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Full Length Article

Effect of Tillage Systems on Energy Use Efficiency in Wheat Based Cropping Sequence

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Abstract

This study was conducted in order to determine how the energy balance affects under different tillage systems and crop rotations in the Central Anatolia Region of Turkey during four year period. The study was carried out using a split-plot randomized complete block design with three replicates. Tillage treatments were put in main plots and crop rotations in sub-plots. Total energy inputs in conventional tillage (CT) (20.69 GJ ha^{-1}) was found to be higher than reduced tillage (RT) (20.01 GJ ha^{-1}) and no-till (NT) (18.95 GJ ha^{-1}). The lowest total energy input was obtained in wheat-fallow (W-F) crop rotation (14.54 GJ ha^{-1}) and highest energy outputs in NT (55.89 GJ ha^{-1}) and W-F crop rotation (47.97 GJ ha^{-1}). It was determined that NT had nearly two times more energy use efficiency than CT. The energy use efficiency values for wheat-fallow (W-F), wheat-chickpea (W-C) and wheat-wheat (W-W) were found 3.35, 2.58 and 1.58, respectively. The highest energy productivity was obtained in NT (86.73 kg GJ^{-1}) and W-F crop rotation (94.46 kg GJ^{-1}). In NT practice, the highest wheat grain yield (1456 kg ha^{-1}) was obtained. NT practice had the most appropriate energy use efficiency for dry lands of the Central Anatolia Region. NT practice with W-F and W-C crop rotations can be recommended for dry lands in the study region.

Keywords: No-tillage; Reduced tillage; Energy balance; Yield

Introduction

Energy balance in farming systems have been studied since 1970s (Pimentel *et al*., 1973). Researchers throughout the world have been conducting energy balance studies using different crops, tillage methods and agricultural production methods in order to evaluate the efficiency and environmental impacts (Hemmat and Eskandari, 2004). Energy balance becomes an important viewpoint in agriculture for users and producers of energy (Risoud, 2000). Energy plays a significant role in agriculture when considered with respect to energy use and agricultural production (Snyder *et al*., 2009).

Agriculture is affected by a great number of natural and cultural factors including diseases, pests, weeds, soil, climate, land size, degree of mechanization, oil prices, management conditions, animal production and the interaction between each other (Kuesters and Lammel, 1999).

Energy used in agriculture production fall under two categories, direct and indirect energy. Direct energy consists of human labor, diesel fuel and electricity components and indirect energy comprises fertilizer, seed, herbicide and machinery components (Pervanchon *et al*., 2002).

Energy use in agriculture has become an important subject in public agendas in recent years. Increase in energy use in agriculture has been causing the depletion of non-renewable energy resources and concurrently, application of chemical fertilizers and pesticides environmental pollution (Nemecek *et al*., 2011). However, the success and profitability of any agricultural production is dependent on energy consumption. Therefore, an effective energy use is required to achieve the sustainability in agriculture. And this could be realized only by ensuring conservation of fossil resources, reduction of air pollution and financial savings (Bailey *et al*., 2003). Integrated farming systems, protected soil tillage applications and organic farming are suggested to reach these objectives (Pervanchon *et al*., 2002).

Conventional soil tillage demands more energy compared to other soil tillage systems. Marakoglu and Carman (2010) stated that conservation tillage had the lowest labor and machinery energy input. Kosutic *et al*. (2005) reported that no-till system requires 85.1% less energy with respect to conventional tillage. Kumar *et al*. (2013) reported that the energy use efficiency increased by 13% in conservation tillage when compared to conventional soil tillage. Yalcin and Cakır (2006) reported that conventional soil tillage had the highest and no-till the lowest fuel consumption. In another study, effects of different soil tillage systems over energy consumption had been studied, no-till had the lowest energy consumption (Tabatabaeefar *et al*., 2009). Similarly, there are many studies showing that the

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energy consumption in conventional soil tillage is more than conservation tillage (Zugec *et al*., 2000; Salem *et al*., 2013).

Crop yield largely depends on weed control, residue management and cultural practices as well as environmental factors such as soil and climate conditions (Shipitalo *et al*., 2000). Crop yields in conservation tillage was either equal or higher than conventional tillage system (Fabrizzi *et al*., 2005; Schillinger *et al*., 2010; Imran *et al*., 2013) and even lower crop yield under conservation tillage are also reported (Zentner *et al*., 2004; Li *et al*., 2008; Moreno *et al*., 2011; Nassi *et al*., 2011).

Conservation tillage methods such as no-till and reduced tillage have become more prevalent for many reasons. For example, conservation tillage protects the soil from water and wind erosions (Morris *et al*., 2010), improves the physical (Martınez *et al*., 2008), chemical (Guzman *et al*., 2006) and biological properties of soil (Fernandez *et al*., 2010). At the same time, conservation tillage saves time in preparing seed bed (Hernanz *et al*., 1995), conserves the soil moisture (Verch *et al*., 2009) and reduces the cost of production (Uzun *et al*., 2012).

Likely, crop rotation is highly beneficial for conserving soil, water resources and productivity. By crop rotation, increase in yield is achieved positively by its impact on water and nitrogen availability in the soil, structure, microbial activity and weed control (Karlen *et al*., 1994).

Continuous soil tillage is characterized by low yield and very high production costs. At the same time, it has a negative impact on soil properties, crop growth, environment, water and wind erosions (Huang *et al*., 2012). These findings emphasize the importance of use of proper soil tillage and sowing method (Hernanz *et al*., 1995).

In literature, a limited research studies report the impact of soil tillage and crop rotation together (Hemmat and Eskandari, 2004; Singh *et al*., 2008; Salem *et al*., 2013). But soil tillage methods used in these studies seems relatively alike to each other and crop rotations are completely different.

Wheat is probably the most important grain grown in the world and staple product for Turkey. In Turkey, it is grown on 7.7 million hectares of land with the total annual production of 22 million tons (TSI, 2013). The energy used for tillage in wheat production is a major direct expense in terms of fuel costs to farmers. While tillage systems used in agricultural production vary across the world, in the Central Anatolia Region of Turkey, continuous wheat production is conducted mainly with intensive conventional tillage (CT), especially moldboard plowing. The most commonly used crop rotations covering large areas in Turkey are wheat-fallow, wheat-chickpea and wheat-wheat.

Nonetheless, most of energy balance studies have been evaluated based on crop and very few on crop rotations. Moreover, studies on both soil tillage and crop rotation together are very few. In these studies, it is impossible to find the same soil tillage and crop rotation. At the same time, energy equivalents used in energy balance studies are selected to cover a great range in literature reviews, and this causes difficulties in comparing results. However, in such types of energy balance studies, it would be a meaningful to look at how the subjects increase or decrease rather than the size of numbers.

Long term energy balance studies concerning soil tillage and crop rotations are fairly limited. Energy balance knowledge will be beneficial to enhance the productivity of winter wheat production. There is need to evaluate the effect of different soil tillage and different crop rotation practices together in order to achieve more sustainable wheat production. Therefore the purpose of the study is to compare and evaluate energy indices, yield and yield components of winter wheat for different soil tillage and crop rotations used in rainfed regions such as the Central Anatolia Region of Turkey.

Materials and Methods

This study was conducted under rainfed conditions during the growing seasons at the Bahri Dagdas International Agriculture Research Institute Konya, Turkey. In this region, the climate is semi-arid with cold winters, rainy springs, hot and dry summers. The prevailing winds in the Konya Basin tend to be dry, resulting in an average relative humidity value of below 50% (TSMS, 2007), with long-term data indicating a mean annual precipitation level of 320.9 mm. The information on agro-climatic conditions is given in Table 1. The experimental field had clay texture with pH of 8.3 (Table 2).

Field Experiment

Using three replicates, with tillage treatments in main plots and crop rotations in sub-plots, a split-plot randomized complete block design was used in present study.

Tillage treatments consisted of conventional tillage (CT), reduced tillage (RT) and no-till (NT). In conventional tillage, four types of machinery used were moldboard plow (MP), combined cultivator and tooth harrow (CCTH), combined spring tooth and rotary harrow (CSTHRH) and seeding machine. Rotary tiller and seeding machine were used in reduced tillage and direct sowing in no-till was performed using a seeding machine without any soil tillage. In all these three practices, disc sowers were used in each seeding machine.

In the study, wheat-fallow (W-F), wheat-chickpea (W-C) and wheat-wheat (W-W) crop rotations were used due to Turkey's large rainfed regions.

The same soil tillage and growing techniques used by the growers in the region were applied. Field operations conducted for each soil tillage and crop rotation are given in Table 3. Soil tillage depths applied were 25 cm for moldboard plow, 10 cm for CCTH, CSTHRH and rotary tiller.

Table 1: Agro-climatic conditions at the Konya Experimental Station

Years	Months												Total
	Sep	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	
	Precipitation (mm)												
2003/04	16.6	9.5	9.8	108.6	34.1	31.1	3.1	40.6	17.2	56.9	4	21.4	352.9
2004/05	0	0	51.3	2.8	29.5	12.9	13.8	31.8	12.5	3.5	12.2	14	184.3
2005/06	20.9	34.7	68	9.8	21.2	23.8	18.4	58.1	17.9	9.9	0.3	0	283
2006/07	20	66.1	51.9	0.1	20.9	19.3	15.4	16.1	16.3	15.9	0.4	6	248.4
Long Term	11.2	29.7	31.9	40.4	37.3	29.3	29.2	31.7	43.3	24.5	6.9	5.5	320.9
	Air temperature (°C)												
2003/04	21.05	11.7	9.3	1.75	-1.7	3.3	8.5	11.85	15.9	19.6	23.75	24.6	-
2004/05	18.6	16.7	6.4	1.55	4.3	1.6	7.1	12.55	16.55	19.95	24.95	23.45	-
2005/06	18.2	11.5	8	0.85	5.45	0.05	8.05	11.9	18.2	20.95	22.8	25.9	-
2006/07	19.85	16.4	5	-0.5	2.35	-1	9.05	9.15	18.25	23.3	25.5	25.1	-
Long Term	16.1	11.6	2.7	-2.1	-5.8	1.35	5.9	10.9	16.6	19.25	23.3	21.55	-

Table 2: Soil physical properties of the experimental area

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture[a]	pH
0-30	21	26	53	Clay	8.3
30-60	23	28	49	Clay	8.3

[a]USDA texture classification

Table 3: Summary of the operations performed for each tillage treatment and crop rotation

Field Operation	Conventional tillage						Reduced tillage						No–till					
	W-F		W-C		W-W		W-F		W-C		W-W		W-F		W-C		W-W	
	W	F	W	C	W	W	W	F	W	C	W	W	W	F	W	C	W	W
MP	1	1	1	1	1	1												
CCTH	1	1	1	1	1	1												
CSTHRH	1	1	1		1	1												
Rotary tiller							1	1	1	1	1	1						
Conventional sower	1		1	1	1	1	1		1	1	1	1						
Direct sower													1		1	1	1	1
Fertilizer machine	1		1		1	1	1		1		1	1	1		1		1	1
Sprayer	1		1		1	1	2	1	2	1	2	2	2	2	2	1	2	2
Harvester	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1
Seed(kg ha^{-1})																		
Wheat	230		230		230	230	230		230		230	230	230		230		230	230
Chick pea				90						90						90		
Fertilizer (kg ha^{-1})																		
Nitrogen (N)	70		70	30	70	70	70		70	30	70	70	70		70	30	70	70
Phosphorus (P_2O_5)	70		70	55	70	70	70		70	55	70	70	70		70	55	70	70
Herbicide (L ha^{-1})																		
Granstar	0.7		0.7		0.7	0.7	0.7		0.7		0.7	0.7	0.7		0.7		0.7	0.7
Glyphosate							6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6

wheat-fallow (W-F), wheat-chickpea (W-C) and wheat-wheat (W-W)

Table 4: Energy equivalents of wheat and chick pea production inputs and outputs

Particulars	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
Human labor	H	1.95	Jarach (1985); Tabatabaeefar *et al*. (2009)
Machinery	H	62.70	Singh (2002)
Diesel fuel	L	56.31	Sing (2002); Shahin *et al*. (2008)
Nitrogen (N)	kg	78.23	Helsel (1992); Alhajj *et al*. (2013)
Phosphorus (P_2O_5)	kg	13.07	Tabatabaeefar *et al*. (2009)
Herbicide	L	120	Canakci *et al*. (2005); Shahin *et al*. (2008)
Seed (wheat)	kg	14.7	Shahin *et al*. (2008); Alhajj *et al*. (2013)
Seed (chick pea)	kg	14.7	Kitani (1999)
B. Outputs			
Wheat grain	kg	14.7	Ozkan *et al*. (2004)
Wheat straw	kg	12.5	Ozkan *et al*. (2004); Shahin *et al*. (2008)
Chick pea grain	kg	14.7	Kitani (1999)

Karahan bread wheat variety appropriate for dry areas and widely grown in Turkey was used in the study. Wheat seeds were sown in October at the rate of 550 seeds m^{-2} and row spacing of 14.5 cm. As fertilizer, 27 kg N ha^{-1} and 70 kg P_2O_5 ha^{-1} were applied during seeding; the remaining 43 kg N ha^{-1} was applied in March as shown in Table 3. Herbicide was used for weed control at tillering stage in April. Total herbicide used before seeding in wheat sowing in reduced tillage and no-till. Experimental plot size was 15 m × 8 m. Crops were harvested using a 1.2 m × 5 m size combine.

Chickpea, Gökce variety appropriate for dry areas was used. The first tillage was done in the fall. In April, seeding was performed using intra-row spacing of 5 cm and inter-row spacing of 45 cm. During the seeding, 30 kg N ha^{-1} and 55 kg P_2O_5 ha^{-1} were used as shown in Table 3. No chemical spraying was applied for the chickpea. Weed control was carried out by hoeing. Total herbicide was used before seeding in chickpea grown in reduced tillage and no-till. Harvesting was done manually.

Grain Yield and Yield Components

Grain yield (GY), biomass yield (BY), harvest index (HI, biomass yield/grain yield), number of spikes m^{-2}, number of grains m^{-2}, number of grains per spike, plant height, thousand kernel weight (TKW), and hectolitre mass (HM) were evaluated. Several days before the harvest, 50 plants randomly selected from each plot were cut from the ground surface level and dried for 5 days. At the end of drying, 50 plants were weighed and biomass yield was determined. By combining these plants, seed yield was found; and thousand kernel weight based on the weight of 400 seeds counted. Crop was harvested by combine harvester. By means of seed yield and values measured from 50 plants, yield components were calculated (Bell and Fischer, 1994). Plant height was obtained measuring the distance between the soil surface and the top end of the spikelet of the spike (excluding awns) at 10 different locations randomly selected from each plot before harvesting (Kün, 1988). Hectolitre mass was determined using the AACC 55-10 method (Anonymous, 2000).

Energy Balance

Energy balance on soil tillage and crop rotations was determined by the methods explained by Hülsbergen *et al.* (2001).

Energy equivalents of the inputs and outputs used in wheat and chickpea productions to evaluate the energy efficiency of the agricultural production are given in Table 4.

Energy Inputs (ETi) were divided into two main groups; direct and indirect energy. Direct energy (Ed) consists of diesel fuel consumption and human labor and indirect energy (Ei) comprises of the energy used for machinery, fertilizer, herbicide and seed.

In agricultural production systems, human labor energy is usually not taken into consideration in energy balance calculations (Borin *et al*., 1997; Hülsbergen *et al*., 2001). But, labor energy has been included in calculations of present study. Fuel consumption for each activity was determined. Direct energy (E_d) was calculated using the formula given below (Hülsbergen *et al*., 2001; Tabatabaeefar *et al*., 2009; Alhajj *et al*., 2013).

$$E_d = (HL \times E_{HL}) + (FC \times E_{FC}) \quad (1)$$

In calculation of indirect energy (E_i), the following formula was used (Hülsbergen *et al*., 2001; Hernanz *et al*., 2014):

$$E_i = ((W \times E_{ME})/(T \times EFC)) + (FE \times E_{FE}) + (HE \times E_{HE}) + (SE \times E_{SE}) \quad (2)$$

In the formula, each addition component mean the energies for machinery, fertilizer, herbicide and seed, respectively. The pertinent component values recommended for agricultural production in the region used are as shown in Table 3.

Energy input is obtained by the sum of direct energy and indirect energy. In calculating the input energy, energy required for storage and transportation was not taken into consideration (Hülsbergen *et al*., 2001). This input energy was calculated for each soil tillage and crop rotation.

$$E_{Ti} = E_d + Ei \quad (3)$$

Energy output for each crop (wheat and chickpea) was obtained by the following formula (Tabatabaeefar *et al*., 2009; Alhajj *et al*., 2013):

$$Eo = Eg + Es \quad (4)$$

While calculating the energy output for wheat; both grain (Eg) and straw (Es) energy values were used. For chickpea, only grain (Eg) energy value was taken into consideration.

Energy parameters used in crop production (net energy, energy use efficiency, specific energy, energy productivity) are given in Table 5 (Hülsbergen *et al*., 2001; Tabatabaeefar *et al*., 2009).

Analysis of variance of the data was performed by MSTAT-C statistics program. LSD test was used in comparison of means.

Results

Grain Yield and Yield Components

In present study, wheat yields varied between 965–1724 kg ha^{-1}. Tillage treatments, crop rotation and the interaction between these were statistically significant ($P \leq 0.05$) (Table 6). The highest grain yields obtained were 1456 kg ha^{-1} in the NT practice among tillage treatments, and 1355 kg ha^{-1} in the W-F practice among crop rotations (Table 7). The highest grain yield obtained in the interaction between NT × W-F was 1724 kg ha^{-1}. All crop rotations with conventional soil tillage were placed in the same group with the lowest values (Table 7).

Table 5: Energy parameters in crop production

Variable	Definition	Unit
Crop Production (CP)	Grain	(kg ha^{-1})
Total Energy Input (E_{Ti})	E_{Ti}=E_d + E_i	(GJ ha^{-1})
Energy Output (Eo)	Eo=Eg + Es	(GJ ha^{-1})
Net Energy (NE)	NE=E_{Ti}-Eo	(GJ ha^{-1})
Energy Use Efficiency (EUE)	EUE=Eo/E_{Ti}	-
Energy Productivity (EP)	EP=CP/E_{Ti}	(kg GJ^{-1})

Table 6: Effects of tillage treatment and crop rotation on winter wheat grain yield and yield components

	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest index (%)	Thousand kernel weight (g)	Plant height (cm)	Number of spikes m^{-2}	Number of grains m^{-2}	Number of grains spike^{-1}	hectolitre mass (kg hL^{-1})
Tillage (T)									
CT	965 c	2443 c	0.396 a	28.01	41.91	266 c	3454 b	13.03	75.63
RT	1190 b	3151 b	0.376 b	27.84	42.50	326 b	4277 b	13.14	73.63
NT	1456 a	4064 a	0.357 c	27.23	47.33	422 a	5331 a	12.71	74.97
Crop Rotation (CR)									
W-F	1355 a	3599 a	0.376	29.49 a	45.61	357	4615 a	12.94	75.60 a
W-C	1143 b	3011 b	0.387	27.40 b	41.30	333	4210 b	12.82	75.06 a
W-W	1113 b	3047 b	0.369	26.18 b	44.83	324	4236 b	13.11	73.58 b
Means	1203	3219	0.376	27.69	43.91	338	4354	12.96	74.75
LSD values									
T	221**	588**	0.015**	NS	NS	40.37**	1016*	NS	NS
CR	57.42**	274**	NS	1.46**	NS	NS	334*	NS	1.05**
T x CR	99.46**	475*	0.036*	2.54*	7.05*	NS	578**	1.66**	NS

NS: not significant. *: $P \leq 0.05$. **: $P \leq 0.01$

Among yield components, some characteristics were found statistically significant in only soil tillage, some in crop rotation, and interaction of both practices (Table 6). The highest biomass yields (BY) were obtained from NT (4064 kg ha^{-1}) and W-F (3599 kg ha^{-1}).

Harvest index (HI) was significant in soil tillage, and insignificant in crop rotations with CT to its highest HI value (0.39).

Thousand kernel weight (TKW) was significant in crop rotations with the highest value for W-F (29.49 g), and was statistically similar to the W-C and W-W rotations. Soil tillage practices were also insignificant.

Plant height for wheat was insignificant with respect to soil tillage and crop rotation practices.

Number of spikes m^{-2} was statistically significant in soil tillage with the highest number of spikes m^{-2} obtained in NT and the lowest in CT.

Number of grains m^{-2} was found statistically significant in both soil tillage and crop rotation.

The highest number of grains per spike was obtained for NT and W-F and the number of grains per spike were statistically insignificant.

The average hectolitre mass (HM) obtained was 74.75 kg hL^{-1}. Soil tillage effect was statistically insignificant and of crop rotation significant. The lowest HM was obtained in W-W crop rotation.

Energy Indices

Energy input: Tillage treatment showed significant effect on energy inputs (Table 8). In comparison to NT, direct energy accounted 2.15 and 1.42 times higher in CT and RT, respectively. Indirect energy inputs contributed more to crop production where fertilizer energy accounted 46.12%, 47.69% and 50.36% for CT, RT and NT, respectively. Seed energy followed the fertilizer energy. Seed energy was maximum in NT by 26.12%, and minimum in CT by 23.92%. Contribution of herbicide and machinery use to indirect energy was quite low. In average, machinery use was determined to be 5.81% and herbicide of 5.18%. In this study, fertilizer energy accounted for the highest contribution in total energy input followed by seed, herbicide and machinery energy.

Energy inputs for crop rotation were found to be 14.54 GJ ha^{-1}, 18.82 GJ ha^{-1} and 26.29 GJ ha^{-1} for W-F, W-C and W-W, respectively (Table 9). Nearly 2 fold difference was found between W-F and W-W crop rotations. Direct energy varied between 15.31% in W-W and 18.69% in W-F. In parallel to this, the fuel consumption was the highest by 4.01 GJ ha^{-1} in W-W crop rotation. The highest consumption with respect to indirect energy occurred in fertilizer energy, seed use followed it. Machinery and herbicide uses were relatively low.

Total energy input was highest by 27.04 GJ ha^{-1} under CT in W-W crop rotation and the lowest by 13.64 GJ ha^{-1} under NT in W-F crop rotation (Table 10).

Energy output: Significant difference with respect to energy output was found between tillage treatments (Table 8). The maximum energy output was 55.89 GJ ha^{-1} in NT and the minimum in CT. This was due to high wheat yield in NT practice. However, the lowest chickpea yield was obtained in NT practice (Table 10).

Table 7: Interaction effects of tillage treatment and crop rotation on winter wheat grain yield (kg ha^{-1})

	Conventional tillage	Reduced tillage	No-til
Wheat-Fallow Rotation	954 d	1387 b	1724 a
Wheat-Chickpea Rotation	973 d	1231 c	1224 c
Wheat-Wheat	966 d	951 d	1421 b
LSD : 99.46**			

Table 8: Effect of tillage treatment on energy variables

Energy Variable	Conventional tillage	Reduced tillage	No-til
Direct Energy (Ed)			
Human Labor	0.026	0.014	0.010
Diesel Fuel	4.51	2.98	2.10
Total Ed	4.54	3.00	2.11
Indirect Energy (Ei)			
Machinery	1.55	1.06	0.88
Seeds	4.95	4.95	4.95
Herbicides	0.11	1.46	1.46
Fertilizer	9.54	9.54	9.54
Total Ei	16.15	17.01	16.84
Energy Input (GJ ha^{-1}) (Ed+Ei)	20.69 a	20.01 b	18.95 c
Energy Output (GJ ha^{-1})	36.75 c	44.99 b	55.89 a
Net Energy (GJ ha^{-1})	16.06 c	24.98 b	36.94 a
Energy Use Efficiency	1.87 c	2.43 b	3.19 a
Energy Productivity (kg GJ^{-1})	51.16 c	69.66 b	86.73 a

Significant difference between energy outputs for crop rotations was found. Whereas W-F and W-C crop rotations are placed in the same group with the highest values and W-W with the lowest energy output value (Table 9).

Net energy: The highest net energy value of soil tillage practices was obtained in NT practice; and the lowest net energy in CT (Table 8). In crop rotations, the highest net energy value was found in W-F crop rotation; and the lowest in W-W (Table 9). Likewise, the highest net energy value was obtained in W-F crop rotation of NT practice. In three soil tillage practices, wheat contributed more to the net energy; and it was followed by chickpea (Table 10).

Energy use efficiency: NT had about two times more energy efficiency than CT practice (Table 8). Energy use efficiency values for crop rotations were in order for W-F, W-C and W-W, respectively (Table 9) with the highest efficiency in W-F crop rotation of NT practice and the lowest in W-W crop rotation of CT (Table 10). In all W-W crop rotations where mono culture is practiced, the lowest energy use efficiency was determined. In terms of crop, the energy use efficiency of wheat was 2.67 on average and of chickpea about 1.41.

Energy productivity: Energy productivity also varied between soil tillage practices and the highest energy productivity was obtained in NT and the lowest in CT (Table 8). Energy productivity values for W-F, W-C and W-W crop rotations were found 94.46 kg GJ^{-1}, 61.06 kg GJ^{-1} and 52.06 kg GJ^{-1}, respectively (Table 9). In interaction, for W-F crop rotation under NT practice, the highest energy productivity was realized. Average energy productivity of chickpea was higher than wheat (Table 10).

Discussion

The average grain yield obtained in present study was quite low compared to other studies. This might have been caused by the insufficient and erratic rainfall during the grain-filling stage (Table 1). For example, Hemmat and Eskandari (2004) obtained wheat yields of 1238 kg ha^{-1} for CT, 1408 kg ha^{-1} for RT and 1600 kg ha^{-1} for NT in wheat-chickpea crop rotation. Tabatabaeefar *et al.* (2009) reported wheat yields of 1588 kg ha^{-1} for CT and 1854 kg ha^{-1} for NT. In a 4 year study, Hernanz *et al.* (1995) reported winter wheat yields of 2350 kg ha^{-1}, 2490 kg ha^{-1} and 2790 kg ha^{-1} in CT, RT and NT, respectively.

Thousand kernel weight (TKW) was insignificant in soil tillage and significant in crop rotations. On other hand, Hemmat and Eskandari (2004) in their study on wheat-chickpea crop rotation obtained TKWs for CT, RT and NT as 34 g, 34 g and 33 g, respectively. Whereas, Tabatabaeefar *et al.* (2009) obtained the TKW 38.81 g for CT and 38.2 g for NT; Di Fonzo *et al.* (2001) and De Vita *et al.* (2007) in their studies and reported higher 1000 kernel weight under NT than CT.

In present study, crop rotation effect was significant for hectolitre mass (HM). Jug *et al.* (2011) found the HM values for CT and NT in winter wheat as 79.4 kg hL^{-1} and 79.3 kg hL^{-1}, respectively. Wozniak (2013) found that HM in wheat was statistically insignificant among soil tillage practices. In the same study, following HM values; 75.6 kg hL^{-1} for CT, 75.2 kg hL^{-1} for RT and 75.2 kg hL^{-1} for herbicide tillage were obtained. Troccoli and Di Fonzo (1999) and De Vita *et al.* (2007) stated that the HM had been affected by climatic conditions more than by soil tillage practices. Particularly, at the grain-filling stage, the shape and size of grain are quite affected by climate conditions.

The lowest energy input in our study was observed in NT. Zentner *et al.* (2004) observed highest energy input in CT and the lowest in NT practices. In their study, Moreno *et al.* (2011) reported that NT practice had lower energy input than CT practice. Hernanz *et al.* (1995) and Singh *et al.* (2008) also found similar results. Fertilizer contributed the highest energy input followed by seed energy input. Contribution of herbicide and machinery use was quite low. Moreno *et al.* (2011) and Zentner *et al.* (2004) also reported that fertilizer use energy accounted for highest contribution in total energy input. In this study, fertilizer energy was followed by seed, herbicide and machinery energy. Many researchers obtained similar results (Hernanz *et al.*, 1995; Sartori *et al.*, 2005; Khaledian *et al.*, 2010; Hernanz *et al.*, 2014).

The highest energy output observed in NT practice of W-F crop rotation and the lowest energy output in the W-W crop rotation of CT. This arises from the highest wheat yield obtained in the NT and W-F crop rotation. Crop residue caused wheat yield to be higher in NT than CT. Yields obtained for wheat and chickpea were relatively low, however, higher compared to chickpea.

Table 9: Effect of crop rotation on energy variables

Energy Variable	W-F	W-C	W-W
Direct Energy (Ed)			
Human Labor	0.013	0.018	0.019
Diesel Fuel	2.70	2.89	4.01
Total Ed	2.72	2.91	4.03
Indirect Energy (Ei)			
Machinery	0.91	1.08	1.51
Seeds	3.38	4.70	6.76
Herbicides	1.14	0.67	1.22
Fertilizer	6.39	9.46	12.78
Total Ei	11.82	15.91	22.27
Energy Input (GJ ha^{-1}) (Ed+Ei)	14.54 c	18.82 b	26.29 a
Energy Output (GJ ha^{-1})	47.97 a	48.26 a	41.40 b
Net Energy (GJ ha^{-1})	33.44 a	29.44 b	15.11 c
Energy Use Efficiency	3.35 a	2.58 b	1.58 c
Energy Productivity (kg GJ^{-1})	94.46 a	61.06 b	52.06 c

Table 10: Effect of tillage treatment and crop rotation on yield and energy variables

Energy Variable	CT			RT			NT			LSD
	W-F	W-C	W-W	W-F	W-C	W-W	W-F	W-C	W-W	
Yield (kg ha^{-1})										
Wheat	954 d	973 d	966 d	1387 b	1231 c	951 d	1724 a	1224 c	1421 b	99.46
Chickpea		533 a			495 a			312 b		177.85
Energy Input (GJ ha^{-1})										
Wheat	15.32 d	13.52 g	27.04 a	14.68 e	13.23 h	26.46 b	13.61 f	12.70 ı	25.39 c	0.00
Chickpea		6.20 a			5.67 b			5.13 c		0.00
Total	15.32 g	19.72 d	27.04 a	14.68 h	18.90 e	26.46 b	13.61 ı	17.83 f	25.39 c	0.01
Energy Output (GJ ha^{-1})										
Wheat	34.72 d	31.62 d	34.25 d	46.97 c	42.64 c	36.40 d	62.23 a	46.21 c	53.56 b	5.90
Chickpea		9.67 a			8.97 a			5.67 b		3.22
Total	34.72 f	41.29 de	34.25 f	46.97 cd	51.61 bc	36.40 ef	62.23 a	51.88 bc	53.56 b	6.39
Net Energy (GJ ha^{-1})										
Wheat	19.40 c	18.09 c	7.21 d	32.29 b	29.41 b	9.94 d	48.62 a	33.52 b	28.17 b	5.89
Chickpea		3.47			3.30			0.53		NS
Total	19.40 c	21.56 c	7.21 d	32.29 b	32.71 b	9.94 d	48.62 a	34.05 b	28.17 b	6.38
Energy Use Efficiency										
Wheat	2.27 d	2.34 d	1.27 e	3.20 c	3.22 c	1.38 e	4.57 a	3.64 b	2.11 d	0.39
Chickpea		1.56			1.58			1.10		NS
Total	2.27 d	2.09 d	1.27 e	3.20 b	2.73 c	1.38 e	4.57 a	2.91 bc	2.11 d	0.36
Energy Productivity (kg GJ^{-1})										
Wheat	62.26 d	72.01 c	41.89 f	94.48 b	93.08 b	49.37 e	126.64 a	96.43 b	64.91 d	6.93
Chickpea		86.01			87.22			60.83		NS
Total	62.26 d	49.36 e	41.89 f	94.48 b	65.16 cd	49.37 e	126.64 a	68.66 c	64.91 cd	5.97

Wheat-fallow (W-F), wheat-chickpea (W-C) and wheat-wheat (W-W)

This also reflected on the energy use efficiency. Energy use efficiency for wheat and chickpea obtained was 2.66 and 1.41, respectively (Table 10). Moreno *et al*. (2011) noted that higher energy output obtained in barley-fallow crop rotation compared to barley-barley. Energy output values generally followed the same path with net energy values (Zentner *et al*., 2004).

Energy use efficiency was lower in CT than NT. Hernanz *et al*. (1995) found energy use efficiencies for CT, RT and NT in winter wheat as 2.74, 3.19 and 3.62, respectively. Borin *et al*. (1997) noted that the energy use efficiency value increased as the number of soil tillage reduced. This coincides with present study findings. Tabatabaeefar *et al*. (2009) found a statistical difference with respect to energy use efficiency between soil tillage practices; and obtained the energy use efficiency values in winter wheat as 4.87 for NT practice and 3.65 for CT. Especially W-W crop rotations under CT and NT practices gave the lowest energy use efficiency (Hernanz *et al*., 1995). Zentner *et al*. (2004) suggest that the energy use efficiency increased in all crop rotations except W-W under NT practice. This applies to the existing study. Moreno *et al*. (2011) found that the energy use efficiency values were 3.85 in barley-fallow crop rotation and 2.00 in barley-barley crop rotation.

Zentner *et al*. (1998) reported that the energy productivity values generally follow the same path with energy use efficiency and similar trend was observed in present study.

This study was conducted in dry conditions for four growing seasons in the Central Anatolia region. Energy balances for three soil tillage and crop rotations was also compared. All soil tillage and crop rotation practices in the trial were the same as practiced by the farmers in the region.

Annual rain amount and distribution affected the crop yield, and thus for the energy output and energy balance. The rain amount and its distribution are highly important in the Central Anatolian region with respect to crop growing technique affecting not only the crop yield but also the effectiveness of fertilizer application. Similarly, there were significant differences in energy inputs and outputs with respect to years (Wilhelm and Wortmann, 2004; Moreno *et al*., 2011). Thus, present study will be an important reference for soil tillage, crop rotation and dry regions.

There are different soil tillage and different crop rotation studies available in energy analysis subject (Hernanz *et al*., 1995; Borin *et al*., 1997; Zentner *et al*., 1998; Zentner *et al*., 2004; Hemmat and Eskandari, 2004; Sartori *et al*., 2005; Khaledian *et al*., 2010; Nassi *et al*., 2011; Moreno *et al*., 2011; Hernanz *et al*., 2014). In these studies, methodologies, locations, soil and climate conditions, and practices are quite different.

Conclusion

In this study, energy indices, winter wheat yields and yield components were examined for various soil tillage and crop rotations used in rainfed regions such as the Central Anatolia Region of Turkey.

Energy efficiency was higher in W-C and W-F crop rotations; thus it can be utilized in dry areas of the Central Anatolia Region.

Among soil tillage practices, the highest wheat grain yield was obtained in the NT practice. The NT practice had the most appropriate energy use efficiency for dry areas of the Central Anatolia Region. When compared to other soil tillage methods, the NT practice can be recommended for dry areas of the study region in W-F and W-C crop rotations.

Nomenclatures

E_{Ti}: Total energy input (GJ ha^{-1}), E_d: Direct energy input (GJ ha^{-1}), E_i: Indirect energy input (GJ ha^{-1}), HL: Human labor (h ha^{-1}), E_{HL}: Human labor energy equivalent (GJ h^{-1}), FC: Fuel consumption (L ha^{-1}), E_{FC}: Fuel energy equivalent (GJ L^{-1}), W: Weight of the implement/tractor (kg), E_{ME}: Manufacturing energy equivalent of the implement/tractor (GJ kg^{-1}), T: Economic life of the implement/tractor (h), EFC: Effective field capacity (ha h^{-1}), FE: Amount of fertilizer (kg ha^{-1}), E_{FE}: Energy equivalent required to produce fertilizer (GJ kg^{-1}), HE: Amount of herbicide (L ha^{-1}), E_{HE}: Energy equivalent required to produce herbicide (GJ L^{-1}), SE: Seed rate (kg ha^{-1}), E_{SE}: Energy equivalent required to produce seed (GJ kg^{-1}), Eg: Grain energy (GJ ha^{-1}), Es: Straw energy (GJ ha^{-1}), Eo: Energy Output (GJ ha^{-1})

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