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Energy Use Efficiency of Strip Tillage Systems for Corn Silage Production in Middle Anatolia

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ABSTRACT

In this study, three different strip tillage applications were used as an alternative to Conventional Tillage (CT). While Original Strip-Till (OST) machine made by the Maschio Gaspardo was used in one of the applications of the strip tillage, the other two Machines [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers] were modified and used in strip tillage. Depending on the strip tillage application used, about 35–40% of soil surface was tilled. For the three applications, the penetration resistance and shear stress of soil ranged from 0.45 to 1.91 MPa and from 0.36 to 0.48 N cm^{-2}, respectively. The energy ratio, energy productivity, specific energy, net energy gain, and energy intensiveness were calculated. There were significant differences (P< 0.01) among the treatments in terms of various energy indices and corn silage yields. In the experiments with no hoeing, the silage yield ranged from 3,714 to 3,953 kg ha^{-1}; whereas, with hoeing, the yield increased, ranging from 3,964 to 4,952 kg ha^{-1}. The average net energy gain of corn silage production with and without hoeing applied was 156,155.68 and 131,037.75 MJ ha^{-1}, respectively. Energy use efficiency was the highest in the MHST method with hoeing. As a result, in terms of energy use efficiency, MHST (Modified Horizontal shaft Strip-Till system) method with hoeing can be suggested for use in the Middle Anatolian Region.

Keyword: Corn silage yield, Energy balance, Energy ratio, Specific energy, Maize.

INTRODUCTION

The increasing world population as well as land and water scarcity have become the main challenge for food security, creating pressure on agricultural production. Therefore, sustainable agriculture is gaining increasing importance. Sustainable agriculture integrates three main goals: environmental health, economic profitability, and social and economic equity.

Tillage is an important process for creating good seedbed conditions for small seeds. The purpose is to create close seed-to-soil contact and an environment that will allow optimal crop establishment and growth. The Conservation Technology Information Centre defines strip-tillage as a modification to a direct seeding system, where disturbance is less than one-third of the total cultivated field. Crop residue is removed from the cultivated strips and placed between rows with the seed being drilled into the strips (Morris *et al*., 2007; Reeder, 2000). Strip tillage is one method practiced for cultivating soil under non-inversion tillage techniques that conserves soil moisture and uses crop residue to protect against soil erosion, thus increasing the environmental benefits for wildlife (Reeder, 2000). Where soil moisture conditions are suitable, strip tillage can be a useful alternative to other non-inversion tillage systems. Strip-tillage creates a narrow, residue-free strip of soil about 20–30 cm wide and 10–20 cm deep. The soil surface between the tilled strips is left undisturbed, as in no-till. Strip tillage creates an environment favorable for rapid seed germination and seedling growth. The tilling

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operation can be completed after harvest or in early spring before seeding. The tilled soil strips with less surface residue are dark, so excess moisture dries and the soil is quicker to warm for timely spring seeding (Morrison, 2002).

Agricultural conservation is an important strategy to reduce energy consumption. The technologies involved maintain water and soil, retain soil moisture, and increase crop yield and soil quality, all of which are beneficial for the sustainable development of agricultural production (Fabrizzi *et al*., 2005; Singh *et al*., 2011). Laufer and Koch (2017) studied the effects of strip tillage on the yields of sugar beet in Central Europe. They found that the plant dry matter yield and white sugar yield were approximately 7% higher for conventional tillage and reduced tillage compared to strip tillage. Plant nitrogen uptake revealed a similar pattern, indicating that nitrogen use efficiency was not affected by the tillage systems.

In the southeastern regions of the USA, soil compaction management relies heavily on the use of deep tillage. The conventional cotton production systems require a minimum of three to five field operations, at a cost of approximately \$12.4 ha^{-1}. Strip tillage systems have shown considerable promise for reducing the energy and labor requirement, equipment cost, soil erosion, and cotton plant damage from blowing sand. Cost savings of approximately \$8 ha^{-1} could be achieved by strip tillage compared to that by conventional methods (Khalilian *et al*., 2004). Sarauskis *et al*. (2015) reported that the kinds of strip tillage machine and the working depth of the narrow tine had the greatest influence on the hourly fuel consumption. Also, increasing the working depth from zero to 200 mm increased the hourly tractor fuel consumption from 10.3 to 24.3%, depending on the working speed. The CO_2 emissions from tractors increased by approximately 20% on average with an increase in the working depth. The range of fuel energy consumption was 412-740 MJ ha^{-1} in conventional tillage, 183-266 MJ ha^{-1} in mulch technology, and 80-284 MJ ha^{-1} in zero tillage (Mileusnic *et al*., 2010). Consequently, there exists a potential to reduce energy inputs and production costs by reducing tillage operations (Hernanz *et al*., 1995)

Energy use in agriculture has become more intensive in response to the increasing population. In order to cover the required food needs of the growing population, chemical fertilizers, pesticides, tractors, farm machinery, electricity, and other natural resources are being used. However, the extensive use of these resources causes environmental problems that threaten public health. All inputs and outputs of a cropping system can be expressed in terms of energy. Hence, energy input and output analysis are used to determine the energy efficiency and the environmental impact of crop production (Pervanchon *et al.*, 2002; Alluvione *et al.*, 2011; Barut *et al.*, 2011). Baran and Gökdoğan (2016) analyzed the energy efficiency of different tillage methods on the production of corn as the secondary crop. Using conventional application, they recorded the highest corn yield of 67,035 kg ha^{-1}, energy use efficiency of 5.52, the energy output of 2,777,793.04 MJ ha^{-1}, energy productivity of 1.33 kg MJ^{-1}, and net energy of 227,493.67 MJ ha^{-1}. Marakoğlu and Çarman (2017) reported that conservation tillage application had the highest wheat grain and biomass yield compared to the conventional tillage. Conservation tillage produced the highest energy use efficiency (energy ratio), energy productivity, and net energy gain for wheat.

In Turkey, recent publications have shown the importance of the corn silage crop for livestock. It has an annual production of nearly 23.2 million tones and a seeding area of about 4.7 million acres. Within the cultivation of forage crops, it ranks second place after alfalfa. Strip tillage method is not used in corn silage production in Turkey. Farmers generally do not know this production technique. In Middle Anatolia, after the plant emerges, farmers apply herbicides. When the plants reach a height

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of about 15–20 cm, they initiate the drip irrigation system in order to save water. As a result, they do not hoe the fields. In addition, in the case of strip tillage applications, it is not appropriate to perform hoeing by conventional methods in terms of protective agricultural technique.

The objective of this study was to evaluate the performance of three different strip tillage systems compared to conventional methods. We aimed to: (1) Measure this performance in terms of the effects on soil parameters and crop responses, (2) Study, for the first time, the effects of the hoeing equipment on plant yields, and (3) Analyze and quantify the energy and material inputs and outputs in corn silage production.

MATERIALS AND METHODS

Experimental studies were conducted on clay-loam soils at the University of Selcuk, Faculty of Agriculture in Research and Education Center, during 2018. It is located 30 km away from Konya province, in the middle Anatolia region of Turkey. Using the randomized block design, the field experiment was organized into four blocks each with the strip tillage and conventional tillage treatments. Each individual trial plot measured 10×100 m. Some of the important physical properties of the experiment field soils are given in Table 1.

In order to determine the penetration resistance of soil, a hand penetrometer (Eijkelkamp, Netherlands) with a 60° cone angle was used. The measurements were made up to a depth of 20 cm, in 5 cm increments, with five replications in each plot, before and after soil tillage.

Table 1. Some of the important physical properties of the experiment field soils.

Soil properties	
Soil texture class (Clay: 43%, Sand: 29%, Silt: 28%)	Clay loam
Soil moisture content (% db)	15.5
Penetration resistance (MPa)	2.64
Shear stress (N cm^{-2})	2.06
Organic matter (%)	0.95
Residue amount (g m^{-2})	324

In order to determine the shearing strength, a soil shear testing device was used, having a diameter (d) of 10 cm and a height (h) of 12 cm. Torque arm having a measuring range of 0–80 Nm was impaled on the shear vane. The maximum Torque (T) was obtained using the device and the shear stress (τ) was calculated using the following equation (Okello, 1991) :

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

Soil moisture content and seedbed temperature were measured at the depths of 0–10 cm in each plot, until the seedlings emerged completely. A Time Domain Reflectometer (TDR 300) that had 12 cm rods was used to determine the soil moisture content. Seedbed temperature was measured using a thr251 model digital soil thermometer. In each plot, 20 measurements were taken randomly on a daily basis. The data were saved into the data logger and then transferred to a computer. The average monthly temperature and rainfall values in the experiment area are given in Table 2.

Four tillage units were attached on the frame in the strip tillage. The distance between the units was set to 70 cm. In the first application, the original strip-till equipment by Maschio Gaspardo was used; whereas the other two applications were modified. The different tillage treatments were performed on May 3, 2018. These treatments included:

1. Conventional Tillage (CT) [Plow+Cultivator–Float (×2)]
2. Original strip-till system (OST)
3. Modified Vertical shaft Strip-Till system (MVST)
4. Modified Horizontal shaft Strip-till System (MHST)

The specifications of the tools used in the experiment are given in Table 3. New Holland TD110 tractor was used in the experiments.

Table 2. Average monthly temperature and rainfall data.

Months	Temperature (°C, Min, Max, Avr)	Rainfall (mm)
May	10.3, 27.3, 18.2	59.6
June	8.8, 34.1, 21.0	16.6
July	10.4, 35.6, 24.9	3.6
August	10.7, 35.6, 24.3	2.0
September	5.3, 33.8, 20	7.2
Total		89

Corn silage variety OSSK 644 (TAREKS Seed Co. Ltd., Turkey) was planted on May 7th. The SK-PMB pneumatic precision seeder with four rows was used for seeding, designed for row crops such as corn and soybean (Sakalak Company, Konya, Turkey). The seed plate operated in a vertical plane and required a vacuum of 3.5–8.0 kPa to select a seed. Air suction from the holes of the seed plate caused the seed to stick to holes 4.5 mm in diameter. The seed was released from the rotating plate by blocking air suction over the opener, which had no seed tube. Each seeding unit was independently mounted on a four-bar parallel linkage system, equipped with joint springs to apply downward force on the seeding unit. It was also comprised of a furrow opener followed by a press wheel, which closed and compacted the seed furrow. In all treatments, 3 kg of corn seed per acre was used for sowing. The seed metering system was adjusted for a nominal seed spacing of 16 cm along the row and a nominal depth of 5 cm. The seeder was calibrated in the laboratory before field operation. The seed metering system was adjusted to 70 cm between the rows.

Fifty-five days after seeding, when the plant height was about 24 cm, hoeing machine was used in all treatments. In conventional practice, a horizontal shaft rotary hoe was used, equipped with C-type blades that had a working depth of 10 cm (Figure 2). In strip tillage applications, a special star-shaped hoeing machine was used, with a working depth of 6.5 cm, which was ground-driven and loosened the soil at the plant root zone. Each working unit consisted of 16 fingers made of hard rubber, connected at an angle of 35° with the horizontal plane, and the distance between two stars was 8–10 cm (Figure 1).

Approximately 45 days after seeding, the herbicide, Mustang (1,000 cc ha^{-1}), was applied for all treatments. After the first hoeing, drip irrigation system was placed in the fields. Total amount of water [89 mm of precipitation (Table 2)+490 mm of irrigation] applied to the plants during the period from planting to harvest was 579 mm. In a study conducted under the conditions of Çukurova, Kanber *et al*. (1990) stated that the irrigation water requirement of the second crop corn varies between 290–427.8 mm and seasonal water consumption between 474.2–530.9 mm.

Energy efficiency of the agricultural system was evaluated by the energy ratio between output and input (Hamzei and Seyyedi, 2016; Marakoğlu and Çarman, 2017). Several parameters including machinery, diesel oil, human labor, chemical fertilizers, seed amounts, chemicals, and irrigation, as well as corn silage output

Table 3. The specifications of the tools used in the experiment.

	Average speed (km h^{-1})	Working depth (cm)	Working/Strip width (cm)
Plough	2.9	24	165
Cultivator-roller combination	6.15	18	220
Original strip tiller	5.21	22	28
Modified vertical shaft strip tiller	4.23	18	26
Modified horizontal shaft strip tiller	4.56	17	25
Modified hoeing equipment for strip Tillage applications	3.0	6.5	2.0
Hoeing equipment with rotary tiller	3.8	10	283/35

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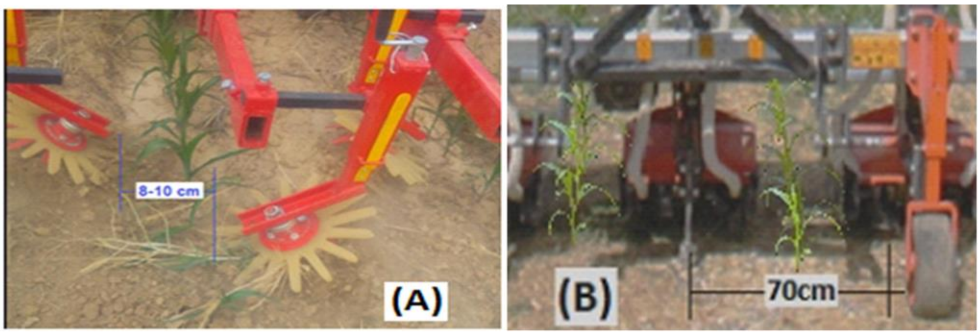

Figure 1. Modified hoeing equipment for strip tillage applications (A) and hoeing equipment with a rotary tiller (B).

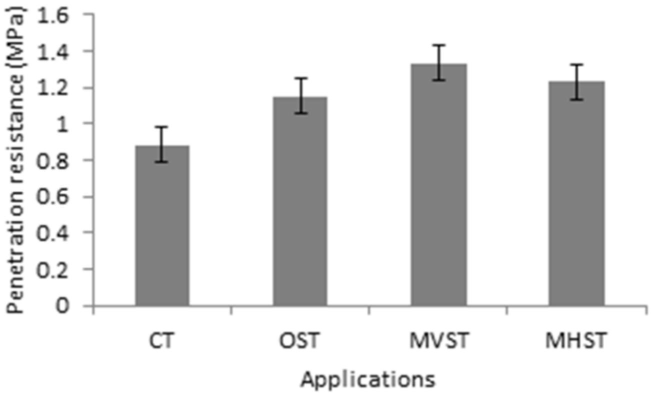

Figure 2. The effect of different soil tillage systems on soil penetration resistance. Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

(based on yields), were used to estimate the energy ratio. The energy equivalent of inputs and outputs in corn silage production are given in Table 4. The resources employed in previous research were used for determining the coefficients of energy equivalence. The results were tabulated after analyzing the data using Microsoft Excel program considering the inputs. Important indicators, such as energy use efficiency (energy ratio), energy productivity, energy profitability, net energy gain, and energy consumption per unit (specific energy) were calculated using the following equations (Tabatabaeefar *et al.*, 2009; Mousavi-Avval *et al.*, 2011; Zangeneh *et al.*, 2012; Marakoğlu and Çarman, 2017).

$$Energy\ use\ efficiency = \frac{Energy\ output\ (MJ\ ha^{-1})}{Energy\ input\ (MJ\ ha^{-1})}$$

$$Energy\ productivity\ (kg\ MJ^{-1}) = \frac{Product\ output\ (kg\ ha^{-1})}{Energy\ input\ (MJ\ ha^{-1})}$$

$$Energy\ profitability = \frac{Net\ energy\ (MJ\ ha^{-1})}{Energy\ input\ (MJ\ ha^{-1})}$$

$$Net\ energy\ gain\ (MJ\ ha^{-1}) = Energy\ output\ (MJ\ ha^{-1}) - Energy\ input\ (MJ\ ha^{-1})$$

$$Specific\ energy\ (MJ\ kg^{-1}) = \frac{Energy\ input\ (MJ\ ha^{-1})}{Product\ output\ (kg\ ha^{-1})}$$

RESULTS AND DISCUSSION

The penetration resistance of the tilled soil for conventional and the three different strip tillage applications is given in Figure 2. As

Table 4. Energy equivalent of inputs and outputs in corn silage production.

Particulars	Unit	Energy equivalent (MJ unit-1)	References
A. Inputs			
1. Human labor	h	2.30	(Kizilasalan, 2009; Barut *et al*., 2011)
2. Tractor	h	158.30	(Doering, 1980)
2. Machinery	h	121.30	(Doering, 1980)
3. Diesel fuel	L	41.00	(Reinhardt, 1993)
4.Chemicals	kg	120.00	(Mandal *et al*., 2002; Singh, 2002; Çanakci *et al*., 2005)
5. Fertilizers			
N	kg	60.60	(Bojoca and Schrevens, 2010)
P	kg	11.10	(Singh *et al.,* 2008)
K	kg	6.70	(Singh, 2002)
7. Irrigation	m^3	2.93	(Çalışır, 2007)
6. Seed (corn silage)	kg	104.00	(Knapp, 1980; Barut *et al.,* 2011)
B. Output			
Silage yield (Biomass)	kg	12.95	(Pimentel and Burgess; 1980)

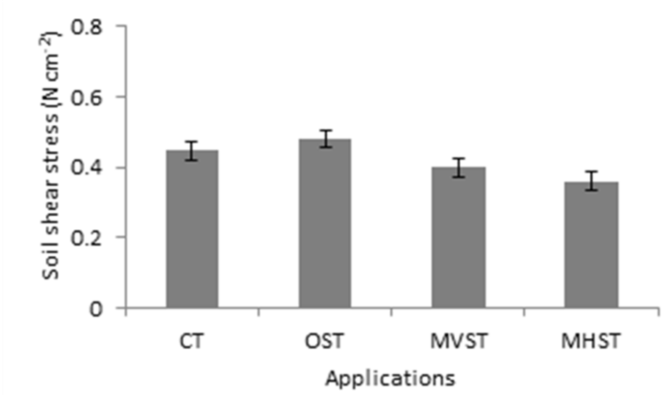

Figure 3. The effect of different soil tillage systems on soil shear stress. Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

expected, the effect on penetration resistance of different applications was significant (P<0.01). The Conventional Tillage (CT) treatment displayed the greatest change in penetration resistance: A decrease of 66.6% was observed compared to before-tillage. Erbach *et al*. (1992) and Çarman (1997) reported similar findings. While there were no differences between the three strip tiller treatments with respect to penetration resistance, there was a significant difference between the conventional treatment and strip tiller treatments. It was found that as the measurement depth increased, the penetration resistance also increased.

Shear stress of soil is an important characteristic in assessing tillage performance. The effects of different strip tillage applications on shear stress of soil are given in Figure 3. The values of shear stress of soil varied between 0.36 and 0.48 N cm^{-2}, depending on the different strip tillage application. The highest change in shear stress of soil, corresponding to a decrease of 82.5%, was obtained using the modified horizontal shaft strip-till system.

The aim of strip tillage is to conserve soil moisture and to make the seedbed warm for germination. Until the seedling emergence was completed, the soil moisture and temperature measurements were conducted periodically, as shown in Table 5. In this study, the soil moisture content in conventional tillage was lower compared to that in strip tillage treatments. The results show that there was a significant difference in soil moisture status between the different tillage systems. With an increase in the width of the strip, the loss of soil moisture via evaporation also increased. As a consequence, soil moisture content was conserved in relatively narrower strips. Despite this, there were no significant differences between the strip tillage treatments. Licht and Al-Kaisi (2005), found that strip tilling can be as effective as no-till technique, with respect to soil moisture conservation within the soil profile. By decreasing the width of the strips, it could be possible to obtain the advantages of no-till (Çelik and Altıkat, 2010). Many studies have reported that by reducing soil tillage, plant residues left at the surface of the soil can help conserve its moisture (Barut *et al*., 2011; Marakoğlu and Çarman, 2017; Altıkat *et al*., 2018)

The magnitude of changes in soil temperature due to strip tillage was highly dependent on air temperature throughout the day, when maximum air temperature often resulted in maximum soil temperature. As the soil is cultivated, the transfer of air temperature to the tilled layer gets easier. Temperature values measured in conventional tillage, having full-width tilling, were found to be 1–2°C higher than those in strip tillage, as shown in Table 5. The results showed that there was a significant difference in soil seedbed temperature status between the different tillage systems. As the width of the strip increased, the temperature of the topsoil layer (0–10 cm) also increased. This finding suggests that in conservation tillage, topsoil has a lower heat capacity and greater thermal conductivity than in strip tillage, due to lower moisture content. The change in soil temperature due to tillage effect was not reflected in the improvement of plant emergence rate index.

Due to the increasing traction force and travel speed, the fuel consumption needs of machines increased. Energy requirements of the different strip tillage systems and their effects on the yield of crops were compared. The fuel consumption for conventional and the three different strip tillage applications varied from 7.3 to 42 L ha^{-1} (Figure 4). The results indicated that the CT system was the greatest consumer of fuel energy with 4.2 L da^{-1}. The Original Strip-Till (OST) system consumed 1.82 L da^{-1}, or 56.6% less than the CT system. Meanwhile, the Modified Horizontal Strip-Till (MHST) system required 0.73 L da^{-1}, which is about 82% less energy than the CT system. Tabatabaeefar *et al*. (2009) compared five tillage treatment systems for wheat production and showed that the energy consumptions in zero tillage (no-till) system and in intensive tillage systems, which used moldboard plow, roller, and drill, were 19%

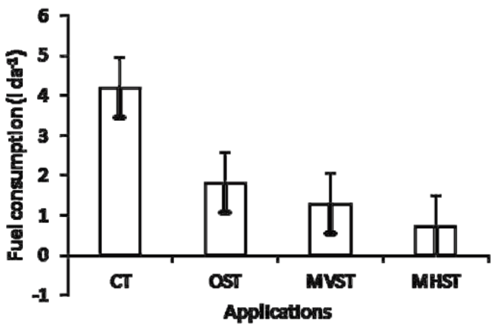

Figure 4. The effect of different soil tillage systems on fuel consumption. Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

Table 5. Soil moisture content and seedbed temperature depending on different tillage.

Applications	Soil moisture content (%)	Seedbed temperature (^{o}C)
	0–10 cm	0–10 cm
CT	20.95a±0.823	19.30a±0.535
OST	22.55b±0.896	17.97b±0.359
MVST	23.42b±0.888	17.55b±0.331
MHST	23.95b±1.303	17.40b±0.632
LSD (0.05)	1.535	0.742

Table 6. Effect of applications on silage yield.

Applications	No Hoeing applied	Hoeing applied	Mean*
CT	39530	46300	42915 a
OST	37610	39640	38625 b
MVST	37490	40950	39220 b
MHST	37140	49520	43330 a
Mean*	37942.5 a	44102.5 b	

and 32.5% of the total consumed energy, respectively.

In this study, corn silage yields varied between 37140 to 49520 kg ha^{-1} (Table 6). The differences between tillage treatments and hoeing applications were statistically significant (P≤ 0.01). The MHST method with hoeing resulted in the highest silage yield of 4952 kg da^{-1}; whereas, the CT method with no hoeing produced a yield of 3,953 kg da^{-1}. Both, CT and MHST practices, were placed in the same group with the highest values (Table 7). Barut *et al*. (2011) studied the effects of alternative soil tillage on energy use in silage production. The silage yields from conventional, minimum soil tillage, and direct sowing applications were 5,573, 5,608, and 4,769 kg ha^{-1}, respectively.

The energy equivalents of the inputs and outputs in the corn silage production and the energy efficiencies are given in Tables 7, 8, and 9. The highest energy input in the form of human labor was 23.09 MJ ha^{-1} in OST method with no hoeing (Table 7). It was 43.7% higher in CT method amounting to 33.19 MJ ha^{-1}. The share of human labor energy in total input energy is less than 1%. The average energy input from tractors and machines for the conventional practices was 1,302.32 MJ ha^{-1}. In trials with hoeing, it was 9.19% higher than in trials with no hoeing. The share of diesel fuel energy ranged between 17.1% for CT method with hoeing and 11.64% for the MHST method with no hoeing. In conventional practice, the average diesel fuel energy was 32% higher than that in strip tillage applications. Among the strip tillage applications, the lowest diesel fuel energy was obtained from the MHST application. The energy from fertilizers amounted to 3,733.7 MJ ha^{-1}. Depending on the applications, the share of the fertilizer energy ranged from 13.44 to 14.56%. The fertilizer energy was reported to have the biggest share in corn silage production, with a changing rate of 61.94% for reduced tillage method and 68.86% for direct seeding method (Barut, 2011). The share of irrigation energy was the highest in the total energy input, with a value of 14,558 MJ ha^{-1}, followed by diesel fuel, fertilizer, and seed energies. The share of irrigation energy ranged between 52.42% in CT method with hoeing and 56.77% in MHST method with no hoeing. Since middle Anatolia is a semi-arid region, irrigation energy has an important share in agricultural production. The share of seed energy varied between 11.24 to 12.17% depending on the method used. For corn silage production, the mean total energy input was 25,645.49 MJ ha^{-1} for strip tillage practices and 27,769.71 MJ ha^{-1} for conventional tillage practices.

Table 7. Amounts of inputs and output in corn silage production in trials with hoeing applied. [a]

	CT		MHST		MVST		OST	
	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%
Human labor	33.19	0.12	28.31	0.11	28.75	0.11	28.19	0.11
Tractor	745.88	2.69	637.56	2.45	647.45	2.46	634.49	2.41
Machinery	556.44	2,00	529.21	2.03	545.56	2.07	577.93	2.20
Diesel fuel	4747.80	17,10	3169.00	12.16	3403.00	12.93	3362.00	12.79
Herbicide	274.80	0,99	274.80	1.05	274.80	1.04	274.80	1.05
Fertilizers								
N	2805.78	10,10	2805.78	10.77	2805.78	10.66	2805.78	10.67
P	876.90	3,16	876.90	3.37	876.90	3.33	876.90	3.34
K	50.92	0,18	50.92	0.20	50.92	0.19	50.92	0.19
Irrigation	14558	52,42	14558	55.88	14558	55.33	14558	55.38
Seed	3120.00	11,24	3120.00	11.98	3120.00	11.86	3120.00	11.87
Total input (MJ ha^{-1})	27769.71	100,00	26050.48	100.00	26311.16	100.00	26289.01	100.00
Output (MJ ha^{-1})								
Silage yield	191867.20		205210.90		169696.80		164268.20	

[a] Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

Table 8. Amounts of inputs and output in corn silage production in trials with no hoeing applied.[a]

	CT		MHST		MVST		OST	
	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%	MJha^{-1}	%
Human labor	30,34	0,11	23,20	0,09	23,64	0,09	23,09	0,09
Tractor	682,36	2,50	523,23	2,04	533,12	2,06	520,16	2,01
Machinery	509,41	1,86	427,86	1,67	444,21	1,71	476,58	1,84
Diesel fuel	4440,30	16,24	2984,80	11,64	3218,50	12,42	3177,50	12,28
Herbicide	274,80	1,00	274,80	1,07	274,80	1,06	274,80	1,06
Fertilizers								
N	2805,78	10,26	2805,78	10,94	2805,78	10,83	2805,78	10,84
P	876,90	3,21	876,90	3,42	876,90	3,38	876,90	3,39
K	50,92	0,19	50,92	0,20	50,92	0,20	50,92	0,20
Irrigation	14558	53,23	14558	56,77	14558	56,20	14558	56,24
Seed	3120,00	11,41	3120,00	12,17	3120,00	12,04	3120,00	12,05
Total input (MJ ha^{-1})	27348,81	100,00	25645,49	100,00	25905,87	100,00	25883,73	100,00
Output (MJ ha^{-1})								
Silage yield	163812,30		153908,20		155358,60		155855,80	

[a] Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

The total energy input was found to be 8.28% higher in conventional practice. The total energy inputs for corn silage production in direct seeding and reduced tillage methods were 21,515.45 and 23,918.82 MJ ha$^{–1}$, respectively (Barut, 2011). Kelm *et al*. (2004) stated that the energy input in conventional corn silage production was in the range of 11.17 GJ ha$^{–1}$. Baran and Gökdoğan (2016) reported that the total energy input varied between 49148.47 to 50423.94 MJ ha$^{–1}$ in conventional and reduced tillage applications, respectively. The two largest components of energy input were fertilizer and fuel consumption. Energy input from fertilizers was more important than diesel fuel consumption because 40–60% of the total energy input came from fertilizer energy compared to 17–36% from diesel fuel consumption (Erdal *et al.*, 2007). In canola production, the most important energy inputs are from chemical fertilizers (65%), diesel fuel (24%), and chemical pesticides (4%) (Unakitan *et al.*, 2010). Similarly, in potato production, energies from fertilizers, diesel fuel, and seed consume were about 72% of the total energy inputs (Hamedani *et al.*, 2010).

In our experiments, the highest net energy gain was 179,160.42 MJ ha^{-1} and the lowest was 128,262.71 MJ ha^{-1}. The average net energy gain was found to be 6.3% higher in conventional tillage practices. Baran and Gökdoğan (2016) reported that in corn silage production, the highest net energy gain was 227,493.67 MJ ha^{-1} for conventional tillage application. The highest net energy gain for corn silage was reported to be 182,688.95 MJ ha^{-1} in reduced tillage practice (Barut, 2011). In this study, the net energy gain was low due to higher energy input in the form of irrigation.

Depending on the application treatments, the energy use efficiency ranged from 5.99 to 7.88. Among the three strip tillage applications, the MHST method produced the highest energy use efficiency. Çanakçı *et al*. (2005) determined that this efficiency value for corn was 3.8 in Antalya, Turkey. Öztürk *et al*. (2006) also observed similar results for corn production and found that the energy use efficiency was highest when using minimum tillage without stubble technique compared to conventional tillage without stubble technique. Komleh *et al*. (2011) found that the average energy use efficiency was 2.27 for corn silage. Singh *et al*. (2008) reported that the energy use efficiency was 3.2 for no-tillage and reduced tillage, 3.0 for conventional tillage in soybean-wheat production, 4.9 for no-tillage, higher in no-tillage and lower in conventional tillage in soybean-lentil and soybean-pea production.

The energy profitability varied between 4.99 and 6.88 depending on the different trials. It reached the maximum value of 6.88 for the MHST method with hoeing. We found that energy productivity was less than 2. It was highest in the MHST method with hoeing at a value of 1.9 while it was lowest in CT method with no hoeing at a value of 1.45. While the energy productivity was 0.085 kg MJ^{-1} for plowing and 0.114 kg MJ^{-1} for direct sowing, energy profitability was

Table 9. The average values of energy input in different tillage systems used for corn silage production. [a]

	No hoeing applied				With hoeing applied			
	CT	MHST	MVST	OST	CT	MHST	MVST	OST
EI (MJha^{-1})	27348,81	25645,49	25905,87	25883,73	27769,71	26050,48	26311,16	26289,01
EO (MJ ha^{-1})	163812,30	153908,20	155358,60	155855,80	191867,20	205210,90	169696,80	164268,20
Net energy gain (MJ ha^{-1})	136463,49	128262,71	129452,73	129972,07	164097,49	179160,42	143385,64	137979,19
Energy use efficiency	5,99	6,00	6,00	6,02	6,91	7,88	6,45	6,25
Energy profitability	4,99	5,00	5,00	5,02	5,91	6,88	5,45	5,25
Energy Productivity (kg MJ^{-1})	1,45	1,45	1,45	1,45	1,67	1,90	1,56	1,51
Specific energy (MJ kg^{-1})	0,692	0,691	0,691	0,688	0,600	0,526	0,643	0,663

[a] Conventional Tillage (CT), Original Strip-Till (OST), [Horizontal (MHST) and Vertical (MVST) shaft rotary Tillers].

3.96 for Cyclo Tiller and 2.65 for plowing, in the case of wheat production in Iran (Tabatabaeefar *et al*., 2009). Marakoğlu and Çarman (2017) reported that energy productivity was calculated to be 1.08 kg MJ^{-1} for conservation tillage (direct seeding) practice in wheat production.

Specific energy consumptions for each kilogram of corn silage in different strip tillage systems were compared, as shown in Table 9. CT method with no hoeing consumed the highest amount of energy, 0.692 MJ kg^{-1}, and MHST method with hoeing consumed the lowest, 0.526 MJ kg^{-1}. Tabatabaeefar *et al*. (2009) calculated that specific energy for wheat production was the highest, at 11.78 MJ kg^{-1}, by conventional tillage, and the lowest at 8.81 MJ kg^{-1} by conservation tillage (no-till). The specific energy for corn production was 3.88 MJ kg^{-1} in Antalya, Turkey (Çanakci *et al.*, 2005) for wheat production in middle Anatolia, when direct seeding system was compared to the conventional system, it was determined that the former system enabled 17% savings in energy (Marakoğlu and Çarman, 2017).

When input energy was classified into different types, it was clear that contributions from direct energy and non-renewable energy were higher in all cropping systems (Zangeneh *et al*., 2012; Baran and Gokdogan, 2016). Among the strip tillage applications, MVST method with hoeing had the highest direct energy input. As expected, the lowest direct energy was observed in MHST method with no hoeing. While the average share of renewable energy was 11.93%, it was as high as 88.07% for non-renewable energy. The share of indirect and non-renewable energy was about 80% in silage production (Barut *et al*., 2011). In a study conducted on corn silage production, while the share of indirect energy was about 75%, that of non-renewable energy was around 86% (Komleh *et al*., 2011). Irrigation was an important input, since we conducted this study in a semi-arid region. Therefore, direct energy input was found to be significantly higher than other studies due to the electrical energy used in irrigation. In grape production, of the total input energy, direct energy accounted for 43%, indirect for 57%, renewable for 39%, and non-renewable for 61% (Hamedani *et al.*, 2011).

CONCLUSIONS

Conservation tillage methods, such as strip tillage, have proven beneficial in agricultural production. The use of these methods can help farmers to increase energy use efficiency by decreasing energy consumption and increasing yield. In this study, we conclude that modified strip tillage systems statistically affect silage yields. A maximum yield of 49,520 kg ha^{-1} was produced using the MHST (with row hoeing) in contrast to the other strip tillage treatments. The highest task times and fuel consumptions were observed in the CT method that included higher field traffic. Envision that this research on strip tillage systems will benefit the farmers in Turkey. This may be achieved by modifying their existing vertical or horizontal shaft rototiller. On the basis of this research, the following conclusions can be drawn:

(i) The total energy consumption in corn silage production varies between 25,645.49 and 27,769.71 MJ ha^{-1}, depending on different tillage systems. In all four tillage systems tested, irrigation has the highest consumption and human labor has the lowest. CT requires the maximum energy input for corn silage production due to intensive machine traffic.

(ii) The MHST method with hoeing produces the highest energy output, while MHST method with no hoeing produces the lowest output. MHST had the highest energy ratio of 7.88, indicating the efficient use of energy in corn silage production.

(iii) Energy productivity, net energy gain, and energy profitability for MHST method with hoeing were higher than other treatments. We conclude that corn silage production is the most profitable due to its higher energy use efficiency in the semi-arid region.

(iv) Energy consumption for each kilogram of corn produced was lowest in MHST method with hoeing. Hence, despite a reduction in some inputs, total output remained higher.

(v) The average share of non-renewable energy for corn silage production was 88.07%. The strip tillage technologies make the saving of fossil energy consumption possible.

Energy use efficiency is one of the principal requirements for sustainable agriculture. Energy use in agriculture has been increasing in response to the growing population, limited supply of arable land, and a desire for higher standards of living. Extensive energy usage causes problems that threaten both public health and the environment. Energy use efficiency in agriculture may minimize environmental problems, prevent the destruction of natural resources, and help promote sustainable agriculture as an economical production system, especially in the middle Anatolia.

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کار آیی مصرف انرژی در سامانه خاکورزی نواری برای تولید ذرت سیلویی در آناتولیا میانه

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چکیده

در این پژوهش، کاربرد سه نوع خاکورزی نواری به عنوان جایگزین خاکورزی معمولی (CT) بررسی شد. به این منظور، در یکی از تیمارهای خاکورزی نواری، دستگاه اصلی پشته-نواری ساخت Maschio Gaspardo (OST) به کار رفت ولی دو دستگاه دیگر یعنی خاکورز دوار با شافت افقی(MHST) وعمودی(MVST) با تغییراتی برای خاکورزی نواری استفاده شد. بسته به تیمار خاکورزی نواری، ۴۰-۳۵٪ خاک سطحی ورز داده شد. برای این سه تیمار مقاومت فرو روی (penetration resistance) و تنش برشی خاک به ترتیب بین ۰/۴۵ تا ۱/۹۱ مگا پاسکال و بین ۰/۳۶ تا۰/۴۸ نیوتن بر سانتی متر مربع بود. سپس، برخه انرژی، بهره وری انرژی، انرژی ویژه، انرژی خالص به دست آ مده، و شدت انرژی محاسبه شد. از نظر نمایه های مختلف انرژی و عملکرد ذرت سیلویی تفاوت های معناداری ($p< 0.01$) بین تیمارهای مختلف وجود داشت. در تیمارهایی که بیلچه زنی (hoeing) نداشت عملکرد سیلویی بین ۳۷۱۴ و ۳۹۵۳کیلوگرم در هکتار بود ولی با بیلچه زنی عملکرد افزایش یافت و در محدوده ۳۹۶۴ تا ۴۹۵۲ کیلو گرم درهکتار بود. میانگین انرژی خالص به دست آمده از ذرت سیلویی با و بدون بیلچه زنی به ترتیب برابر 156155.68 MJ ha^{-1} و 131037.75 MJ ha^{-1} بود. کار آیی مصرف انرژی در روش های MHST همراه با بیلچه زنی بیشترین مقدار را داشت. بنا بر این، از نظر کارآیی مصرف انرژی، روش MHST (سامانه تغییر یافته خاک ورزی با خاکورز-نواری دارای شافت افقی) همراه با بیلچه زنی را می توان برای استفاده در منطقه آناتولیای مرکزی پیشنهاد کرد.

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