The impact of the tillage systems on input-output energy, soil pulverization, and grain yield of barley

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Abstract This study aimed to evaluate the effects of tillage systems and tillage speed on, fuel consumption, soil pulverization, and barley grain production, as well as the effects of five tillage systems on energy input-output. The investigation was comprised of three conventional tillage systems involving the use of disk plow + disk harrow + roller (T1), disk plow + two passes of a disk harrow (T2), and moldboard plow + cultivator (T3), and two reduced tillage systems, involving cultivator + roller (T4) and cultivator + disk harrow (T5). Three plowing speeds of 2.70, 5.68, and 6.14 km h^{-1} were used to prepare the soil for barley planting. The results showed that conventional tillage systems T1, T2, and T3 had the highest fuel consumption values, grain yield, and the lowest value of soil pulverization compared to the reduced tillage systems (T4 and T5). Increasing the operating speed from 2.70 to 6.14 km h^{-1} led to a decrease in fuel consumption and soil pulverization index by 21.29% and 19.33% respectively and it had no significant effect on barley grain yield. The interaction between the tillage system and operating speed had a significant effect (p<0.05) on fuel consumption and soil pulverization index, while it had no significant effect on barley grain yield. Conventional tillage (T2) led to an increase in the average of the total energy consumed for barley production compared to T1, T3, T4, and T5 by 9.02%, 22.58%, 34.39%, and 41% respectively. While reduced tillage (T5) achieved the lowest total energy-consuming input value of 7586 MJ ha^{-1}. Reduced tillage system (T4) achieved the highest energy efficiency, energy productivity, and the lowest specific energy values of 3.53, 0.24 kg MJ^{-1}, and 4.16 MJ kg^{-1} respectively. However, the results showed there were no significant effects (p<0.05) between T3 and T5 in terms of specific energy and energy productivity.

Keywords: tillage systems, fuel consumption, soil pulverization, input-output energy, and grain yield of barley.

Citation: Nassir, A. J., S. J. Muhsin, A. A. Mishall, and F. M. Almusawi. 2023. The impact of the tillage systems on input-output energy, soil pulverization, and grain yield of barley. Agricultural Engineering International: CIGR Journal, 25(4): 68-83.

1 Introduction

Soil preparation for agriculture requires plowing the soil several times to obtain a suitable seedbed. About 60% of the energy consumed in agriculture is related to plowing practices, therefore essential to take into consideration the passage times of tillage machines and choose appropriate tillage equipment according to the type of soil and the crop to be cultivated to decrease energy consumption (Singh, 2016; Fernandez et al., 2019). The availability of many types of primary and secondary tillage equipment makes the process of selecting the appropriate tillage equipment for optimal agricultural production more difficult. Much research has been done to determine the best tillage equipment to use in order to achieve tillage goals at the lowest possible cost. Tillage practices are carried out to pulverize the surface layer of soil, mix the soil with fertilizer,

Received date: 2022-12-12 **Accepted date:** 2023-06-06

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organic matter, and previous plant residues, as well as control weeds (Sartori et al., 2016). But tillage processes may be a major reason for erosion and degradation of soil, therefore as well as increasing energy consumption, consequently the selection of tillage methods should be dependent on the conditions, texture types of the soil, and the nature of the cultivated crop (Liu et al., 2021).

Farmers and environmentalists are concerned about the energy used for tillage to crop production, whereas considerable energy input is consumed due to using fossil fuel, which represents a significant direct cost for producers (Tabatabaeefar et al., 2009). High energy consumption for tillage is typically accompanied by high machinery costs and labor inputs. In a study conducted by Memon and Arshad (2018) on the energy required for maize production, they reported that the output energy for deep tillage had a value of 84187 MJ ha^{-1}, followed by conventional tillage at 75088 MJ ha^{-1}, and the lowest value of the energy reached 62931 MJ ha^{-1} with no-tillage. Pratibha et al. (2019) confirmed that fuel consumption varies according to tillage equipment; the moldboard plow + disk harrow had the highest fuel consumption value of 27 L ha^{-1}, while the cultivator required the lowest fuel consumption value of 12.75 L ha^{-1}. Carman et al. (2021) found that using the reduced tillage method (cultivator + leveling machine) saved fuel consumption by 50.47% and that there were no significant differences between them in grain yield compared with using the traditional tillage system.

The soil pulverization index (PI) is one important indicator of soil's physical properties. Soil pulverization creates favorable field circumstances for plant growth by increasing water-holding capacity, and increasing available nitrogen in the soil via aeration operation. The success of crops is extremely dependent on pulverization quality, which can be accomplished through various soil-tilling techniques (Ahmadi and Mollazade, 2009). PI values indicate the amount of soil pulverization depending on the operating conditions in terms of tillage depth, speed, tillage methods (plow type and number of passes), and soil circumstances (Upadhyay and Raheman, 2019). The PI is reduced when using secondary tillage equipment after primary tillage equipment. Nassir (2017) observed that the tillage method of using a moldboard plow after a heavy chisel plow decreased (PI) compared with using a heavy chisel plow and digger moldboard plow separately by a percentage of 56.47% and 48.90%, respectively.

The grain yield of barley was affected by the tillage method, so the optimal method of tilling should be selected to increase grain yield. Mousavi-Boogar et al. (2022) reported that barley grain yield was 2122.5, 1766.5, and 1159.5 kg ha^{-1} for conventional tillage, reduced tillage, and no tillage, respectively. Abdipur et al. (2012) investigated the impact of five tillage methods on barley yield, and they found that the chisel plow + disc harrow achieved the highest grain yield of 1848 kg ha^{-1}, followed by the moldboard plow without inversion bottom + disc harrow, sweep plow + disc harrow, power harrow, and moldboard plow without inversion bottom + disc harrow, which were given grain yield of 1741, 1700, 1674, and 1548 kg ha^{-1}, respectively.

In the southern and central regions of Iraq, conventional and reduced tillage systems are commonly used in order to prepare the soil for planting (Al-Hadithi and Al-Shuwaili, 2018). Therefore, the objective of the study was to determine the impact of five tillage systems and three operating speeds on fuel consumption, soil pulverization index, and barley crop yield. Given the lack of studies on energy consumption in Iraq, the current study also aimed to evaluate the total energy consumed, as well as the energy use efficiency and energy productivity for barley grain yield based on farm operations and semi-arid farmland energy sources.

2 Materials and methods

2.1 Site description, experimental design, and tillage treatments

The study was conducted in November 2021 at the agriculture station research facility at the agriculture college, the University of Basrah (30° 30′

N, 47° 49′ E), in southern Iraq. The climate in this region is semi-arid, with a long-term mean annual rainfall of 250 mm (Al-Lami et al., 2021). Most of the rainfall happens during winter. Monthly average temperatures range from a high and low of 45°C indicated in July to a low of 12°C noted in January. Temperatures and humidity at the study location throughout the barley growth season are shown in Figure 1. The soil texture class of the upper layer (0–40 cm) in the experimental field was silty loam (35% clay, 47% silt, and 18% sand). The bulk density, pH (in saturation extract), electrical conductivity (in saturation extract), and organic matter in the surface soil layer before sowing was evaluated as 1.33 Mg m^{-3}, 7.56, 5.74 dS m^{-1}, and 0.49%, respectively. The experiment was established as a split-plot randomized complete block design with two factors with three replications. Five different tillage systems were arranged in main plots consisting of T1 (conventional tillage with disk plow + disk harrow + roller), T2 (conventional tillage with moldboard plow + cultivator), T3 (conventional tillage with disk plow + two passes of disk harrow), T4 (reduced tillage with cultivator + roller), and T5 (reduced tillage cultivator + disk harrow).

Three different operation speed levels (3.70, 5.68, and 7.04 km h^{-1}) as the sub-plot. The plot area was adjusted to 20 m × 30 m. Apart from tillage, management was approximately the same in all treatments. The seeds in each plot were broadcast manually. A Massey Ferguson 400 Xtra tractor was used to carry out all tillage treatments. The tractor is powered by a Perkins 3.5-liter engine, providing a maximum power of 82 hp, and weighing 3396 kg. In this study, three operation speeds were used: 3.70, 5.68, and 7.04 km h^{-1}. The average plowing depth in field tests at 25 and 15 cm for conventional tillage and reduced tillage, respectively. Table 1 shows the specifications of the tillage machines. The barley seeds (Al-Khair) were sown on 25 November 2021 at a seeding rate of 180 kg ha^{-1}. Each plot was fertilized with 105 kg ha^{-1} triple super phosphate (48% P_2O_5) fertilizer and 50 kg ha^{-1} potassium fertilizer. Nitrogen (170 kg ha^{-1} urea) fertilizer was applied in three batches based on soil analysis results, 55 kg ha^{-1} at barley seed sowing, 55 kg ha^{-1} at barley tilling, and 60 kg ha^{-1} at barley stem elongation. The sprinkler irrigation system was used for irrigation the barley field (Figure 2), and the irrigation frequency was twice a week. Herbicides for weed control were applied at a dose of 5 kg ha^{-1} by manual spreading.

(a) the middle growing season

(b) the end growing season

Figure 2 Barley field a- in b- in

2.2 Operating speed

The operating speed of the tractor was determined by the time needed by the tractor to travel a distance of 30 m between the marked lines. The stopwatch was utilized to estimate the time taken by the tractor to travel the needed distance. The number of rotations made by the rear wheel of the tractor to travel over the measured distance was also considered in determining the operating speed of the tractor.

2.3 Fuel consumption

To determine the amount of fuel required for agricultural machinery, the tractor's fuel tank was filled to its full capacity before beginning the task. When the work in the test plot was done, the tank was refilled with a graduated cylinder of 1000 ml. The amount of fuel needed to refill the tank of the tractor is considered the amount of fuel used.

In the unit of L ha^{-1}, the fuel consumed was determined by dividing the fuel consumed (liter) by the area covered (m^2), as shown in Equation 1 (Leghari et al., 2016).

$$FC = \frac{FQ}{A} \times 10^4 \qquad (1)$$

where, FC is fuel consumption (L ha^{-1}), FQ is fuel consumption required to cover the plot area (L), A is plot area (m^2), and 10^4 is convert the area from meter square to hectare.

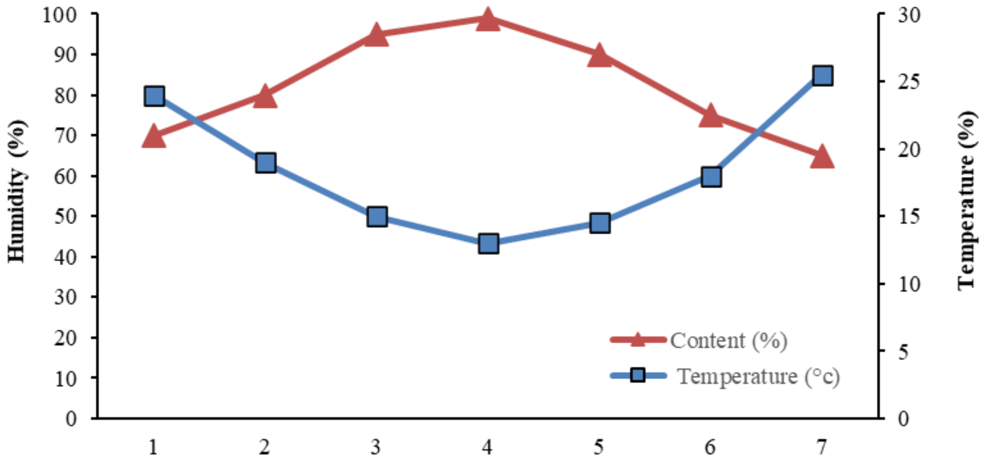


Figure 1 Monthly temperature, relative humidity, and total amount of rainfall in the period from October to April during 2021/2022

2.4 Soil pulverization Index

Soil samples were collected randomly for each tillage treatment with three replicates after three weeks of air drying for the determination of the soil PI. The degree of soil pulverization was measured by determining the MWD of soil clods after tillage practices by using a sieve analysis technique. The soil samples were passed through a set of eight sieves with mesh sizes of (100, 70, 50, 35.7, 25, 12.50, 7.5, and 1.75 mm). The sieve analysis was done by using an electrical sieve shaker, as shown in Figure 3. The PI was calculated using the equation mentioned in Alamooti and Hedayatipoor (2019).

$$SP = \frac{\sum_{t=1}^{n} W_t \times \bar{x}_i}{W_{total}} \qquad (2)$$

where, W_i is the mass of the soil obtained between two sieve openings x_i and x_{i+1} (kg), W_{total} is the weight of the total soil clods mass (kg), n is the number of sieves, $\bar{x}_i$ is calculated using the following equation:

$$\bar{\bar{x}}_i = \frac{1}{2}(x_i + x_{i+1}) \qquad (3)$$

Where, i is the sieve number, and i+1 is the sieve number that follows it.

2.5 Grain yield of barley

Barley grain yield was determined for each tillage treatment by manually harvesting a randomly selected one square meter area with three replications (humidity of plants less than 15%).

Figure 3 A view of the electrical sieve

2.6 Input and output energy computation

In order to compute the energy input-output for barley grain production under various tillage systems. The amounts of fuel oil consumption, irrigation, human labor, machinery, chemical fertilizers, seeds, and herbicides as well as grain yield were multiplied by their energy equivalents (in kilograms or liters) (Table 2), this experiment was laid out in a completely randomized design with three replicates. All tillage machines were pulled by the same tractor, which has an economic life of 12000 h. The actual operating depth and widths of each machine utilized, demonstrated in Table 1, were determined from the measurements with three replications in each plot. The machinery energy input for industrialization of the tractor and agricultural machinery was computed utilizing Equation 4 (Barut et al., 2011; Karaağaç et al., 2014).

$$ME = \frac{M \times EQ}{EI \times AFC} \quad (4)$$

where, *ME* is the machinery energy (MJ ha^{-1}), *M* is the mass of the tractor or machine (kg), *EQ* is the energy equivalent for the manufacturing of the tractor or agricultural machines (MJ kg^{-1}), *EI* is the economic life (h), and *AFC* is the actual field capacity (ha h^{-1}). The AFC values under the operation circumstances were calculated by dividing the area covered per hectare by the time required to complete the agricultural operation per hour (Hanna, 2016). The EFC values of all agricultural machinery are presented in Table 1. Figure 4 shows tillage machines used in the study.

2.7 Energy index

Energy efficiency, energy productivity, specific energy, and net energy were calculated based on the energy equivalents presented in Table 2, by the following equations: (Banaeian and Zangeneh, 2011; Houshyar et al., 2015; Nassir et al., 2021).

$$Energy\,efficiency = \frac{Output\,energy\,(MJ\,ha^{-1})}{Intput\,energy\,(MJ\,ha^{-1})} \quad (5)$$

$$Energy\ productivity(kg\,MJ^{-1}) = \frac{Crop\ yield\ (Kg\,ha^{-1})}{Intput\,energy\,(MJ\,ha^{-1})} \quad (6)$$

$$Specific\,energy(MJ\,kg^{-1}) = \frac{Intput\,energy(MJ\,ha^{-1})}{Crop\ yield\,(Kg\,ha^{-1})} \quad (7)$$

$$Net\,energy(MJ\,ha^{-1}) = Output\,energy(MJ\,ha^{-1}) - Intput\,energy(MJ\,ha^{-1}) \quad (8)$$

Table 1 A description of tillage machines and their properties used in barley grain yield

	Tillage machines				
Tillage systems	Disk plow	Disc harrow	Roller	Moldboard plow	Cultivator
T1	+	+	+	-	-
T2	+	+	-	-	-
T3	-	-	-	+	+
T4	-	-	+	-	+
T5	-	+	-	-	+
Working tools	Concave disks	Concave disks	Corrugated roller	Helical moldboard	solid tine
Tool Number	3	8	1	3	15
Working width (cm)	155	264	311	152	200
Diameters (cm)	60	30	25		
Working depth (cm)	25	15	5	25	15
Mass (Kg)	420	750	250	550	395
Energy Equivalent (MJ kg^{-1})	99.2	99.2	99.2	9.22	99.2
Machinery useful life (h)	2000	2000	2000	2000	2000
Field capacity (ha h^{-1})	0.27	1.15	2.46	0.21	2.12
Machinery energy (MJ ha^{-1})	77.16	32.35	5.04	129.93	9.24
Fuel-oil consumption (L ha^{-1})	22.39	17.50	13.54	24.67	16.87

Table 2 Energy equivalents of inputs and output in grain yield of barley

Definition	Unit	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs			
Diesel fuel-oil	L	56.31	Gozubuyuk et al. (2020)
Human labor	h	1.96	Ziaei et al. (2015)
Tractor	kg	158.5	Gözübüyük et al. (2012)
Disk plow	kg	66.14	Ramah and Baali (2013)
Moldboard plow	kg	99.2	Ramah and Baali (2013)
Disk harrow	kg	99.2	Ramah and Baali (2013)
Cultivator	kg	99.2	Ramah and Baali (2013)
Roller	kg	99.2	Ramah and Baali (2013)
Combine harvester	kg	83	Ramah and Baali (2013)
Sprinkler Irrigation	m^3	1.2	Ramah and Baali (2013)
Fertilizer (P_2O_5)	kg	12.44	Sahabi et al. (2013)
Fertilizer (N)	kg	11.15	Sahabi et al. (2013)
Fertilizer (K)	kg	11.15	Sahabi et al. (2013)
Seed	kg	14.7	Sahabi et al. (2013)
Herbicide	L	238	Sahabi et al. (2013)
B. Output			
Barley grain yield	kg	14.7	Nassir et al. (2021)

Figure 4 Tillage machines used in the study

2.8 Statistical analysis

The data of the experiment were analyzed by GenStat software version 17. The factors were five tillage systems (T1, T2, T3, T4, and T5) and three tillage speeds (3.70 (S1), 5.68 (S2), and 7.04 (S3) km h^{-1}). The data were analyzed as a randomized complete block design for fuel consumption, soil pulverization index, and barley crop yield. The data on energy input output for barley grain yield were analyzed in a completely randomized design. The mean values of the parameters were compared using LSD to identify a significant difference at a probability level of 5% (Hinkelmann and Kempthorne, 2007).

3 Results and discussion

3.1 Fuel consumption

The results showed a significant difference among the fuel consumption values for the five tillage systems (Table 3). The conventional tillage systems

(T1, T2, and T3) recorded high fuel consumption values of 53.28, 57.09, and 41.54 L ha^{-1}, respectively. While the reduced tillage systems (T4 and T5) had low fuel consumption values of 30.41 and 34.22 L ha^{-1}, respectively. This means the reduced tillage system (T4) saved fuel compared to conventional tillage systems (T1, T2, and T3) by 42.92%, 46.73%, and 26.79%, respectively, while the reduced tillage system (T5) saved fuel by 35.77%, 40.06%, and 17.62% respectively. This large variation in fuel consumption values was because of the greater number of tractor travels and tillage practices related to the conventional tillage systems as well as in conventional methods the tillage machines work at a considerable depth which requires more energy to pulverize the large soil volume, thereby, fuel consumption increasing compared to reduced tillage systems. Similar results were also reported by Moitzi et al. (2013) who found that a higher fuel consumption value was registered in the conventional tillage system (40 L ha^{-1}), while a lower fuel consumption value was found in the minimum tillage system (27.20 L ha^{-1}). Also, our findings are close to those reported by Becker et al. (2019), Khalil et al. (2021), Damanauskas and Janulevičius (2022), and Saldukaitė-Sribikė et al., 2022).

The data in Table 3 showed that increasing the operating speed from 2.70 to 6.14 km h^{-1} led to a decrease in fuel consumption from 38.78 to 48.07 L ha^{-1} (19.33%). This was attributed to the effective utilization of tractor capacity when operating at a relatively high speed, leading to energy savings and decreasing the time required to accomplish the tillage operations, thereby saving fuel at an increasing operating speed. These results are consistent with the findings of Ranjbarian et al. (2017), who reported that increasing the operating speed from 1.5 to 3 Km h^{-1} decreased fuel consumption by 34.81%. Moreover, Almaliki et al. (2016) reported that fuel consumption was reduced by 96% when the operating speed increased from 1.40 to 5.62 km ha^{-1} where an increase in operating speed results in decreasing the time required to conduct the work needed (tillage practice).

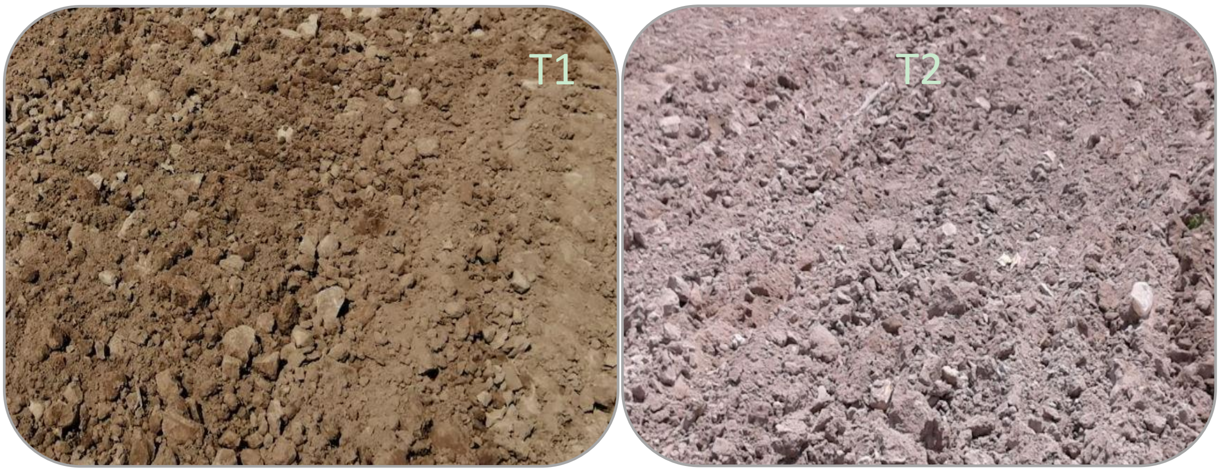
Table 3 shows a significant interaction (p<0.05) between tillage methods and speed of operation on fuel consumption. The reduced tillage (T4 and T5) and high speed of 6.14 km h^{-1} recorded low fuel consumption values of 25.90 and 29.56 L ha^{-1} respectively. While conventional tillage (T1, T2, and T3) had a high fuel consumption value of 58.50, 62.78, and 37.89 L ha^{-1} respectively at the slow speed of 2.70 km h^{-1}, This was attributed to (T4 and T5) operating at a shallow depth of 15 cm, and this required low energy consumption. On the other hand, a higher operating speed decreased the time required for tillage operations, thereby saving a considerable amount of fuel. This is in accordance with Kareem and Sven (2019) who indicated that the maximum fuel consumption was noticed with moldboard plowing at 1.5 km h^{-1} (26.5 L ha^{-1}) and the lowest fuel consumption was observed with chisel plowing at 3 km h^{-1} (10.72 L ha^{-1}).

3.2 Soil pulverization Index

Tillage systems had significant effects on soil pulverization index (p<0.05) (Table 3). The conventional tillage (T2) had the lowest soil pulverization index value of 16.33 mm. The second lowest value of soil pulverization index was recorded by conventional tillage (T1), which was 18.02 mm. While the reduced tillage systems (T4 and T5) had the highest soil pulverization index values of 36.79 and 33.38 mm, respectively. Conventional tillage systems decrease the soil pulverization index considerably (high soil pulverization) when compared with reduced tillage systems. For example, when compared to conventional tillage systems T1, T2, and T3, with reduced tillage systems (T4), the soil pulverization index decreased by 51.02%, 55.61%, and 36.31%respectively, however (T5) decreased the pulverization index of soil by 46.02%, 51.08% and, 29.81% respectively. This was because the soil was loosened by primary tillage machines (plows) and then pulverized by secondary tillage machines (disk harrow, cultivator, or roller), resulting in the increased pulverization of the soil (low pulverization of soil). Muhsin (2017) reported that the pulverization index of soil decreased by 57.95% when using a moldboard plow compared to using the moldboard plow+ disk harrow in silty loam soil. Figure 5 illustrates the soil pulverization under different tillage practices.

The operating speed had a significant (p<0.05) effect on the soil pulverization index. The values of the soil pulverization index decreased as the operating speed increased (Table 3). Increasing the operating speed from 2.70 to 6.14 km h^{-1}, the soil pulverization index decreased from 28.79 to 22.66 mm by 21.29%. The decrease in the soil pulverization index values with increasing operating speed was attributed to the increasing colliding of soil blocks with each other during tillage operations. This led to the soil blocks crumbling into smaller clods, thereby reducing the value of the soil pulverization index (high soil pulverization). This is in accordance with Nassir (2018), who found that the soil pulverization index decreased by 51.70% when the operating speed increased from 3.70 to 7.22 km h^{-1}. He stated that increasing the acceleration and movement of the soil clods may lead to an increase in the collision of the soil blocks, resulting in the soil blocks shattering into small fragments and leading to an increase in the soil's pulverization. Also, Alwan (2019) reported that the results showed that soil pulverization index decreased with the increase in operating speed. Increasing the operating speed from 4.37 to 6.76 km h^{-1} led to a significant decrease in the soil pulverization index from 18.01 to 12.86.mm (28.60%), Also, Upadhyay and Raheman (2020) reported that the conventional disk harrow reduced the size of soil clods by 38.31%, 44.07%, and 25.99%, respectively, when compared to the passively-driven disk harrow at forward speeds of 3.46, 4.55, and 6.82 km h^{-1}.

The data in Table 3 showed there was a significant effect (p<0.05) for the interaction between the tillage system and operating speed on the soil pulverization index. where conventional tillage (T2) and a high speed of 6.14 km h^{-1} caused the lowest soil pulverization index value of 14.33 mm, while reduced tillage (T5) with a low speed of 3.70 km h^{-1} the had the highest soil pulverization index value of 38.27 mm. The results also showed that conventional tillage systems at low operating speeds decrease the soil pulverization index significantly more than that of reduced tillage systems at high operating speeds. For example, conventional tillage (T1) at speed of 3.70 km h^{-1} recorded a soil pulverization index value of 18.35 mm, while the reduced tillage (T4) with a high speed of 6.14 km h^{-1} recorded a soil pulverization index value of 33.87 mm. This means the tillage system has greater effect of operating speed on the soil pulverization index. This is in agreement with Nassir et al. (2022).



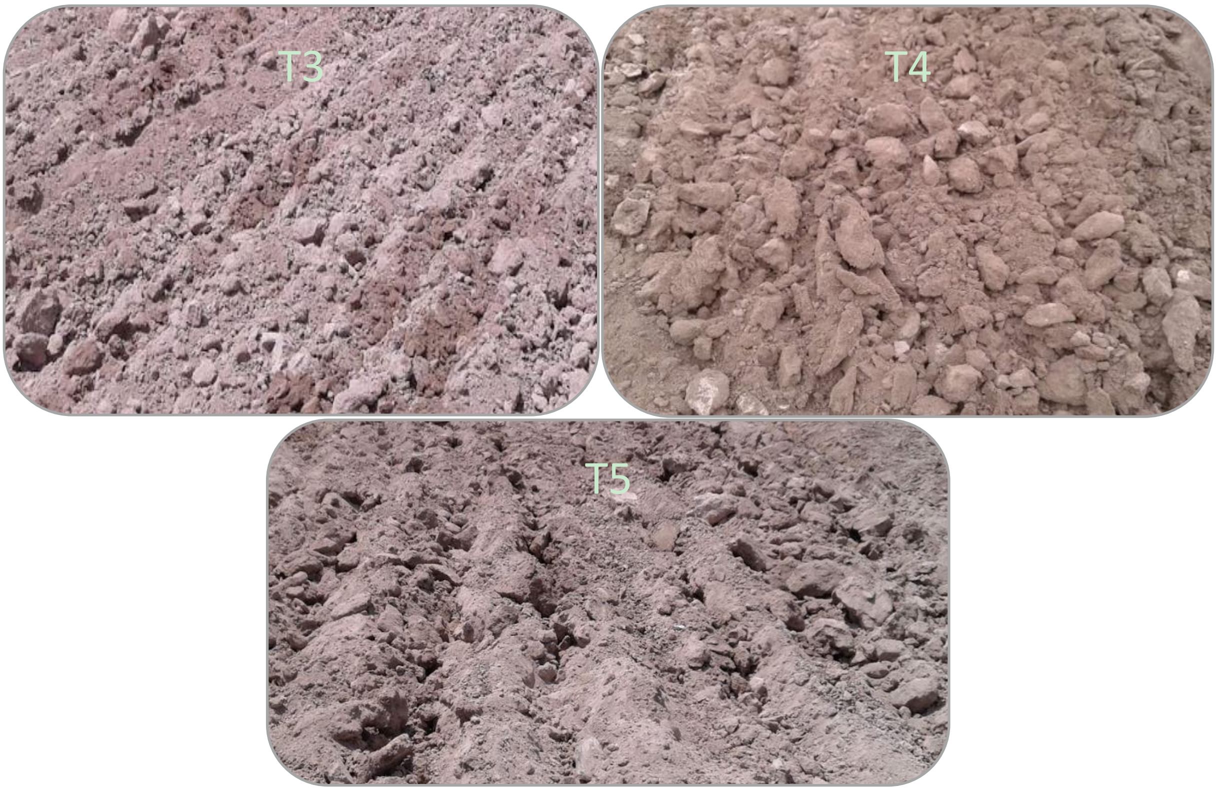


Figure 5 Soil pulverization under different tillage systems (T1, T2, T3, T4, and T5)

Table 3 Effect of tillage system and speed on fuel consumption, soil pulverization index, and grain yield of barley

	Fuel consumption (L ha^{-1})	Soil pulverization index (mm)	Grain yield (kg ha^{-1})
Tillage systems			
T1	53.28	18.02	2183
T2	57.09	16.33	2236
T3	41.54	23.43	2059
T4	30.41	36.79	1964
T5	34.22	33.38	1764
LSD $_{(0.05)}$	0.640	0.53	50
Operating speeds (km h^{-1})			
3.70	48.07	28.79	2036
5.68	43.08	25.33	2042
7.04	38.78	22.66	2056
LSD $_{(0.05)}$	0.640	0.45	n.s
Tillage systems × Operating speeds			
T1× 3.70	58.50	19.8	2163
T1× 5.68	52.66	18.1	2189
T1× 7.04	48.69	16.17	2198
T2× 3.70	62.78	18.35	2219
T2× 5.68	56.64	16.29	2239
T2× 5.68	51.85	14.33	2250
T3× 3.70	45.36	27.54	2045
T3× 5.68	41.36	23.5	2060
T3× 7.04	37.89	19.24	2071
T4× 3.70	34.87	40	1950
T4× 5.68	30.47	36.5	1961
T4× 7.04	25.90	33.87	1981
T5× 3.70	38.86	38.27	1750
T5× 5.68	34.25	32.2	1762
T5× 7.04	29.56	29.67	1778
LSD $_{(0.05)}$	1.43	0.93	n.s

3.3 Grain yield of Barley

The results presented in Table 3 showed that the tillage system had a significant effect (p<0.05) on the grain yield of barley. The conventional tillage system (T2) gave the highest grain yield of barley of 2236.10 kg ha^{-1}, and T1 gave the second highest grain yield value of 2183 kg ha^{-1} closely followed by T3, which gave a grain yield value of 2059 kg ha^{-1}. While the reduced tillage systems (T4 and T5) gave the lowest grain yield values of 1764 and 1964 kg ha^{-1} respectively. This indicates that conventional tillage systems resulted in a greater grain yield than reduced tillage systems. The grain yield of conventional tillage systems T1, T2, and T3 was higher than that of reduced tillage (T4) by 11.18%, 13.87%, and 4.86%, respectively, and by 23.80%, 26.78%, and 16.76%, respectively, when compared to the reduced tillage system (T5). This was because of the increased pulverization and loosening of soil clods, which facilitate the movement of the roots and increase their spread to reach considerable depths. Spreading the root assisted in increasing the absorption of water and nutrients from the soil, thereby increasing dry matter production and grain yield. This is in agreement with the findings reported by Ramadhan (2013), who found the grain yield of barley increased for conventional tillage systems compared with reduced tillage system from 2310.32 to 2372.31 kg ha^{-1}.

The results showed that there was no significant effect (p<0.05) of operating speed on grain yield. The results also revealed that the interaction between tillage system and operating speed had no significant effect (p<0.05) on grain yield (Table 3).

3.4 Energy inputs for barley grain production under different tillage systems

The total energy input-output was determined by the amount of inputs and energy equivalents shown in Table 2. The results indicate that there were significant differences (p<0.05) among tillage treatments (Table 4). T2 increased the average of the total energy consumed for barley production compared to T1, T3, T4 and T5 by 9.02%, 22.58%, 34.39% and 41% respectively. In the T2 treatment, irrigation operations were the most energy-consuming input (34%), followed by fuel oil (30%), seeds (24.1%), nitrogen fertiliser (4.27%), phosphor fertilizer (2.86%), machinery (2.10%), human labour (2.08%), herbicide (1.52%) and potassium fertilizer (0.28%). While the reduced tillage system (T5) achieved the lowest total energy-consuming input (7786.01 MJ ha^{-1}), seeds consumed the highest energy (40%), followed by irrigation operations (25.5%), fuel oil (24.75%) nitrogen fertilizer (6.02%), phosphor fertilizer (3.78), human labor (2.81%), machinery (0.54%) and potassium fertilizer (0.38%).

In all treatments (T1, T2, T3, T4, and T5) inputs energy consumed by irrigation operations, seed, fuel-oil, and nitrogen fertilizer reached 90%, 91%, 96%, 85%, and 91%, respectively, of the total energy input for barley production. The reason could be that different tillage systems were used to prepare the soil. This means that the amounts of irrigation water, seeds, fuel oil, fertilizers, labor, and machinery size are different, which makes the energy inputs different. For example, conventional tillage systems performed with more times of passage in the field, and this led to increased fuel consumption and human labor, as well as an increased number of tillage machines and hours worked. However, increased soil pulverization under conventional tillage could lead to increased moisture loss from the soil by evaporation, particularly from the surface layer, thus requiring more irrigation compared to the seedbed, which was prepared by reduced tillage systems (Busari et al., 2015).

Consequently, with the increase in individual compounds of energy-consuming input, the total energy-consuming input will increase. For example, the irrigation operations consumed energy amounts of 3121.7, 3694.66, 2650.72, 2619, and 1991.02 MJ ha^{-1} for T1, T2, T3, T4, and T5 respectively. These results were consistent with the findings of Gozubuyuk et al. (2020) who found that the major energy input-consuming components for silage maize production in conventional tillage systems reached 90% for fuel oil, irrigation, seeds, and nitrogen fertilizers, with each component accounting for 20.49%, 39.96%, 13.05%, and 16.57%, respectively.

In the present study fuel -oil had the second place in most tillage treatments and a similar trend was shown in a study conducted using three different tillage systems, the conventional tillage system, TS1; conservation tillage systems, TS2, and TS3 in the Sivas province of Turkey by Altunaş et al. (2020) where found that the proportion of chemical fertilizer input in the total energy inputs for TS1, TS2, and TS3 was 85.4%, 88.94%, and 87.81%, respectively. Subsequently, fuel-oil occupied the second position in terms of contribution to energy inputs. Seed energy had the third rank and human labor had the lowest percentage in all three tillage systems. Similarly, Hamedani et al. (2011) in Iran, indicated that nitrogen fertilizer has the greatest portion of the total energy at 39% followed by diesel energy at 20.92%.

3.5 Energy output of barley grain production under different tillage systems

The average barley grain yield for the T1, T3, T3, T4 and T4 systems was 2183.33, 2236.10, 2059.20, 1963.72, and 1763.67 kg ha^{-1}, respectively (Table 3). Accordingly, energy outputs were calculated, which were 32095, 32871, 30272, 28867, and 25926 MJ ha^{-1} respectively (Table 4). The results showed that T2 achieved the highest output energy value of 32871 MJ ha^{-1}, while T5 had the lowest energy output value of 25926 MJ ha^{-1} and the second lowest energy output value for T4 of 28867 MJ ha^{-1}. This means that the energy output increased when using conventional tillage systems; in contrast, the energy output decreased for reduced tillage systems. The percentage increase between the high and low values of energy output reached 26.29%. Differences in energy output values between tillage systems could be attributed to differences in soil preparation methods and their effect on the physical, chemical, and biological properties of the soil. Conventional tillage systems created a suitable seedbed, which had a positive effect on the barley crop, leading to an increase in yield and, thus, increased energy production. Tabatabaeefar et al. (2009) found the energy output of wheat reached 6827 and 8760 MJ ha^{-1} by using moldboard plow and cyclo-tiller tillage systems.

3.6 Energy index

3.6.1 Energy use efficiency

Tillage treatments (T1, T2, T3, T4, and T5) had different energy use efficiency for barley grain production (Table 5). The results showed that the energy use efficiency applying reduced tillage systems T5 and T4 obtained the highest energy use efficiency with an average value of 3.42 and 3.53, respectively. In contrast, the energy use efficiency utilizing conventional tillage systems T1, T2, and T3 decreased to 3.19, 2.99, and 3.38, respectively. This was because the total energy input was low for reduced tillage systems T5 and T4, it reached 8169 and 7586 MJ ha^{-1}. In comparison, the energy input for conventional tillage systems T1, T2, and T3 was high at 10070, 10978, and 8956 MJ ha^{-1} respectively. Results fall within the reported range. In a study carried out by Taner et al. (2015) in Turkey, they found that energy use efficiency tended to increment with decreases in soil tillage practices, with values of 3.97 and 3.11 registered for conventional and reduced tillage systems respectively.

3.6.2 Energy productivity

Table 5 shows the values of energy productivity for T1, T2, T3, T4, and T5. In the current investigation, the reduced tillage system T4 achieved the highest energy productivity value of 0.24 kg MJ^{-1} while conventional tillage system T2 had the lowest energy productivity value of 0.22 kg MJ^{-1} and the reason could be attributed to the decreasing the input energy under the reduced tillage system. T3 and T5 recorded the same value of energy productivity (0.23 kg MJ^{-1}) due to the input energy for T3 and T5 being close to each other, and this might be returned to perform each tillage treatment in two passes. Prior studies have documented similar results. Kumar et al. (2013) indicated significant differences (p<0.05) in energy productivity between tillage treatments, with the CT (two passes of disk harrow +

cultivator + planker) achieving a higher value of energy productivity in wheat production compared to RT (single pass of disk harrow+ rotavator) by 29.41%. In contrast, Gozubuyuk et al. (2020) concluded that CT treatment had a low energy productivity value of 3.51 kg MJ^{-1} compared to RT treatment, which recorded a high energy productivity value of 3.83 kg MJ^{-1}.

3.6.3 Specific energy

The effects of tillage systems on specific energy were significant (p<0.05) (Table 5), except for the T3 and T5 treatments, where statistical analysis showed no significant differences between them in specific energy. The highest specific energy value (4.91MJ kg^{-1}) was obtained from the conventional tillage system T2 and it was followed by T1 and T3 with 4.61, and 4.35 MJ kg^{-1}. The lowest values were achieved by reduced tillage treatments T4 and T5, it was 4.16, and 4.30 MJ kg^{-1} respectively. Prior studies reported similar results. Taner et al. (2015) reported that the specific energy for wheat production under a conventional tillage system was higher than that of a reduced tillage system by 26.85%. Nasseri (2019) confirmed that the conventional tillage system had a high specific energy value of 10.50 MJ kg^{-1} and decreased with the conservation tillage system to 4.90 MJ kg^{-1}, i.e., the specific energy was reduced by 53.33%. Gozubuyuk et al. (2020) found that CT treatment had a high specific energy value of 0.289 MJ kg^{-1} compared to RT treatment, which recorded a low energy specific value of 0.263 MJ kg^{-1}.

3.6.4 Net energy

The results of the net energy production of barley under different tillage systems are shown in Table 5. T1 recorded the highest value of net energy compared to T2, T3, T4, and T5 by 0.60%, 3.33%, 6.41%, and 21.42% respectively. The results also indicate that the conventional tillage system led to a higher net energy compared to the reduced tillage system. The average net energies for conventional tillage systems T1, T2, and T3 were 22025, 21893, and 21316 MJ ha^{-1}, respectively. In contrast, the reduced tillage system showed lower average net energies, with T4 and T5 recording values of 20698 and 18340 MJ ha^{-1}, respectively.

The reason for increasing net energy could be attributed to the energy output from barely grain yield being significantly greater than the total energy input under conventional tillage system. The high value of net energy in barley grain production under conventional tillage systems could be returned to increase the yield of barley grain despite the increased input energy of conventional tillage systems. The findings are closer to the values reported by Baran et al. (2016) who indicated that the net energy by using conventional tillage systems (16039.23 MJ ha^{-1}) was more than that of reduced tillage (9549.20 MJ ha^{-1}) in sunflower farms, and differ from the finding of Kumar et al. (2013) who found that the net energy by involving a reduced tillage system (127520 MJ ha^{-1}) was greater than that of a conventional tillage system (120030 MJ ha^{-1}) system in wheat production.

Table 4 Energy requirements (MJ ha^{-1}) computed for the input-outputs of different tillage practices in barley grain production

	Tillage systems					
Energy parameters	T1	T2	T3	T4	T5	LSD $_{(0.05)}$
fuel-oil	3000.38	3214.74	2338.93	1712.57	1927.12	55.48
Human labor	225.89	229.68	220.15	214.33	218.81	1.84
Machinery	114.54	231.46	139.17	14.29	41.59	0.65
Nitrogen	468.86	468.86	468.86	468.86	468.86	n.s
Phosphate	294.52	294.52	294.52	294.52	294.52	n.s
Potassium	30.36	30.36	30.36	30.36	30.36	n.s
Irrigation	3121.71	3694.66	2650.72	2619	1991.02	97.39
Herbicides	167.73	167.73	167.73	167.73	167.73	n.s
seeds	2646	2646	2646	2646	2646	n.s
input	10070.00	10978.00	8956.44	8167.66	7786.01	190.2
output	32095	32871	30272	28867	25926	729.0

Table 5 Energy efficiencies in different tillage systems in barley grain production

Tillage systems	Energy output	Energy input	Energy efficiency	Energy productivity	Specific energy	Net energy
	(MJ ha^{-1})	(MJ ha^{-1})	(%)	(kg MJ^{-1})	(MJ kg^{-1})	(MJ ha^{-1})
T1	32095	10070	3.19	0.22	4.61	22025
T2	32871	10978	2.99	0.20	4.91	21893
T3	30272	8956	3.38	0.23	4.35	21316
T4	28867	8169	3.53	0.24	4.16	20698
T5	25926	7586	3.42	0.23	4.30	18340
LSD $_{(0.05)}$	729.0	190.2				

4 Conclusion

In this study, three conventional tillage systems and two limited tillage systems were tested in order to select the most efficient tillage system in terms of reducing energy input consumption and increasing the grain yield of barley and conclude the following:

The use of reduced tillage systems (T4 and T5) led to significant fuel savings of up to 46.73% compared to conventional tillage systems (T1, T2, and T3). Particularly, T4 revealed a fuel decrease of 42.92% and T5 revealed a decrease of 35.77%, emphasizing the possibility of these tillage systems decreasing energy consumption in agriculture operations.

Increasing the tillage speed resulted in a decrease in fuel consumption and soil pulverization index.Conventional tillage systems at a high tillage speed of 7.04 km h^{-1} gave a low pulverization index, while reduced tillage systems at a low tillage speed of 3.70 km h^{-1} gave a high pulverization index. The conventional tillage system (T2) and high speed (7.04 km h^{-1}) gave the greatest grain yield value of 2250 kg ha^{-1}, while the reduced tillage system (T5) and low speed (3.70 km h-1) gave the lowest grain yield value of 1750 kg ha^{-1}.

Reduced tillage system (T5) gained the lowest total energy-consuming input (7786.01 MJ ha^{-1}), where seeds consumed the highest energy (40%), followed by irrigation operations (25.5%), fuel oil (24.75%), nitrogen fertilizer (6.02%), phosphor fertilizer (3.78%), human labor (2.81%), machinery (0.54%), and potassium fertilizer (0.38%)

Energy output was decreased under reduced tillage system and increased under conventional tillage systems.

Reduced tillage systems (T4 and T5) had higher energy use efficiency than conventional tillage systems (T1, T2, and T3) due to lower total energy input.

T4 achieved the highest energy productivity value, while T2 had the lowest value due to decreasing input energy.

Conventional tillage systems had higher net energy production than reduced tillage systems due to significantly greater energy output from barley grain yield.

It can be recommended to use the conventional tillage system when the objective is to maximize energy output and productivity. However, if the objective is to gain higher energy use efficiency and lower specific energy values, then reduced tillage systems may be a better choice, and also being recommended to conduct further research in different regions to confirm the findings of this study. Additionally, future research could investigate the environmental impacts of different tillage systems to provide a more comprehensive analysis of their sustainability.

Acknowledgments

The authors wish to express their sincere thanks and appreciation to the Department of Agricultural Machines and Equipment at the University of Basrah for assisting in providing tillage machines and tractors in this study.

References

Abdipur, M., N. A. Heidarpur, B. Vaezi, V. Bavei, A. H. Ghanbari, and S. Talaee. 2012. The effect of different tillage methods on yield and yield components of bread wheat under rained conditions. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 12(9): 1205-1208.

Ahmadi, H., and K. Mollazade. 2009. Effect of plowing depth and soil moisture content on reduced secondary tillage. *CIGR EJournal*, 11: Manuscript MES 1195.

Al-Lami, A. M., Y. K. Al-Timimi, and H. K. Al-Shamarti. 2021. Spatiotemporal analysis of some extreme rainfall indices over Iraq (1981–2017). *Scientific Review Engineering and Environmental Studies (SREES)*, 30(2): 221-235.

Al-Hadithi, A., and A. Al-Shuwaili. 2018. Evaluation of soil compaction in the irrigated areas of Dhi-Qar Governorate, Southern Iraq. *Mesopotamia Environmental Journal*, 5(3): 31-39.

Almaliki, S., R. Alimardani, and M. Omid. 2016. Fuel consumption models of MF285 tractor under various field conditions. *CIGR Journal*, 18(3): 147-158.

Alamooti, M. Y., and A. Hedayatipoor. 2019. Effect of conservative tillage on physical properties of soil in irrigated wheat production. *CIGR Journal*, 21(4): 90-95.

Altunaş, E., E. Özgöz, M. Güzel, and B. Özgenlk. 2020. Effects of tillage systems on energy efficiency in safflower farming of Central Anatolia of Turkey. *Turkish Journal of Agricultural Engineering Research*, 1(1): 1-11.

Alwan, A. A. 2019. A field study of soil pulverization energy by using different moldboards types under various operating condition. *Basrah Journal of Agricultural Sciences*, 32: 373-388.

Banaeian, N., and M. Zangeneh. 2011. Study on energy efficiency in corn production of Iran. *Energy*, 36(8):5394-5402.

Baran, M. F., R. Polat, and O. Gökdoğan. 2016. Comparison of energy use efficiency of different tillage methods on the secondary crop sunflower production. *Fresenius Environmental Bulletin*, 25(11): 4937-4943.

Barut, Z. B., C. Ertekin, and H. A. Karaagac. 2011. Tillage effects on energy use for corn silage in Mediterranean Coastal of Turkey. *Energy*, 36(9): 5466-5475.

Becker, R. S., A. dos Santos Alonço, T. R. Francetto, D. P. Carpes, B. C. C. R. Zart, and A. R. Moreira. 2019. Operational performance of crop residue cutting discs in the no-tillage system. *CIGR Journal*, 21(2): 78-85.

Busari, M. A., S. S. Kukal, A. Kaur, R. Bhatt, and A. A. Dulazi. 2015. Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3(2): 119-129.

Carman, K., E. Cıtıl, and T. Marakoglu. 2021. Energy use efficiency of strip tillage systems for corn silage production in Middle Anatolia. *Journal of Agricultural Science and Technology*, 23(2): 293-306.

Damanauskas, V., and A. Janulevičius. 2022. Effect of tillage implement (spring tine cultivator, disc harrow), soil texture, forward speed, and tillage depth on fuel consumption and tillage quality. *Journal of Agricultural Engineering*, 53(3): 1371.

Fernandez, M. R., R. P. Zentner, M. P. Schellenberg, O. Aladenola, J. Y. Leeson, M. S. Luce, B. G. McConkey, Cutforth. 2019. Soil fertility and quality response to reduced tillage and diversified cropping under organic management. *Agronomy Journal*, 111(2): 781-792.

Gözübüyük, Z., A. Çelik, İ Öztürk, O. M. Demir, and C. Adıgüzel. 2012. Comparison energy use efficiency of various tillage-seeding systems in production of wheat. *Journal Agricultural Machinery Sciences*, 8(1): 25-34.

Gozubuyuk, Z., U. Sahin, M. C. Adiguzel, and E. Dasci. 2020. Energy use efficiency of deficit-irrigated silage maize in different soil tillage practices on a high plain with a semi-arid climate. *Archives of Agronomy and Soil Science*, 66(12): 1611-1626.

Hamedani, S. R., Z. Shabani, and S. Rafiee. 2011. Energy inputs and crop yield relationship in potato production in Hamadan province of Iran. *Energy*, 36(5): 2367-2371.

Hanna, M. 2016. Estimating the field capacity of farm machines. Iowa State Univ., Ames, IA, USA. Available at: https://www.extension.iastate.edu/agdm/crops/pdf/a3-24.pdf/. Accessed 11 April 2018.

Hinkelmann, K., and O. Kempthorne. 2007. *Design and Analysis of Experiments, Volume 1: Introduction to Experimental Design* (Vol. 1). New Jersey, USA: John Wiley & Sons.

Houshyar, E., H. R. Zareifard, P. Grundmann, and P. Smith. 2015. Determining efficiency of energy input for silage corn production: An econometric approach. *Energy*, 93(Part 2): 2166-2174.

Kareem, K. I., and P. Sven. 2019. Effect of ploughing depth, tractor forward speed, and plough types on the fuel consumption and tractor performance. *Polytechnic Journal*, 9(1): 43-49.

Karaağaç, H. A., S. Aykanat, R. Gültekin, and M. F. Baran. 2014. Determination of energy using efficiency at corn production in Adana. *Journal of Tekirdag Agricultural Faculty*, 11(3): 75-81.

Khalil, A. H. S., A. B. Saeed, and M. M. Balel. 2021. Effect of some conservation tillage practices on growth and yield attributes of rainfed sorghum (*Sorghum bicolor* (L.) Moench) at Alfula, West Kordofan State, Sudan. *Journal of Agricultural Science & Engineering Innovation (JASEI)*, 2(1): 24-29.

Kumar, V., Y. S. Saharawat, M. K. Gathala, A. S. Jat, S. K. Singh, N. Chaudhary, and M. L. Jat. 2013. Effect of different tillage and seeding methods on energy use efficiency and productivity of wheat in the Indo-Gangetic Plains. *Field Crop Research*, 142: 1–8.

Leghari, N., A. Ali, and M. A. Mangrio. 2016. Relative efficiency of different tillage practices and their effect on soil physical properties under semi-arid climate of Tandojam, Pakistan. *Mehran University Research Journal of Engineering & Technology*, 35(2): 239-246.

Liu, Z., S. Cao, Z. Sun, H. Wang, S. Qu, N. Lei, and Q. Dong. 2021. Tillage effects on soil properties and crop yield after land reclamation. *Scientific Reports*, 11(1): 4611.

Memon, S. Q., and N. Arshad. 2018. Energy requirements and performance of different soil tillage systems on the yield of maize crop. *Advances in Crop Science and Technology*, 6(1): 1000334.

Moitzi G., T. Szalay, M. Schüller, H. Wagentristl, K. Refenner, H. Weingartmann, P. Liebhard, J. Boxberger, and A. Gronauer. 2013. Effects of tillage systems and mechanization on work time, fuel and energy consumption for cereal cropping in Austria. *CIGR Journal*, 15(4): 94-101.

Mousavi-Boogar, A., K. Azizi, M. Feizian, and H. R. Eisvand. 2022. Effects of different tillage systems on soil properties, and yield and yield components of barley. *Archives of Agronomy and Soil Science*, 68(13): 1784-1795.

Muhsin, S. J. 2017. Determination of energy requirements, plowed soil volume rate and soil pulverization ratio of chisel plow under various operating conditions. *Basrah Journal of Agriculture Science*, 30(1): 73-84.

Nasseri, A. 2019. Energy use and economic analysis for wheat production by conservation tillage along with sprinkler irrigation. *Science of the Total Environment*, 648: 450–459.

Nassir, A. J. 2017. The effect of tillage methods on energy pulverization requirements under various operating conditions in silty loamy soil. *Thi-Qar University Journal for Agricultural Researches*, 6(2): 55-73.

Nassir, A. J. 2018. Effect of moldboard plow types on soil physical properties under different soil moisture content and tractor speed. *Basrah Journal of Agricultural Sciences*, 31(1): 48-58.

Nassir, A. J., S. J. Muhsin, and D. R. Ndawi. 2022. The technical evaluation of three different types of tillage combined machines and compared them with individual tillage machines. *Basrah Journal of Agricultural Sciences*, 35(2): 341-361.

Nassir, A. J., M. N. Ramadhan, and A. A. M. Alwan. 2021. Energy input-output analysis in wheat, barley and oat production. *Indian Journal of Ecology*, 48(1): 304-307.

Pratibha, G., I. Srinivas, K. V. Rao, B. M. K. Raju, A. K. Shanker, A. Jha, M. U. Kumar, K. S. Rao, and K. S. Reddy. 2019. Identification of environment friendly tillage implement as a strategy for energy efficiency and mitigation of climate change in semiarid rainfed agro ecosystems. *Journal of Cleaner Production*, 214: 524-535.

Ramah, M., and E. H. Baali. 2013. Energy balance of wheat and barley under Moroccan conditions. *Journal of Energy Technologies and Policy*, 3(10): 20-27.

Ramadhan, M. N. 2013 Tillage systems and seeding rates effect on yield components, seed yield, and biological yield of barley cultivars. *Journal of Basrah Researches (Sciences)*, 39(1): 33-46.

Ranjbarian, S., M. Askari, and J. Jannatkhah. 2017. Performance of tractor and tillage implements in clay soil. *Journal of the Saudi Society of Agricultural Sciences*, 16(2): 154-162.

Sahabi, H., H. Feizi, and S. Amirmoradi. 2013. Which crop production system is more efficient in energy use: Wheat or barley? *Environment, Development and Sustainability*, 15: 711-721.

Saldukaitė-Sribikė, L., E. Šarauskis, S. Buragienė, A. Adamavičienė, R. Velička, Z. Kriaučiūnienė, and D. Savickas. 2022. Effect of tillage and sowing technologies nexus on winter wheat production in terms of yield, energy, and environment impact. *Agronomy*, 12(11): 2713.

Sartori, G. M. S., E. Marchesan, R. D. David, R. Carlesso, M. T. Petry, N. P. Aires, R. Giacomeli, B. B. Aramburu, and A. L. da Silva. 2016. Soybean tillage systems and physical changes in surface layers of two Albaqualf soils. *Revista Brasileira de Ciência do Solo*, 40: e0160019.

Singh, T. P. 2016. Energy and economic assessment in tillage and sowing for rotavators, conventional and not ill wheat establishment. *Agriculture & Forestry*, 62(4): 101–108.

Tabatabaeefar, A., H. Emamzadeh, M. G. Varnamkhasti, R. Rahimizadeh, and M. Karimi. 2009. Comparison of energy of tillage systems in wheat production. *Energy*, 34(1): 41–45.

Taner, A., R. Z. Arisoy, Y. Kaya, I. Gültekin, and F. Partigöç. 2015. The effects of various tillage systems on grain yield, quality parameters and energy indices in winter wheat production under the rainfed conditions. *Fresenius Environmental Bulletin*, 24(4a): 1463-1473.

Upadhyay, G., and H. Raheman. 2019. Comparative analysis of tillage in sandy clay loam soil by free rolling and powered disc harrow. *Engineering in Agriculture, Environment and Food*, 12(1): 118-125.

Upadhyay, G., and H. Raheman. 2020. Comparative assessment of energy requirement and tillage effectiveness of combined (active-passive) and conventional offset disc harrows. *Biosystems Engineering*, 198: 266-279.

Ziaei, S. M., S. M. Mazloumzadeh, and M. Jabbary. 2015. A comparison of energy use and productivity of wheat and barley (case study). *Journal of the Saudi Society of Agricultural Sciences*, 14(1): 19-25.