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Energy Analysis of the Tillage Systems in Second Crop Corn Production

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ABSTRACT. The aim of this experiment, to examine the energy input and output in the second crop corn production using four different tillage systems for soil preparation: (1) minimum tillage with stubble (MTS), (2) minimum tillage without stubble (MT), (3) conventional tillage with stubble (CTS), and (4) conventional tillage without stubble (CT). Corn was sown as a second crop just after harvest of wheat. Direct and indirect energy inputs consisting of machinery, fertilizers, seeds, irrigations and chemicals were converted into energy units according to their amounts being consumed. The machinery and fuel energy inputs for the tillage operation were reduced 53.7% with MT compared to CTS. The total energy input for producing corn utilizing CTS was 20,608 MJ/ha, compared to 19,102 MJ/ha for producing corn with MT. When the grain yield was taken into account, the energy output/input ratios for MTS, MT, CTS and CT were estimated to be 6.3, 7.6, 6.6 and 7.0, respectively. The tillage systems did not statistically affect uniformity of plant spacing, but statistically affected the yield. The grain yield was the greatest (8,719 kg/ha) in CT compared to the other tillage treatments. *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <http://www.HaworthPress.com> © 2006 by The Haworth Press, Inc. All rights reserved.]*

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INTRODUCTION

Agricultural machinery use is considered the main factor contributing to the total energy inputs in the agricultural system. Tillage represents half of the operations carried out annually in a field. Consequently, there is a potential to reduce energy inputs and production costs by reducing tillage (Hernanz et al., 1995; Sijtsma et al., 1998; Cavalaris and Gemtos, 2004). In addition, reduced tillage methods promote soil conservation. Reduced tillage is defined as tillage types leaving 15-30% residue cover on the soil surface after planting or 1,200-2,400 kg/ha of small grain residue equivalent throughout the critical wind erosion period (Köller, 2003). It is essential to prevent loss of the soil fertility while taking measures to increase the yield per area. One of the main factors in sustainable soil fertility is plant nutrients derived from decomposition of organic matter being decomposed by microorganisms comprising consistent nutrient resource in soil. The most natural way of returning the plant nutrients depleted from soil is to return organic matter formed by biological methods into the soil.

Considerable research has been performed on different tillage systems in agricultural production (Lal, 1999; Uri, 1999; Krzic et al., 2001; Ishaq et al., 2003; Sarrantonio and Molloy, 2003). Ghuman and Sur (2001) investigated the effects of three different tillage systems (minimum tillage with residue, minimum tillage without residue and conventional tillage) on the soil quality and grain yield in a maize and wheat for 5 years. The grain yield in the minimum tillage with residue treatment remained below the conventional tillage treatment during the first 2 years but was subsequently greater than the conventional tillage. The researcher indicated that minimum tillage with residue improves soil quality and yield. Conservation tillage systems that are low in labor, time, energy and production cost have been considered important as time goes by. Some research shows that conventional tillage and planting systems weren't economical because of high production cost in spite of reaching the highest yield. With the use of tillage systems that involve fewer field operations, task time and fuel consumption are reduced. In this context, task time and fuel consumption in conventional tillage systems that have more operations are higher than in other tillage systems. Parsch et al. (2001) compared conservation tillage vs. conventional tillage with soybean, grain sorghum, corn and cotton. Except for

cotton, conventional tillage resulted in higher average net returns than conservation tillage. The study confirmed the increased variable costs and decreased equipment costs that accompany conservation tillage systems. Conservation tillage is an ecological approach including many different soil management systems. Single tillage system is not suitable for all soils and climatic conditions. Therefore, the choice of the best suited tillage system must be harmonious to the particular agro-ecological environment. Cavalaris and Gemtos (2004) evaluated the tillage efficiency and energy requirement for five methods of soil preparation for sugar beet crop. Even though a lot of work is done with other crops, the research concerning the adaptation to reduced tillage for second crop corn production is limited.

The main objectives of the present study were: (1) to evaluate the effects of different tillage systems on energy consumption and the crop yield; and (2) to determine the energy output/input ratios for the different tillage systems.

MATERIALS AND METHODS

The study was carried out on production plots of 300 m^2 with 29% sand, 25% silt and 46% clay on an experimental field of Çukurova University from 1999 to 2000. Corn was sown as a second crop just after harvest of wheat. Four different methods of soil preparation for the second crop corn production were tested:

1. *Minimum tillage with stubble (MTS)*: tillage with a rotary tiller at a depth of 15 cm and final preparation with a field scrubber twice.
2. *Minimum tillage without stubble* (MT): tillage with a rotary tiller at a depth of 15 cm and final preparation with a field scrubber twice.
3. *Conventional tillage with stubble (CTS)*: tillage with a moldboard plow at a depth of 25 cm, tillage with a disk harrow at a depth of 7 to 8 cm, and final preparation with a field scrubber three times.
4. *Conventional tillage without stubble (CT)*: tillage with a chisel plow at a depth of 35 cm, tillage with a disk harrow at a depth of 7 to 8 cm, and final preparation with a field scrubber twice.

The tillage implements were operated with a standard tractor of 70 kW, whereas planting and cultivation operations were performed with a tractor of 50 kW. Tillage equipment consist of three moldboard plows

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with a depth of 25 cm, rotary tiller with "L" knife, depth of 15 cm and working width of 2 m, chisel plow with depth of 35 cm and working width of 2.1 m, disc harrow with 20 discs and working width of 2 m, and field scrubber with 3 m.

The study was carried out on plots of 6 m × 50 m in a completely randomized block design with three replications for 2 years. Residues left on the field surface after wheat (*Triticum aestivum* L.) harvesting were burned at plots with non-stubble while they were mixed into soil with tillage equipment at stubbled plots. The amount of stubble mixed into the soil was 3,380 kg/ha. It is difficult for tillage equipment to prepare effective seedbed and achieve good seed-soil contact when stubble loads are greater than 4,000-5,000 kg/ha (Valzano et al., 1997). Wheat residue was left 3,400 kg/ha on plots with stubble.

All of the experiment area was irrigated after burning of non-stubble plots. The fertilizer was spread at the rate of 500 kg/ha by a spinning disc distributor and then tillage was applied. Corn was planted in July and harvested in November of the following year. Planting was performed by using single seed drill at 15 kPa vacuum pressures and at 1.3 m/s travel speed, with row distance of 70 cm and spacing in row of 20 cm. ISADORA-AG9241 corn variety was planted by pneumatic precision planter with four rows. The number of corn seed per hectare used for the all treatments was 99,430. Cultivation practices (fertilization, irrigation, hoeing, and plant protection) were the same for all the treatments according to the needs of the highest yield. After plant emergence, the operations such as cultivation (2 times), fertilization, pesticide application (2 times) and irrigation (5 times) were performed at the same time and same dose on all plots.

Energy equivalents of the inputs and outputs used in the second crop corn production are given in Table 1. Machinery energy inputs are calculated on the basis of its weight, with the coefficient appropriate for its class. The following formula was used to estimate the machinery energy inputs (Yaldız et al., 1990b; 1991):

$$ME = \frac{W \times E}{T \times EFC} \tag{1}$$

where; *ME* is the machine energy input in MJ per hectare; *W* is the weight of the implement in Kg; *E* is manufacturing energy of the agricultural machines or implements in MJ/kg; *T* is the economic life of the implement in h; and *EFC* is the effective field capacity in ha per hour.

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TABLE 1. Energy equivalents of different input and output used in corn production

Inputs	Quantity per unit area (ha)	Energy equivalent (MJ/unit)	Reference
Human labor (h)	–	2.3	Yaldız et al., 1990a; 1990b
Manufacturing energy (MJ/kg)			
Tractor	–	158.3	Doering, 1980
Agricultural implements	–	121.3	
Fuel (L)			
Diesel	–	47.8	Cervinka, 1980
Oil (Lubricant)	–	42.5	
Chemical fertilizers (kg)			
Nitrogen	175	60.6	Özkan et al., 2003
Phosphorus	175	11.1	
Potassium	75	6.7	
Chemicals (kg)			Yaldız et al., 1990a; 1990b
Herbicides	2	238	Helsel, 1992
Insecticides	2	199	Özkan et al., 2003
Seed (kg)	26.7	30	Pimentel and Burgess, 1980
Irrigation (m^3)	–	0.63	Yaldız et al., 1990a; 1990b
Outputs (kg)			Pimentel and Burgess, 1980
Corn seed		16.7	
Plant stem		3.8	

The values of 158.3 MJ/kg and 121.3 MJ/kg were used for the manufacturing energy of the agricultural tractor and implements, respectively (Doering, 1980). The effective field capacity of each implement was determined in the operation conditions. The task times for the tillage systems were measured by using a chronometer in order to obtain management data of farm machineries used in seedbed preparation. Fuel energy input for each application was calculated based on the fuel consumption in the operation conditions. At the beginning of each operation, the fuel tank of the tractor was filled fully, and then refilled fully at the end of each operation to determine fuel consumption. The fuel energy input was es-

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timated multiplying the total fuel consumption with diesel fuel energy equivalent. The oil consumption of the tractor was calculated depending on its power as follows:

$$OC = 0.004 \times P_t \quad (2)$$

where; OC is the oil consumption of the tractor in L per hour; and P_t is the power of the tractor in kW.

Human energy input was estimated based on the power consumed in each operation. In November, the plants were harvested by hand. Energy outputs were calculated for each method of tillage from the crop yield on seed and plant stem. The energy equivalent of seed and corn stem was considered as 16.7 MJ/kg and 3.8 MJ/kg, respectively (Pimentel and Burgess, 1980). The experiment data was analyzed by MSTAT-C statistics packet programmer. Statistical significance was determined by variance analysis and least significance difference (LSD) test.

RESULTS AND DISCUSSION

Evaluation of Machinery Energy Input with the Tillage Implements

Machinery energy inputs with the tillage implements for the different methods of soil preparation are given in Table 2. The total machinery energy inputs with the tillage implements for MTS, MT, CTS and CT were 1,383 MJ/ha, 1,288 MJ/ha, 2,784 MJ/ha and 1,641 MJ/ha, respectively. The fuel and oil energy inputs were the highest in total energy input with the values of 1,215 MJ/ha, 1,131 MJ/ha, 2,451 MJ/ha and 1,436 MJ/ha for MTS, MT, CTS and CT, respectively. On the other hand, the machinery energy inputs of MTS, MT, CTS and CT were only 168 MJ/ha, 157 MJ/ha, 333 MJ/ha and 205 MJ/ha, respectively. The share of the machinery energy inputs for all tillage systems was found as 12% of the total energy input for tillage operation. The machinery energy inputs of MT were 53.7% lower than that of CTS.

Considering total machinery energy input with the tillage implements for the second crop corn production, the following results can be drawn: (1) The fuel and oil energy inputs of CTS were 50.5%, 53.8% and 41.4% higher than that of MTS, MT, and CT, respectively. (2) The machinery energy inputs of CTS were 49.5%, 52.9%, and 38.4% higher than that of MTS, MT, and CT, respectively. (3) Since the moldboard

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TABLE 2. Machinery and fuel energy inputs with the tillage implements

Tillage system	Tillage implements	Operation period (h/ha)	Fuel consumption (L/ha)	Machinery energy (MJ/ha)	Fuel and oil energy inputs (MJ/ha)	Total energy input (MJ/ha)
Minimum tillage with stubble (MTS)	*Tractor*	1.453	–	90.1	–	**1382.8**
	Rotary tiller	0.633	15.85	57.5	765.1	
	Field scrubber	0.82	9.2	20.7	449.4	
Minimum tillage without stubble (MT)	*Tractor*	1.491	–	86.6	–	**1288.3**
	Rotary tiller	0.787	13.7	46.2	664.2	
	Field scrubber	0.704	9.6	24.1	467.2	
Conventional tillage with stubble (CTS)	*Tractor*	1.557	–	190.7	–	**2784.6**
	Plough	0.44	18.8	24.3	903.8	
	Disk harrow	0.492	18.4	91.1	885.3	
	Field scrubber	0.625	13.7	27.2	662.2	
Conventional tillage (CT)	*Tractor*	2.564	–	114.3	–	**1641.2**
	Chisel	0.91	11.2	20.8	546.1	
	Disk harrow	0.97	8.6	46.2	422.5	
	Field scrubber	0.704	9.6	24.1	467.2	

plow was pulled at the greatest depth, it was the most energy consuming implement. The rotary tiller had the lowest energy demand but also had the shallowest tillage depth. The chisel plow had lower energy demand than the other tillage implements. (4) The total energy consumption values show that significant energy savings could be obtained with the reduced tillage methods.

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Evaluation of the Total Energy Input and Output with the Tillage Systems

The energy equivalents of the input and output in the second crop corn production and energy output/input ratios are illustrated in Table 3. The total energy input to produce a hectare of corn in MT using only manpower was 58 MJ. The human labor in CTS was 14.6% greater than that of MT. In CTS, the human labor for the tillage operations was folded of MTS and MT. The majority of the man power is devoted to harvesting for all the tillage systems. The machinery energy inputs for the cultural practices were the highest in MTS. It was 37.9% higher than the others. The chemical fertilizers were the highest in the total energy input with the value of 13,050 MJ/ha followed by diesel fuel, oil and irrigation. In other words, the share of chemical fertilizers in the total energy input were 67.5%, 68.3%, 63.3% and 67% for MTS, MT, CTS and CT, respectively. The contributions of chemicals, machinery and seed inputs remained at relatively low levels.

The total energy input for producing corn utilizing CTS was 20,608 MJ/ha, compared to 19,102 MJ/ha with MT. Considering the limited margins for energy conservation with tillage, it is obvious why a reduction in net energy, energy efficiency and the energy productivity was achieved. However, the energy outputs were 13.8 to 15.8 times greater than the energy inputs depending on the tillage methods. The energy output/input ratio for producing corn utilizing MTS, MT, CTS and CT were 14.2, 15.8, 13.6 and 15.3 MJ of corn per input MJ. The highest output/input was utilizing MT, with the value of 15.8. When the grain yields only are taken into account, the energy output/input ratios were 6.3, 7.6, 6.6 and 7.0 for MTS, MT, CTS and CT, respectively. However, Canakci et al. (2004) determined that the energy output/input ratio for cultivating maize was 3.8 in Antalya region of Turkey. On the other hand, Pimentel and Burgess (1980) established that the energy output/input ratios were 3.5, 3.7, 3.8, 3.9, 4.2 and 4.6 for corn production in California, Wisconsin, Indiana, Pennsylvania, Ohio and Illinois, respectively.

Uniformity of Plant Distribution and Grain Yield

As presented in Table 4, according to the results of LSD, tillage systems have not statistically affected uniformity of plant spacing ($P < 0.05$). Nevertheless, high plant emergence, quality of feed index, low multiples index, miss index and standard deviation were indications of

TABLE 3. The energy output/input relationship for the second crop corn production

Inputs	Total energy equivalent (MJ/ha)			
	Minimum tillage with stubble (MTS)	**Minimum tillage without stubble (MT)**	**Conventional tillage with stubble (CTS)**	**Conventional tillage without stubble (CT)**
Human labor	*60*	*58*	*68*	*63*
Tillage	6	6	14	8
Cultural practices	12	11	13	13
Harvesting	41	41	41	41
Machinery	*605*	*474*	*650*	*522*
Tillage	168	157	333	205
Cultural practices	437	317	317	317
Diesel fuel and oil	*2,178*	*2,095*	*3,415*	*2,399*
Tillage	1,215	1,131	2,451	1,436
Cultural practices	963	963	963	963
Chemical fertilizers	*13,050*	*13,050*	*13,050*	*13,050*
Nitrogen	10,605	10,605	10,605	10,605
Phosphorus	1,943	1,943	1,943	1,943
Potassium	503	503	503	503
Chemicals	*874*	*874*	*874*	*874*
Herbicides	476	476	476	476
Insecticides	398	398	398	398
Irrigation	*1,750*	*1,750*	*1,750*	*1,750*
Seed (kg)	*801*	*801*	*801*	*801*
Total energy input (MJ/ha)	**19,315**	**19,102**	**20,608**	**19,459**
Yield				
Corn seed	121,710	145,607	136,589	136,071
Plant stem	152,000	156,237	146,858	161,612
Total energy output (MJ/ha)	**273,710**	**301,844**	**283,447**	**297,683**
Energy output/input ratio				
Total energy equivalent of grain yield/Total energy input	**6.3**	**7.6**	**6.6**	**7.0**
Total energy output/Total energy input	**14.2**	**15.8**	**13.6**	**15.3**

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TABLE 4. Plant density (plant/ha) and yield (kg/ha) values of tillage systems

Tillage method	cm[a]	Plant/ha[b]	Kg/ha[c]
Minimum tillage with stubble (MTS)	24.1	59,211	7,288 b
Minimum tillage without stubble (MT)	24.6	58,056	8,179 ab
Conventional tillage with stubble (CTS)	23.2	61,611	8,148 ab
Conventional tillage without stubble (CT)	22.4	63,699	8,719 a

[a]Mean plant distance on row; [b]Non-significant; and [c] Significant at $P < 0.01$.

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better uniformity of plant spacing (Kachman and Smith, 1995). Among tillage systems, the lowest miss/skip index (8.0%) and mean plant spacing (22.4 cm) were on CT plots. Multiples index (1.9%) were lowest on MTS plots; quality of feed index (79.9%) and emergence rate (79.7%) were lowest on CTS plots. The highest miss index (17.3%) and average plant spacing (24.6 cm) were on CTS plot. Multiples index (3.1%) was the highest on MT plots; emergence percentage (89.1%) and quality of feed index (89.1%) were highest on CT plots. The quality of feed index was highest on plots where the values of multiples index and miss index were low. Mean plant spacing (22.4 cm) closest to theoretical spacing was found on the CT plot. Standard deviation of spacings between plants varied from 8.9 to 9.9 cm. The MTS had the lowest standard deviation.

Although seeding distance of the pneumatic planter was adjusted to 21 cm, average plant distance in the row was more than 21 cm (Table 4). Plant density of tillage systems was reduced in 6.4% to 14.7% proportions to desired plant density, 68,027 plants per hectare. This may have stemmed from planter, soil and weather conditions.

It was determined at the end of evaluation that tillage systems statistically ($P < 0.01$) affected the yield (Table 4). The grain yield was the greatest (8,719 kg/ha) in the CT compared to other tillage treatments. The lowest grain yield was 7,288 kg/ha in the MTS. This result could be attributable to plant density. As the plant density increased, so did grain yield. While plant number per area on stubble plots was lower, weed number per area was higher. Even though expected that the yield on plots with stubble would be higher, this result had not materialized. Due to the fact that weeds share water, nutrients and light by competing with crops, weeds and low plant density on stubble plots may be considered a factor which has decreased grain yield.

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The Task Time and Fuel Consumption

As can be seen from Table 5, for field operation, the lowest time spent was found 4.0 h/ha in MT, whereas the highest time spent was found 7.5 h/ha in CTS. Similar findings were observed for fuel consumption. This situation shows that task time for field tillage increases due to increasing the pass number. Owing to less field traffic, the lowest fuel was consumed as 28.8 L/ha in CTS. Generally, tillage systems with rotary tiller had less task time and fuel consumption in comparison with other tillage systems with moldboard plow and chisel plow due to fewer passes.

CONCLUSIONS

In this experimental research, the energy output/input analysis was performed for the second-crop corn production with different tillage systems. Energy inputs vary with the method of production, i.e., with full mechanization. Because of the low percent that tillage consumes on the total energy inputs, the margins for energy conservation were low. Taking into account the significant environmental advantages that can be obtained with the adoption of a reduced tillage system; MT appears the best method for the substitution of the moldboard plow. The results indicate that the level of fertilizer was one of the significant determinants of the total energy input. It can be concluded that the second crop corn production is the most remunerative due to its higher energy output/input efficiency.

TABLE 5. Task time ([d]) and fuel consumption ([e]) for different tillage systems

Tillage methods	Fuel consumption	Task time [d]	
	(L/ha)[e]	ha/h	h/ha
Minimum tillage with stubble (MTS)	29.1 c	0.24 ab	4.2
Minimum tillage without stubble (MT)	55.4 a	0.13 c	7.5
Conventional tillage with stubble (CTS)	28.8 c	0.25 a	4.0
Conventional tillage without stubble (CT)	33.0 b	0.21 b	4.7

[d,e] Significant at $P < 0.01$.

Tillage systems were affected significantly on grain yield. The grain yield was the lowest in MTS, whereas; the yield was the greatest in CT. The lowest task time and fuel consumption were determined in MT that included less field traffic and non-residue on soil.

Different tillage treatments have proved to be statistically unimportant on uniformity of plant spacing on row. The results show that there has been a problem in tillage systems used on stubble plots. It is essential that conservation tillage systems be used to preserve natural life and sustaining soil fertility. In this context, selected tillage systems should be improved and new tillage systems functioning by mixing previous crop residue into soil should be investigated. So, further research is needed to overcome this problem in the tillage systems with residue.

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