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Effects of Tillage Systems on Energy Efficiency in Safflower Farming of Central Anatolia of Turkey

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ABSTRACT

The present study was conducted to determine the best appropriate soil tillage system to be used in safflower farming in Sivas, Turkey in terms of energy use efficiencies. Linas and Remzibey-05 safflower cultivars were used in experiments. Tillage systems were arranged as; conventional tillage system-1 (TS-1) with moldboard plough, conservation tillage system-2 with gobble disk (TS-2) and conservation tillage system-3 with chisel plough (TS-3). The energy consumptions of safflower tillage systems and cultivars and have given the significant differences as statistically. The lowest total energy input was observed in gobble disk tillage system (TS-2), the greatest total energy input was observed in conventional tillage system (TS-1). With regard to energy efficiency parameters (except for specific energy), Linas cultivar had better outcomes in conventional tillage system. Net energy value of Linas cultivar in conventional tillage system was 27% greater than the net energy value of Remzibey-05.

RESEARCH ARTICLE

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INTRODUCTION

Safflower (*Carthamus tinctorius* L.) has about 30-50% oil content. Safflower is frequently used for production of oil and most important of all, in biodiesel production, but also used in dye, varnish, dye, feed industries, margarine, as herbal tea and for the pharmaceutical industry (Rahamatalla *et al.,* 1998; Wang *et al.,* 1999; Weiss, 2000; Öğüt and Oğuz, 2006).

The current oil production level of Turkey is not sufficient to meet the demands, although soil and climate conditions are quite available for oilseed production in Turkey. Therefore, the potential production areas should be increased to oilseed needs and meet vegetable oil of Turkey. Safflower is highly tolerant to salinity and droughts and it has an important role in the prevention of erosion. Thus, safflower production should be increased to meet oilseed needs and vegetable oil. Safflower can be mostly incorporated into the production patterns of Central Anatolia of Turkey (Kurt *et al.,* 2011).

Sivas province is the second-largest province of Turkey with a 27 202 km^2 surface area located in the Central Anatolia region. The oilseed cultivated areas have recently been observed a significant increase, although the cereal production is dominant in Sivas province. The oilseed cultivated areas increased to 19 110 decares in 2016 (Anonymous, 2016).

Energy is one of the largest controllable costs in most organizations and there is considerable scope for reducing energy consumption and hence cost (Jekayinfa, 2006). Energy analyses to be performed for agricultural production activities constitute a significant approach in identification and grouping of agricultural systems in terms of energy consumption. Sustainable agricultural principles, economy, energy and emission (environment) have together been investigated to assess agricultural productions in recent years. Energy requirements are continuously increasing in agricultural sector. Improved energy efficiencies in tillage systems will reduce energy requirements and improve productivity.

The agricultural mechanization practices are among the significant production factors to be considered in on-time performance of productivity and economic programs within agricultural production activities. The major share of energy inputs comes from tillage and fertilizer in any of the agricultural production systems, which are solely dependent on non-renewable energy sources. The non-renewable energy is expensive and liable to exhaust in near future (Billore *et al.,* 2009). However, high energy use of today's conventional tillage systems points out the necessity of alternative tillage systems in crop production activities.

Several previous studies investigated energy efficiency for different crops produced in different regions of Turkey and compared energy use efficiencies of different tillage systems. For instance, energy use efficiency and cost analysis studies were performed in Central Anatolia region [(maize in Konya (Konak *et al.,* 2004), potato in Nevşehir (Özgöz *et al.* 2017)], in Mediterranean region [(main crop maize in Adana (Karaağaç *et al.,* 2014), rapeseed in Adana (Arıkan, 2011), sorghum in Çukurova (Eren and Öztürk, 2011), cotton in Adana (Şehri, 2012)], in Thrace region [(rapeseed in Kırklareli (Baran and Gökdoğan, 2014), second crop sunflower in Kırklareli (Baran and Karağaç, 2014)] and Easter Anatolia region [wheat in Erzurum (Gözübüyük *et al.,* 2012)].

Data in the scientific literatures about tillage systems in safflower farming in Turkey and thus in Central Anatolia region are insufficient. The primary objective of the present study was to determine effect of the tillage systems on energy use efficiencies in safflower farming in dry-farming lands in Sivas province of Central Anatolia region.

MATERIAL and METHODS

This study was conducted over the safflower cultivated fields of a farmer in Kavak village of Gürün town of Sivas province in Central Anatolia region. The research site has a slope of 0-2% and an altitude of 1 260 m. Experimental site has a soil depth of 0-120 cm. Fields were normal dry farming lands without a stoniness problem. Semi-terrestrial climate is dominant in Gürün town of Sivas province. The first frost date to be considered in agricultural production is generally 25 October and the last frost date is around 28 March. Experiments were conducted in growing season of 2017. The experimental soils were clay-loam in texture (as silt, clay, and sand values of 35%, 34%, and 31%, respectively). In the experiment soil samples taken from 0 to 30 cm soil profile, total N, organic matter content, available K, and P were 0.015%, 2.17%, 6.30 and 3.65 ppm, respectively. In the research site, the terrestrial climate is dominant, the average precipitation, temperature, and relative humidity from planting to harvest of safflower from April to October were 21.09 mm, 17.71°C, and 45.79% (Anonymous, 2017a).

In this experiment, different tillage systems as the conventional tillage system, TS-1 (moldboard plow + cultivator + planter); conservation tillage systems, TS-2 (gobble disk + planter), and TS-3 (chisel+ disk harrow + planter) were used. Technical specifications for tractor, agricultural machines and tools and combine harvester used over the experimental fields are presented in Table 1.

Linas and Remzibey-05 safflower cultivars were used in experiments. Linas cultivar is commonly used in Sivas province of Central Anatolia region. To assess the effects of tillage systems on different cultivars, Remzibey-05 cultivar which was considered as adapted to regional conditions was selected. Linas safflower cultivar with orange-leaved flower head has 17.9% oleic acid, 71.3% linoleic acid, 37-38% oil content, and 85-90 cm plant height. Remzibey-05 safflower cultivar with yellow-leaved flower head has 21% linoleic acid, 69% oleic acid, 35-38% oil content, and 60-80 cm plant height (Anonymous, 2017b).

The experimental design was conducted in randomized blocks - split plots. In this experiment, the total area was 600 x 6 = 3 600 m^2, and each plot has a size of 600 m^2. About 4 m and 1 m spacings were provided between the cultivars and the experimental plots. The experiment was conducted as three replications for tillage systems and safflower cultivars. The stubble density and stubble height values of the safflower experimental fields were 8.17 kg da^{-1} and 24.15 cm, respectively.

Table 1. Technical specifications for tractor and agricultural machines used over the experimental fields.

Machines	Type of connection	Number of units	Width (mm)	Depth (mm)	Weight (kg)	Economic life* (h)	Operational speed (km h^{-1})	Work performance (h ha^{-1})
Moldboard plow	Mounted	3 moldboards	900	250	335	2 000	5.41	2.0532
Chisel	Mounted	7 feets	2 100	250	420	2 000	5.76	0.8260
Cultivator	Mounted	11 feets	2 700	100	540	2 000	5.49	0.6751
Gobble disk	Mounted	20 disks	2 200	150	1 390	2 000	5.58	0.8147
Disk harrow	Mounted	22 disks	2 250	100	506	2 000	5.74	0.9415
Centrifugal broadcasters	Mounted	Single disk	1 000	-	220	1 200	9.88	0.1012
Planter	Pulled	18 rows	2 556	40	1 010	1 500	5.79	0.6752
Sprayer	Mounted	16 spray nozzles	8 000	-	380	1 500	8.31	0.1504
Combine harvester (NH TC 50-70)	-	-	4 570	-	8 720	3 000	3.00	0.7319
Tractor (TÜMOSAN 8075)	4WD	-	-	-	3 500	16 000	-	-

*: ASAE (2011)

Sowing was performed with 10 days delay on 22 April 2017 because of climate conditions (snowfall). Sowing rate, row spacing, and sowing depth were performed as 5.13 kg da^{-1}, 12.5 cm, and 5 cm, respectively. 20% Nitrogen (N), 17% Ammonium Nitrogen (NH_4-N), 3% Urea Nitrogen (NH_2-N), 20% Phosphate (P_2O_5) and 1% Zinc (Zn) containing 20.20.0 + Zn (Super Composed) were applied as base fertilizer at sowing. Ammonium Sulphate ($(NH_4)_2SO_4$) was used as top fertilizer on 30 April 2017. Formula Super 5 EC with 50 g l^{-1} Quizalofop-p-ethyl active substance was used for weed control on 2 July 2017. Side effects were removed and 3 different 1 m^2 sections were harvested in each plot on 2 October 2017. Seeds were separated, weighted and seed yield per decare was determined. For seed yields, 10 plants were used from each tillage system and cultivars.

The energy analyses were performed by using the energy equivalents of production inputs and outputs used for tillage systems and Linas and Remzibey-05 safflower cultivars. Direct energy inputs in safflower culture are composed only of fuel and oil consumptions. by using the following equations, the fuel consumptions were calculated (ASAE, 1999; ASAE, 2011; Heller *et al.*, 2003). Values used in equations and relevant values for centrifugal broadcasters, sprayer and combine harvester were taken from Evcim (1990), Özden and Soğancı (1996), ASAE (1999), and ASAE (2011). Oil consumption (OC) was considered as 4.5% of fuel consumption (Özcan 1985; Alpkent 1984).

$$D_i=F_i\,(A+B\,S+C\,S^2)W\,T \quad (1)$$

$$P_T=(D_i\,S)/3.6\,E_m\,E_t \quad (2)$$

$$Q_{diesel}=P_T(2.64(P_T/P_{Tmax})+3.91-0.203\sqrt{738(P_T/P_{Tmax})+173}) \quad (3)$$

Where; A, B, and C are machine-specific parameters, D_i is draft force (N); W is machine width (m); S is field speed (km h^{-1}); T is tillage depth (cm); F is a dimensionless soil texture adjustment parameter; i is 1 for fine, 2 for medium and 3 for coarse textured soils; E_m is the mechanical efficiency of transmission and power train. (E_m=0.96 for tractors with gear transmissions); P_{Tmax} is the maximum available PTO power (kW); E_t is traction efficiency; Q_{diesel} is diesel fuel consumption (l h^{-1}); P_T is the total power required for an operation (kW).

The fuel consumption value obtained from Equation 3 was multiplied by field capacity to get fuel consumption per hectare (L). Therefore, energy inputs included man labor energy, machine and tractor manufacture energy, chemical fertilizer energy, chemical herbicide energy and seed energy. Total energy input was calculated by adding the energy values calculated by multiplying energy equivalents provided in Table 2 with the current use quantities. Machine energy was calculated by using the following equation.

$$ME=(G.\,E)/(T\,.\,C_a) \quad (4)$$

Where; *G is* agricultural machine weight (kg), C_a is field capacity (ha h^{-1}), *E*: Energy equivalent, *ME is* machine energy (MJ ha^{-1}) (Table 2), *T is* machine economic life (h).

Safflower seed yields were the considered as the output in present research. Total energy output was calculated by multiplying seed yield with the energy equivalent of the product (Table 2). To determine and compare the energy efficiencies of different tillage systems used in safflower production, total energy inputs and outputs were calculated separately. Then comparisons were made for tillage systems (TS-1, TS-2, TS-3), Linas and Remzibey-05 cultivars. The resultant values were subjected to variance analyses and multiple comparison tests (LSD) with SPSS 17 statistical software to put for the differences between tillage systems and safflower cultivar. The values calculated from the above-given equations and used in energy efficiency parameters provided.

Energy productivity, net energy, specific energy, energy use efficiency, and energy profitability were calculated by using the following formulates (Mandal *et al.,* 2002; Mohammadi *et al.,* 2008; Mohammadi *et al.,* 2010).

$$EP_r = Y/EI \quad (5)$$

$$NE = EI - EO \quad (6)$$

$$SE = EI/Y \quad (7)$$

$$EUE = EO/EI \quad (8)$$

$$EP = NE/EI \quad (9)$$

Where; EP_r is energy productivity (kg MJ^{-1}), Y is yield (kg ha^{-1}), EI is energy input (MJ ha^{-1}), NE is net energy (MJ ha^{-1}), EO is energy output (MJ ha^{-1}), SE is specific energy (MJ kg^{-1}), EUE is energy use efficiency, EP is energy profitability.

Table 2. Energy equivalents for inputs and outputs used in safflower farming.

Inputs	Unit	Energy equivalent (MJ $unit^{-1}$)	References
Agricultural machinery	-	121.3	Doering (1980)
Tractor	-	158.3	Doering (1980)
Human labour	Hour	2.3	Kızılaslan (2009)
Fertilizers			
1) Nitrogen, N	Kilogram	60.6	
2) Phosphorus, P	Kilogram	11.1	Bojaca and Schrevens, (2010)
3) Potassium, K	Kilogram	11.15	
Fuel (diesel)	Liter	47.8	Hetz, (1992)
Oil	Liter	42.5	Hetz, (1992)
Chemical (herbicide)	Kilogram	238.0	Zangeneh et al. (2010)
Seed	Kilogram	14.0	Acaroğlu (2006)
Output			
Product (oil production from the seed, refined)	Kilogram	39.5	Acaroğlu (2006)

RESULTS and DISCUSSION

Total indirect and direct energy inputs of tillage systems and the share of each energy input in total inputs are provided in Table 3. Safflower seed yields and energy outputs of safflower cultivars and different tillage systems has been given in Table 4.

Operational times, operational speeds and economic lives are provided in Table 1 for each machine based on processes carried out. Fuel consumptions of each machine were calculated by using the Equations 1, 2 and 3 based on operational widths, depths and speeds. Unit area fuel consumption values used to calculate energy requirements were determined by multiplying hourly fuel consumptions with field capacities. Field capacity value of combine harvester, sprayer and centrifugal broadcaster were determined based on operational times throughout the experiments and fuel consumption values were taken from the literatures. Among the tillage machines, while moldboard plow had the greatest fuel consumption with 23.05 l ha^{-1}, cultivator had the lowest fuel consumption with 2.96 l ha^{-1}.

Table 3. Indirect and direct energy inputs of tillage systems in safflower farming (MJ ha^{-1}).

Inputs	Tillage systems		
	TS-1	TS-2	TS-3
Direct			
Fuel	2 108.1 (%7.7)	1 060.57 (%4.0)	1 384.0 (%5.2)
Oil	89.98 (%0.3)	48.06 (%0.2)	61.00 (%0.2)
Indirect			
Labor	138.1 (%0.5)	136.4 (%.05)	155.7 (%0.6)
Machine manufacture	383.9 (%1.4)	388.8 (%1.5)	370.0 (%1.4)
Chemical fertilizer	23 430 (%85.4)	23 430 (%88.9)	23 430 (%87.8)
Herbicide	238.0 (%0.9)	238.0 (%0.9)	238.0 (%0.9)
Seed	1 043.4 (%3.8)	1 043.4 (%4.0)	1 043.4 (%3.9)
Total	27 431 (%100)	26 345 (%100)	26 682 (%100)

TS-1: Moldboard plow + cultivator + planter; TS-2: Gobble disk + planter; TS-3: Chisel + disk harrow + planter

Table 4. Safflower yields and energy outputs of safflower cultivars and different tillage systems.

Tillage systems	Yield (kg ha^{-1})		Energy output (MJ ha^{-1})	
	Linas	Remzibey-05	Linas	Remzibey-05
TS-1	885.5 a**	845.0 a**	34 977 a**	33 378 a**
TS-2	728.2 c	702.1 c	29 764 c	27 733 c
TS-3	784.0 b	751.7 b	30 968 b	29 692 b

**: Differences between the means indicated with the same latter in the same column are not significant ($P<0.01$); TS-1: Moldboard plow + cultivator + planter; TS-2: Gobble disk + planter; TS-3: Chisel + disk harrow + planter

Total fuel consumptions of tillage systems were ordered as TS-1>TS-3>TS-2. Total fuel consumption of the conventional tillage was 83.67 l ha^{-1}, and fuel consumptions of TS-3 and TS-2 were respectively 15.97% and 23.90% less than the conventional tillage. In other words, with conservation tillage systems, respectively 13.35 l and 20 l fuel saving were achieved. Such findings also indicated that conservation tillage systems might reduce costs and energy consumptions and might have significant contributions to preservation and sustainable use of natural resources. In previous studies, Daşcı (2017) in a study carried out in Muş province of East Anatolia region, reported fuel consumption of safflower farming (excluding harvest) as 13 l ha^{-1}. Yalçın and Çakır (2006) investigated energy use efficiencies for the tillage systems and no-till systems used in maize farming of Aegean region (İzmir-Ödemiş) located at west sections of Turkey and reported the greatest fuel consumption for conventional tillage system (60.51 l ha^{-1}).

Total energy inputs of TS-1, TS-2 and TS-3 were respectively calculated as 27 431 MJ ha^{-1}, 26 345 MJ ha^{-1} and 26 682 MJ ha^{-1}. As compared to conventional tillage system, 3.96% less energy was used in gobble disk system and 2.73% less energy was used in TS-3 (Table 3). Similarly, Özgöz *et al.* (2017) reported greater total energy input for conventional tillage in potato farming and Marakoğlu *et al.* (2010) in chickpea farming of Central Anatolia region; Bayhan (2016) reported again greater total energy input for conventional tillage in second crop sunflower farming in Trace

region. Jain et al. (2007) reported the energy consumption was higher under deep tillage followed by conventional tillage compared to both the zero tillage packages.
Within direct and indirect energy inputs of the tillage systems, chemical fertilizer input had the greatest share. The share of chemical fertilizer input in total inputs of TS-1, TS-2 and TS-3 was respectively identified as 85.41%, 88.94% and 87.81%. Following the chemical fertilizer energy input, fuel consumption had the second place. Seed energy had the third place and human labor had the leash share in all three tillage systems (Table 3).

It was reported in previous studies carried out in different regions of Turkey under different soil and climate conditions that fertilizer energy input had the greatest share in total energy input. For example; Baran and Gökdoğan (2015) reported the share of chemical fertilizer input in sugarcane farming of Trace region (Kırklareli) as 41.97% and it was followed by fuel consumption (21.16%). Marakoğlu *et al.* (2010) investigated energy use efficiency of four tillage systems in chickpea farming of Central Anatolia region (Konya) and reported that fertilizer energy had the greatest share in total energy inputs, and it was respectively followed by seed, fuel-oil and machine energies. Barut et al. (2011) reported the greatest energy inputs of all tillage systems in second crop maize farming of Mediterranean region respectively as fertilizer energy (conventional tillage: 64.28% and no-till: 68.86%), seed energy (conventional tillage: 13.22% and no-till: 14.16%) and fuel energy (conventional tillage: 10.84% and no-till: 5.18%). Similarly, Kızılaslan (2009) in Turkey and Mohammadi *et al.* (2008), and Hamedani *et al.* (2011) in Iran, reported that fertilizer energy had the greatest share in total energy inputs, and it was followed by fuel energy.

Present findings revealed that fuel energy and fertilizer energy should be taken into consideration to reduce energy inputs in production activities. Undoubtedly chemical fertilizers are used for high yields. However, fertilizations should be performed on time at required quantities with appropriate techniques. Green fertilization and manure applications can also be used as an alternative practice to reduce chemical fertilizer energy inputs (Öztürk, 2011). Considering the livestock potential of the Sivas province of Central Anatolia, where the present research was conducted, it was seen that there was a great potential to increase livestock manure uses in agricultural practices. The ratio of fuel (diesel) in energy balance of agricultural systems varies between 10-70% based on required mechanization levels for the production of certain products. Size of production lands is among the most significant factor influencing fuel consumptions. Operational depth, soil texture, fertilization practices, mechanization level, transportation distance and method should be taken into consideration while selecting proper machines and machine combinations to have greater energy use efficiencies (Öztürk, 2011).

In all tillage systems, greater yields were obtained from Linas cultivar than Remzibey-05 cultivar. The lowest yield was obtained from TS-2 (Linas: 728.2 kg ha^{-1}; Remzibey-05: 702.1 kg ha^{-1}, the greatest yield was obtained from TS-1 (Linas: 885.5 kg ha^{-1}; Remzibey-05: 845.5 kg ha^{-1}). Tillage systems had significant effects on yields of both cultivars ($P<0.01$), thus tillage systems were placed into different statistical groups (Table 4). In different regions of Turkey, there are several studies about safflower yield parameters carried out. In studies carried out in Central Anatolia region (Konya, Ankara, Yozgat), Aegean region (İzmir) and Southeast Anatolia (Siirt) region, seed yields as between 88-211.61 kg da-1 (Keyvanoğlu, 2015; Sayılır, 2015;

Adalı, 2016; Yurteri, 2016; Yılman, 2017). Seed yields vary mostly based on climate, cultivars, sowing time, soil characteristics, seedbed quality, and several other factors. Energy outputs of the tillage systems were calculated based on yields of tillage systems. Energy equivalents were the same for both cultivar, but energy outputs were different because of different yield levels of the safflower cultivars. Energy outputs were calculated by multiplying yield quantities with energy equivalents. Energy outputs exhibited a similar change with the yields. Total energy outputs varied between 29 764 - 34 977 MJ ha^{-1} for Linas cultivar and between 27 733 - 33 378 MJ ha^{-1} for Remzibey-05 (Table 4). As compared to conventional tillage system, energy outputs of Linas and Remzibey-05 cultivars were respectively 17.51% and 12.94% lower in TS-2 and 20.35% and 12.41% lower in TS-3. In a previous study, Daşcı (2017) investigated energy efficiency in safflower farming at Berce Agricultural Enterprise of Muş province in East Anatolia region and reported safflower yield as 688.6 kg ha^{-1} and total energy output as 27 200 MJ ha^{-1}.

As energy efficiency indicators, specific energy, energy ratio, net energy, yield, energy efficiency, and energy profitability of Linas and Remzibey-05 safflower cultivars were calculated, and statistical comparisons are provided in Table 5.

Table 5. Energy efficiency parameters of Linas and Remzibey-05 safflower cultivars.

Energy parameters	Linas			Remzibey-05		
	TS-1	TS-2	TS-3	TS-1	TS-2	TS-3
Energy ratio	1.275 a**	1.092 c	1.161 b	1.217 a**	1.053 c	1.113 b
Energy efficiency (kg MJ^{-1})	0.032 a**	0.028 c	0.029 b	0.031 a**	0.027 c	0.028 b
Specific energy (MJ kg^{-1})	30.998 a**	34.035 c	36.186 b	32.470 c**	37.534 a	35.503 b
Net energy (MJ kg^{-1})	7 544 a**	2 418 c	4 286 b	5 945 a**	1 388 c	3 009 b
Energy profitability	0.275 a**	0.092 c	0.160 b	0.217 a**	0.053 c	0.113 b

**: Differences between the means indicated with the same latter in the same row are not significant (P<0.01);
TS-1: Moldboard plow + cultivator + planter; TS-2: Gobble disk + planter; TS-3: Chisel + disk harrow + planter

Effects of tillage systems on energy parameters of both cultivars were found to be significant (P<0.01). In Linas cultivar, the greatest net energy and energy profitability values (7 544 MJ and 0.275, respectively) were obtained from conventional tillage system (TS-1) and it was followed conservational tillage by chisel tillage system (TS-3) respectively with 4 286 MJ and 0.160. The lowest values were obtained from TS-2. Except for energy efficiency, Remzibey-05 cultivars also had similar energy efficiency parameters. As compared to Remzibey-05 cultivar, net energy value of Linas cultivar was 27% greater in TS-1. Linas cultivar had greater energy efficiency indicators (except for specific energy) than Remzibey-05 cultivar (Table 5).

Previous researchers also investigated energy efficiencies under different soil climate and soil conditions of Turkey. For instance, Barut *et al.* (2011) in Mediterranean region reported the greatest energy use efficiency of silage maize farming as 8.78, energy efficiency as 2.12 MJ kg^{-1} and energy profitability as 7.78 for minimum tillage and reported the least values for no-till system. Marakoğlu *et al.* (2010) investigated energy efficiency of conventional tillage, reduced tillage, pre-sowing weed controlled and uncontrolled tillage systems in chickpea farming at Konuklar Agricultural Enterprise of Konya Province of Central Anatolia region and reported that conventional tillage had the greatest energy output/input ratio (2.00) and it was respectively followed by reduced tillage system (1.81), no-till + herbicide (0.87) and no-till (0.205) systems. Bayhan (2016) investigated energy efficiency of different tillage system [gobble disk (DT), rototiller (ROT), gobble disk + combined harrow (DT + K) and direct sowing (DIR)] in second crop sunflower farming of Thrace region and reported that direct sowing had the greatest energy output/input ratio (11.82) and gobble disk tillage systems had the lowest ratio (9.57).

CONCLUSIONS

In this research, tillage systems were compared for safflower farming with regard to energy use efficiencies in Central Anatolia. There were significant differences in energy consumptions of tillage systems and safflower cultivars. The lowest total energy input was observed in gobble disk tillage system (TS-2), whereas the greatest total energy input was observed in conventional tillage system (TS-1). Linas safflower cultivar had greater yields than Remzibey-05 cultivar in all tillage systems. Tillage systems had significant effects on energy efficiency parameters of both cultivars. Linas cultivar and conventional tillage system had better outcomes, except for specific energy with regard to energy efficiency parameters. The chemical fertilizer energy had the greatest share and it was followed by fuel energy and seed energy inputs within the total energy input. Such findings revealed that for environmental preservation and sustainability, measures should be taken to reduce chemical fertilizer and fuel energy inputs, and proper tractor-machine match should be supplied based on plot sizes.

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