbarnıa* and *Fahranı* (2014), they analyzed the fuel consumption of different tillage applications and in conventional tillage, reduced tillage and direct seeding it was found 59.33 L ha^{-1}, 29.67 L ha^{-1}, 14.33 L ha^{-1} respectively. Marakoğlu and Çarman (2017) reported that fuel consumption values were 50% decreased in reduced tillage application in wheat.

Bonari et al. (1995) insisted on their research to determine the yield and soil's physical properties by using the combined machines for different tillage methods in order to investigate the level of energy consumption under different conditions for tillage methods. Reduced tillage method provided less than 55% fuel consumption but there was no importance for yield in tillage methods. Similarly, Craciun et al. (2004) reported 60% reduction in fuel consumption by reduced tillage applications.

Mean germination time (MED) values ranged from 38.3 days to 43.3 days. The germination ratio value was found between 0.42 and 0.71 m^{-1} day^{-1}. While comparing percentage of emergence applications, the highest percentage of emergence was found in conventional application with 76.8% and the lowest in direct seeding application was 61.2%. (Figure 5). The effect of the applications on the percentage of emergence was found to be significant (P <0.01).

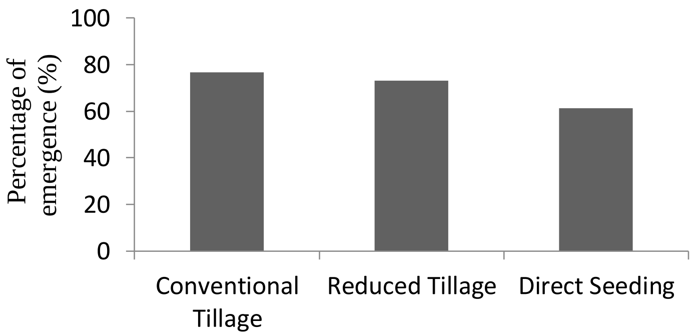

Figure 5
Percentage of emergence of applications

The grain yield values of the applications ranged between 822-921 kg ha^{-1} (Figure 6). The highest grain yield was obtained in the conventional application, while it decreased by 1.95% in reduced tillage and by 10.7% in direct seeding method. According to Meral (1996), depending on Çukurova conditions, seed yield was 1.258 kg ha^{-1} which was observed in Yenice, Dinçer and 5-154-2 varieties in barren and sole conditions; therefore, the seed yield was dropped to 172 kg ha^{-1} in the base area. Öztürk et al., (2009) stated that the average seed yield value was 1,899 kg ha^{-1} but it decreased to 928 kg ha^{-1} in dry and aqueous conditions. In the production year of the experiments, if the average yield values are low, the plants may suffer from low rainfall in the vegetation periods (121.2 mm). The effect of the applications on grain yield was found to be significant (P <0.01). Prihar et al., (1975) defined that high yield in conventional tillage method is related to good root growth and high amount of water used, and the hard soil layer under working depth in reduced tillage area may prevent root growth and water use.

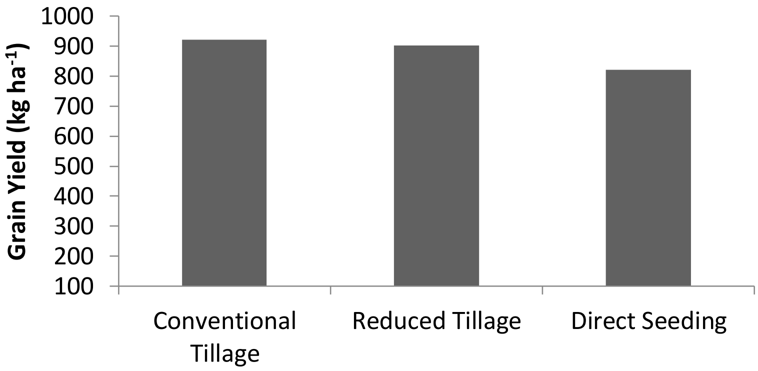

Figure 6
Grain yield values of applications

Akbarnia and Farhani (2014) investigated the effects of different tillage applications on wheat yield. The grain yield values were 8.07 t ha^{-1} in conventional soil tillage and 7.90 t ha^{-1} in reduced tillage, in addition to these, it was 6.33 t ha^{-1} in direct seeding.

When Table 7 is examined, the share of the most production inputs in the applications are followed by the fertilizer energy, and the fuel, seed, herbicide and machinery energies respectively. In direct sowing the seed energy input is higher than the fuel energy input. Hamedani et al., (2011) stated that energy consumed in production of grapes was 45,213. 66 MJ ha^{-1} and this energy is dividing to outputs so the highest level was 37.25% for fertilizer. Konak et al., (2004) stated that the highest rate of total energy inputs in maize production is fertilizer energy followed by the seed, instrument-machine and fuel-oil energies.

Baran and Ark. (2016) stated while comparing the different tillage and seeding methods in the production of silage corn, fertilizer inputs were the highest value of the production inputs in Cukurova region.

Baran ve Karaağaç (2014) determined that irrigation energy has the highest value in consumption rate and it was 30.36% in the second product sunflower production. In addition, fertilizer energy rate was 28.78 % and fuel-oil energy rate was 24.74%.

Conventional application, in reduced tillage application and direct seeding application, the share of the fuel-oil energy values in the total energy input was determined as 22.86%, 14.40% and 6.20% respectively. Moreover, the conventional application has about 3.69 times more fuel-oil energy input than the direct seeding method. When the applications were examined in terms of the energy value required for the production of one kg of product, the best result was obtained by direct seeding with 3.44 MJ kg^{-1} followed by reduced tillage application, and conventional application, respectively. Direct seeding application has the lowest energy input in terms of labor, tractor and machinery inputs. According to Marakoğlu and Çarman (2017), same results were observed from wheat production at direct seeding in Middle Anatolia.

In agricultural mechanization applications, unit energy consumption can be reduced by using machines such as combined machines and direct seeding machines. However, the application of protective soil tillage methods helps to protect the soil's organic structure and prevents soil erosion (Hargrave, 1982).

The highest value of net yield energy obtained from reduced tillage was 40,917.16 MJ ha^{-1} and from conventional applications was 40,427.49 MJ ha^{-1}, in addition to these, from direct seeding it was 38,591.87 MJ ha^{-1}. In other words, the highest value of energy obtained from direct seeding was 0.29 kg MJ^{-1} and from reduced tillage it was 0.28 kg MJ^{-1}; in addition to these, from conventional applications it was 0.25 kg MJ^{-1}. Marakoğlu and Çarman (2017) stated that the value of yield energy obtained from reduced tillage in wheat production was 0.82 – 0.93 kg MJ^{-1} and from conventional applications it was 0.83 kg MJ^{-1}. Moghimi et al., (2013) found that the value of net yield energy was 54 937.18 MJ ha^{-1} and the yield energy was 0.13 kg MJ^{-1} in production of wheat.

Table 7
Energy balance

A.Input	Conventional Tillage		Reduced Tillage		Direct Seeding	
	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%
Labor	8.39	0.08	6.90	0.08	2.21	0.03
Tractor	206.26	2.03	203.88	2.22	65.25	0.79
Machine	168.19	1.65	186.35	2.03	217.89	2.63
Fuel-oil	2328.80	22.86	1324.30	14.40	512.50	6.20
Herbicide	300.00	2.95	300.00	3.26	300.00	3.63
Fertilizer (N)	5260.80	51.65	5260.80	57.21	5260.80	63.60
Fertilizer (P)	938.86	9.22	938.86	10.21	938.86	11.35
Seed	974.80	9.57	974.80	10.60	974.80	11.78
Total input	10186.10	100.00	9195.89	100.00	8272.31	100.00
B. Output						
Yield grain	22094.79		21662.97		19719.78	
Yeld biomass	28518.80		28450.08		27144.4	
Total output	50613.59		50113.05		46864.18	
Parameters						
EI	10186.10		9195.89		8272.31	
EO	50613.59		50113.05		46864.18	
Yield of net energy (Mj ha^{-1})	40427.49		40917.16		38591.87	
The rate of output / input (%)	4.97		5.45		5.67	
The rate of net energy (%)	3.97		4.45		4.67	
Energy efficiency (kg MJ^{-1})	0.25		0.28		0.29	
Energy requirement per product unit (MJ kg^{-1})	3.95		3.59		3.44	

Obtaining from the reduced tillage application in the unit area the net yield energy was 1.21% more than conventional application and 6.02% more than the direct seeding applications. When the applications are evaluated in terms of energy efficiency, it was determined that direct seeding application rate was 16% higher than the conventional applications and it was 12% higher than the reduced tillage applications.

Çanakçı et all (2005), estimated that the energy rate of wheat production was 2.8 and of maize production was 3.8 in Antalya.

Karaağaç et all (2011), tried to make the energy balance of wheat and maize in a company, and the number of values related to wheat, specific energy, energy sources of these plants is 3.50, 4.20 MJ kg^{-1} and 0.24 kg MJ^{-1}, corn 6.54, 2.25 MJ kg^{-1} and 0.44 kg MJ^{-1}.

The following evaluations can be made from these assessments.

-The output/input ratio obtain from direct seeding was 14.11% higher than the conventional application and 4.04% higher than the reduced tillage application.

-Although low yield was obtained from direct seeding method, the input quantity was less than other methods, in direct seeding the net energy ratio was 17.6% higher than the conventional applications and it was 4.94% higher than the reduced tillage.

-Net energy yield was at the highest rate at reduced tillage application and it was ordered by conventional application and direct seeding, respectively. Thus it is important for the spreading of protective soil tillage methods.

-In conventional application, energy consumption for the unit product was detected to be 14.8% higher than direct seeding and 10.02% higher than reduced tillage.

- The fact that the energy required for the unit product amount was less than the other applications of direct seeding application, it was effective in the possibility to enable the establishment of an alternative application in the economic conditions.

- If the yield values are low from applications in one year, the average rainfall and temperature values of the region may be low during the vegetation period and year.

-It is possible that direct seeding method is more advantageous than other methods according to the fuel consumption, time, labor and work success and at large production areas works can be done in a timely manner, depends on it, waste of time can be reduced.

-Production of safflower can be done in dry agricultural regions of Middle Anatolia where fallow application is done in agricultural production.

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