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Effect of Tillage Systems on energy used maize production and Soil Compaction under the semi-arid region

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Abstract: The experiments were conducted in clay soil at the Agricultural Research Station of University of Basrah (Karmat Ali Campus) in July 2022. The study aimed to assess the effect of various tillage systems on soil compaction, grain yield, and energy use efficiency in maize production. The experiment was organized in a complete randomized block design (RCBD) with four tillage systems namely: CTm (moldboard plow + spike teeth rollers), CTs (chisel plow + disk harrow), DP (subsoiler + spike teeth rollers), and RT (disk harrow + spike teeth rollers). Results indicated that deep tillage (DP) gave the lowest soil penetration resistance value of 1.15 MPa compared to CTm, CTs, and RT by 26.75, 20.69, and 40.41% respectively. Soil penetration resistance was increased by 46.56% at the end of the season compared to the beginning season. The results also showed that DP and RT exhibited the highest and lowest maize grain yield values of 5820 and 4225 kg respectively. Energy analysis showed that DP recorded the highest energy efficiency of 8.02% and a net energy value of 85082.27 MJ ha^{-1}. In contrast, the RT system obtained the lowest energy consumption efficiency of 6.29% and a net energy value of 59347.54 MJ ha^{-1}. Irrigation and fuel-oil consumption are the most energy-intensive inputs. The results showed that DP is significantly efficient in productivity and energy use efficiency in maize production. DP was the most effective strategy to increase maize yield and energy efficiency, making it the most favourable option for field performance in maize farming.

Keywords: Input-output energies, Maize yield, Soil penetration resistance, Tillage.

Introduction

In most agricultural activities, energy is one of the most controllable expenditures, and there is a great deal of scope to cut costs by consuming less energy (Lu *et al.,* 2020). An important method of identifying and classifying agricultural systems according to energy use is to conduct energy studies for agricultural production activities. To evaluate agricultural products in recent years, researchers have looked at the concepts of sustainable agriculture and the economics, energy, and environment. The energy needs are steadily increasing, productivity will increase, and energy requirements will decrease with improved energy efficiency in tillage systems (Sun *et al.,* 2022). In all agricultural production systems that rely exclusively on non-renewable energy sources, the majority of energy inputs are derived from tillage and fertilizer. Solaymani (2021) point out that non-renewable energy is costly and likely to run out soon. Land preparation, irrigation, harvesting, post-harvest processing, and the transportation of agricultural inputs and outputs require direct support energy. Insecticides and fertilizers are examples of indirect support energy applications. In production techniques, boosting productivity is critical. Tillage operations can be defined as a change in soil properties caused by the operation of plowing tools. This practice requires considerable energy to break down and invert soil. Tillage practices need the direct utilization of energy, particularly fossil fuel, which tractor engines operate to convert into mechanical energy. Primary tillage treatments require energy of 70% of the total energy used before seeding (Yang *et al.,* 2022). Choosing an appropriate tillage system can reduce energy consumption as well as minimize environmental pollution. Decreasing the intensity of plowing leads to decreased fossil fuel consumption, increased energy efficiency use, decreased soil erosion, and energy needed for land preparation. Omulo *et al*., (2022) indicated that minimum tillage systems lead to 55% lower fossil fuel consumption than traditional tillage systems without a significant difference in grain yield. A study conducted by Saglam *et al*. (2020) reported the energy consumption of various tillage techniques, which involved the mouldboard plow and drill, the chisel plow and drill, and no-till and drill. They state that the energy consumption of reduced tillage and no-till systems is lower than that of conventional tillage by 54% and 84% respectively. Compared to the CT system, Moldovan *et al*., (2018) found that the RT system saved 7.8% of the energy, while the NT saved 12.4%. The energy usage was recorded at 23538.9 MJ ha^{-1}. In each system, the fertilization factor made the largest contribution to the overall energy, varying by as much as 7%. Energy input and output must be collected for equipment utilized in soil preparation and crop production to assess tillage energy requirements and choose suitable crop production systems.

A significant phase of soil deterioration, soil compaction affects the soil's capacity to produce crops by reducing the soil's natural biological activity, water and nutrient availability, and susceptibility to soil erosion. The complete breakdown of the soil's physiological profile indicates soil compaction (Pires *et al.,* 2017; Shaheb *et al.,* 2021).

Tillage systems can drastically alter the soil's physical, chemical, and biological characteristics by influencing soil temperature, water content, and filtration. One of the main causes of deterioration is soil compaction. Hussain *et al*., (2020) define compaction as a physical form of soil degradation that modifies soil structure and lowers soil productivity. Conventional soil culture is the most effective in preserving soil moisture because it prolongs the presence of agricultural residues in the soil, decreases evaporation, and increases infiltration. In the study by Mileusnić *et al*., (2022). plant yields decrease after using the NT system for a few years. This may be the consequence of large tractor seeders and harvesters gradually compacting the soil, especially when operating on wet ground. Biberdzic *et al*., (2020) reported that the highest soil compaction (2.47 MPa) was measured in NT and was significantly higher than in RT and CT by 11.03 and 17.36%, respectively.

The study objective was to assess the effect of various tillage techniques on soil compaction. The study highlights the energy use soil health, energy efficiency, and crop productivity of conventional, reduced, and no-till systems. By analyzing the relationship between tillage methods, soil compaction, and agricultural output.

Materials &methods

This research was conducted at the Agricultural Research Station affiliated with the College of Agriculture, University of Basrah (47°45'00"E30°34'14"N). The soil texture was clay. Soil samples were collected from a depth of 25 cm to determine some soil properties (Table 1)

Table (1): Soil properties at soil depth 0-25 cm.

Soil properties	Unit	Value
Sand	g kg-1	137.324 ± 0.07
Silt	g kg-1	317.746 ± 0.01
Clay	g kg-1	544.93 ± 0.73
Texture		Clay
Real density	Mg m-3	2.623 ± 0.06
Bulk density	Mg m-3	1.321 ± 0.58
Total porosity	%	49.637 ± 0.21
Moisture content	%	18.5 ± 0.18
Mean weighted diameter (MWD)	mm	0.192 ± 0.06
Saturated water conductivity	m day-1	0.177 ± 0.58
Penetration resistance	MPa	2.25 ± 0.21
Organic matter	g kg-1	3.26 ± 0.18

The experimental unit's area was 3 x 25 m^2, with three replicates for each treatment. It was completely randomized block design with four tillage treatments. The resulting values were subjected to analysis of variance and multiple comparison test (LSD) using Gen stat version17 software in order to determine the differences between the tillage regimes. The treatments arrangement was depended on tillage intensities as follows:

CTm: Moldboard plow + Spike tooth rollers.

CTs: Chisel plow + disk harrow.

DP: Subsoiler + Spike tooth rollers.

RT: disk harrow + Spike tooth rollers

The technical specifications of the tillage machines used in the experiment are summarized in Table 2.

Grain yield of maize

Samples of corn were collected at the end of the growing season. Ten plants were harvested from each experimental unit and then grain yield and component were measured. The plants were oven-dried at a temperature of 70 C until weight stability the grains were separated from the cobs. The grain weight of maize was adjusted to standard moisture content at 15%. The weight of maize grain was converted into mega grams per hectare based on the following equation. (Tandzi & Mutengwa, 2020).

$$Grain\ yield\ (Mg\ ha^{-1}) = \frac{Total\ grain\ weight\ (Mg)}{Plot\ area\ (m^2)} * 10000\ m^2 \quad (1)$$

Soil penetration resistance

The soil penetration resistance was measured using an Eijkelkamp penetrologger, a machine with a rod of 80 cm in length, its end is equipped with a cone with an area of 20.60 cm2 and the cone's angle of inclination from the top is 30 degrees. The cone penetrates the soil to the required depth when the device handle is manually pressed by applying a constant force downward. The measurements were taken in two periods at the beginning and end of the growing season. This device can read the soil penetration force data for each depth of 1 cm up to 80 cm. Each measurement was repeated three times for each treatment and all soil penetration resistance data were saved in the device's memory. After the measurements, the device was connected to the computer, and then all recorded data was transferred to the computer in the unit of MPa (Nassir *et al*., 2025).

Table (2): The technical specifications of the tillage machines used in the experiment

	Tillage machines				
Tillage systems	Moldboard plow	Chisel plow	Subsoiler	Disc harrow	Roller
Working tools	Deep digger moldboard	Curved Shanks	Straight shank	Concave disks	Rigid spike
Tool Number	4	7	1	8	1
Working width (cm)	150	175	100	270	300
Diameters (cm)				26	22
Working depth (cm)	25	30	50	15	10
Mass (Kg)	570	673	420	750	250
Energy Equivalent ($MJ\ kg^{-1}$)	99.22	99.22	99.22	99.22	99.22
Machinery useful life (h)	2000	2000	2000	2000	2000
Field capacity ($ha\ h^{-1}$)	0.27 ± 0.07	0.24 ± 0.10	0.18 ± 0.62	1.20 ± 0.9	2.55 ± 1
Fuel-oil consumption ($L\ ha^{-1}$)	20.67 ± 0.81	23.50 ± 1.10	28.54 ± 0.57	18.21 ± 1.25	12.89 ± .34

Preparing the soil & performing field operations

The soil was tilled according to the tillage treatments (CTm, CT DP, and RT), all tillage treatments were performed with a Massey Ferguson 400 Xtra tractor. The tractor has a 3.5-liter Perkins engine that weighs 4012 kg and can produce up to 82 horsepower. The experimental units were determined Maize seeds, Zea mays, Maha variety, were planted on 7/10/2022 at a seed rate of 25 kg per hectare, with three seeds per hole. The distance between one hole and another in the same line was 30 cm and the distance between one line and another was 75 cm, with two lines for each experimental unit. After germination, the plants were thinned to one plant. Chemical fertilizer was added to all experimental units equally according to the fertilizer recommendation followed (FAO, 2018). Nitrogen fertilizer was added in the form of urea (46% N) at a rate of 200 kg N ha^{-1} in three equal batches at planting, germination, and flowering. Triple superphosphate fertilizer (p% 20.21) was added at a rate of 130 kg P ha^{-1} at planting, and potassium (k% 43) at a rate of 100 kg K ha^{-1} in two batches, the first at a rate of 15% of the total quantity and the second during the flowering period. The fertilizer was added in the form of lines near the planting lines and at a depth of 3 cm. The irrigation process was carried out using the spate irrigation method (the average values of electrical conductivity and pH of irrigation water were 2.54 dSm^{-1} and 6.9, respectively). The amounts of irrigation water for all experimental units were determined on the mechanical irrigation meter and the American evaporation basin, class A. 20% was added as additional water for washing requirements until the end of the experiment and harvest on 27/12/2022.

Agricultural practices, including broadcasting seeds, fertilizer application, harvesting, and irrigation, were implemented consistently throughout all experimental units using different tillage systems. The input and output energy for each tillage system vary from one another. As a result, the study compared the energy consumption efficiency and related indicators of the four tillage strategies.

The energy analyses used the energy equivalents of production inputs and outputs of maize for tillage systems. The only direct energy inputs in maize production are oil and fuel consumption. The fuel consumptions were computed using the following equations

$$D_F = F_i\,[A + BS + S\,C^2]W_d T_d \qquad (2)$$

Where: A, B and C: are machine-specific parameters, D_F: is draft force (N), W_d: is machine width (m), T_d: is plowing depth F_i: is a dimensionless soil texture adjustment parameter; i is 1 for fine, 2 for medium and 3 for coarse-textured soils, S: is operation speed ($km\ h^{-1}$);

$$P_{TO} = \frac{D_F * S}{3.6\,M_E * T_E} \qquad (3)$$

Where: P_{TO}: is the total power needed to complete a task (kW), M_E: is the mechanical efficiency of transmission. (M_E=0.96 for tractors with gear transmissions), T_E: is traction efficiency ASAE (2011).

$$Q_{di} = P_{TO}\left[2.64\left(\frac{P_{TO}}{P_{TO\,max}}\right) + 3.91 - 0.203\sqrt{738}\left(\frac{P_{TO}}{P_{TO\,max}}\right) + 173\right] \qquad (4)$$

Where: Q_{di}: is diesel consumption ($L\ h^{-1}$), $P_{TO\,max}$: is the maximum power of power take-off (PTO)

By dividing the fuel consumption value from equation (4) by the field capacity, the fuel consumption was obtained in liters per hectare. It included the energy inputs for human labor, the energy of manufacturing agricultural equipment and tractors, the energy of chemical fertilizer, the energy of insecticides and fungicides, the energy of herbicides, and the energy of seeds. Total energy inputs were calculated by adding the values to the energy calculated by multiplying the energy equivalents shown in Table 2 by the quantities (ASAE, 2011; Heller *et al.,* 2003). Values used in equations for seed and fertilizer broadcasters, sprayers, and combined harvesters mentioned by ASAE (2011). Oil consumption was considered as 4.5% of fuel consumption (Altuntaş, 2020).

used in the current experiment. The machine energy was calculated using the following equation:

$$ME = \frac{G_{mw} * E_e}{M_{ec} * C_{fc}} \qquad (5)$$

Where; ME is machine energy (MJ ha^{-1}), Gmw: is the mass of the machines used in the agricultural operations. (kg), Cfc: is Actual field capacity (ha h^{-1}), Ee: is energy equivalent (Table 2), M_{ec}: is machine economic life (h).

The production of maize grain and straw was considered an output of the current study. Total energy production was calculated by multiplying the production of seeds and straw by the equivalent energy of the product (Table 3) to determine and compare the energy efficiency of the different tillage regimes used to produce maize. Total energy inputs and outputs were calculated separately, and then comparisons were made for the different tillage systems. The values were calculated from the equations mentioned above and used in in energy efficiency parameters provided.

Energy efficiency, energy productivity, energy intensity, and energy gain for maize yield (grain and straw) were calculated by using the following equations (Nassir *et al.,* 2023).

$$E_{ff} = \frac{O_E}{I_E} \qquad (6)$$

$$E_P = \frac{C_Y}{I_E} \qquad (7)$$

$$SP_E = \frac{I_E}{C_Y} \qquad (8)$$

$$N_E = O_E - I_E \qquad (9)$$

Where: E_{ff}: Energy efficiency, O_E: Output energy ($MJ\ ha^{-1}$), I_E: Input energy ($MJ\ ha^{-1}$), E_P: Energy productivity $(kg\ MJ^{-1})$, C_Y: Grain yield $(kg\ ha^{-1})$, SP_E: Specific energy $(MJkg^{-1})$, N_E: Net energy $MJ\ ha^{-1}$.

Table (3):Energy equivalents of the input and output used in maize production (grain and straw)

Definition	Unit	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs			
Diesel fuel-oil	L	56.31	Memon &Arshad (2018).
Human labor	h	1.96	Memon & Arshad (2018).
Tractor	kg	158.5	Choudhary *et al.* (2021))
Surface irrigation	m^3	1.2	Nassir *et al*. (2023).
Fertilizer (P_2O_5)	kg	12.44	Memon & Arshad (2018).
Fertilizer (N)	kg	11.15	Memon & Arshad (2018).
Fertilizer (K)	kg	11.15	Memon & Arshad (2018).
Seed	kg	30	Nassir *et al*. (2023).
Herbicide	L	238	Nassir *et al.* (2023).
B. Output			
Maize grain yield	kg	16.7	Memon and Arshad (2018).

Results & Discussion

The soil penetration resistance (MPa)

The data in Table 4 showed that the tillage systems significantly affected the soil penetration resistance values. The reduced tillage system RT recorded the highest soil penetration resistance of 1.93 MPa, followed by the conventional tillage systems CTm and CTs which recorded soil penetration resistance of 1.57 and 1.45 MPa, respectively. In contrast, the deep tillage system Dp recorded the lowest soil penetration resistance of 1.15MPa, which can be linked to the decrease in the bulk density of the soil plowed by deep tillage as a result of the increase in the loosened large soil volume compared to the loosened surface area by other tillage systems. This result is consistent with Wang *et al*., (2021) who mentioned that deep tillage by subsoiler led to lower soil penetration resistance values than shallow tillage. The t-test showed highly significant differences between the growth stages of maize crops in the values penetration resistance of soil (Table 4).

The values of penetration resistance of soil increased with the progress of the crop growth stages, and the percentage of increase at the end of the season compared to the beginning of the season (immediately after plowing) was 46.56%. This can be ascribed to the increase in bulk density values and the decrease in the total porosity of the soil as a result of the effect of irrigation processes that cause the movement of fine clay particles with irrigation water and their deposition in the pore spaces, thus increasing the penetration resistance of the soil.

Table (4): Soil penetration resistance (MPa) at the beginning and end growth season

Tillage systems	Growth season periods Beginning	End	Mean
CTm	1.26 ± 1.52[a]	1.87 ± 2.04[d]	1.57 ± 1.78[i]
CTs	1.13 ± 1.15[b]	1.76 ± 1.76[e]	1.45 ± 1.46[jf]
DP	0.87 ± 0.82[c]	1.43 ± 2.37[f]	1.15 ± 1.60[kb]
RT	1.68 ± 1.00[d]	2.18 ± 2.11[g]	1.93 ± 1.55[l]
Mean	1.24 ± 1.23	1.81 ± 2.07	
$t_{0.01}$= 4.01**			

The similar letters show no significant differences (p<0.05) based on LSD0.05.
****indicates significant differences in the significance probability of 0.01 based on the t-test.**

The results are consistent with Ren *et al*., (2019) who found that the highest soil penetration resistance was recorded at the end of the maize growing season of 2 MPa, while the lowest soil penetration resistance was recorded at the beginning of the growing season of 1.10 MPa.

Grain yield of maize

The results of the statistical analysis showed a highly significant effect of tillage treatments on grain yield (Table 5). The deep tillage treatment DP achieved the highest grain yield, reaching 5820 kg ha^{-1}, followed by the conventional tillage treatment CTm, which recorded a grain yield of 5210 kg ha^{-1}, while the reduced tillage treatment RT recorded the lowest yield, reaching 4225 kg ha^{-1}. The results also showed that the deep tillage treatment DP increased grain yield by 11.71, 17.10 and 37.75% compared to the other tillage treatments CTM, CTS and RT, respectively. The increase in yield is attributed to the mechanical effect of deep tillage DP in increasing soil loosening, increasing soil total porosity, and decreasing apparent density with increased effectiveness of soil microorganisms, which helped increase root growth, which led to increased absorption of nutrients by the plant, which was positively reflected on plant growth and then increased yield. These results are consistent with Ramadan (2021), who indicated that deep tillage increased maize yield by 16.05 and 33.53% compared to traditional and reduced tillage systems, respectively.

Input-output energy parameters

Total energy inputs and outputs were calculated based on the input values and their energy equivalents presented in Table 2. The results showed that there were statistically significant differences (p < 0.05) between tillage systems (Table 5) in energy input to mechanization and fuel oil.

Table (5): Energy inputs (MJ ha^{-1}), fuel-oil consumption (L ha^{-1}), and grain yield (kg) for the tillage systems of maize production.

Input energy	Tillage systems CTm	CTs	DP	RT
Machinery	109.60 ± 0.58[a]	170.12 ± 1.41[b]	120.62 ± 0.94[c]	35.87 ± 0.82[d]
Fuel-oil	1974.8 ± 2.08[a]	2454.38 ± 3.51[b]	2646.57 ± 4.20[c]	1830.05 ± 1.64[d]
Irrigation	3201.58 ± 0.82[a]	3201.58 ± 3.86[a]	3201.58 ± 4.50[a]	3201.58a ± 2.64[a]
Labor	213.47 ± 0.72[a]	213.47 ± 2.17[a]	213.47 ± 2.49[a]	213.47 ± 0.85[a]
N	2230 ± 3.50a	2230 ± 2.49[a]	2230 ± 2.03[a]	2230 ± 1.57[a]
P	1617.2 ± 1.63[a]	1617.2 ± 3.16[a]	1617.2 ± 1.27[a]	1617.2 ± 2.48[a]
K	1115 ± 2.05[a]	1115 ± 4.20[a]	1115 ± 1.63[a]	1115 ± 4.13[a]
Herbicides	217.29 ± 1.15[a]	217.29 ± 2.16[a]	217.29 ± 3.30[a]	217.29 ± 1.67[a]
Seed	750 ± 0.84[a]	750 ± 3.04[a]	750 ± 3.79[a]	750 ± 1.23[a]
Total input energy	11428.94 ± 3.47[a]	11969.04 ± 2.51[b]	12111.73 ±1.63[c]	11210.46 ± 4.18[d]
Total output energy	87007 ± 2.24[a]	82999 ± 1.11[b]	97194 ± 0.68[c]	70558 ± 1.35[d]
Fuel-oil consumption	35.07 ± 0.73[a]	43.59 ± 0.88[b]	47.00 ± 1.04[c]	32.50 ± 0.86[d]
Grain yield	5210 ± 0.52[a]	4970 ± 0.39[b]	5820 ± 0.45[c]	4225 ± 1.28[d]

The similar letters show no significant differences (p<0.05) within one row based on $LSD_{0.05}$.

DP increased the average total energy consumed for maize production compared to CTm, CTs and RT by 5.97%, 1.19% and 8.04%. Energy outputs increased by 11.71%, 17.10% and 37.75%, respectively. This may be due to the increased grain yield of DP treatment compared to other tillage systems. In DB, irrigation was the most energy-intensive input (21.85%), closely followed by fuel oil (26.43%), then nitrogen, phosphorus and potassium fertilizers (18.41, 13.35 and 9.21% respectively), seeds (6.19%), human labor (2.08%), herbicides (1.79%), human labor (0 1.7%) and machinery (1%). The reason may be that different tillage systems are used for soil preparation. This means that the size of the machines is different as well as the fuel and oil consumption, which leads to different energy inputs. For example, in DP deep tillage system, a large tillage depth may require higher traction force to break up the large volume of soil, which leads to increased slippage of the tractor wheels and thus increased fuel consumption and hence increased energy for seedbed preparation operations. The results align with the research conducted by Gozubuyuk *et al*., (2020). Their study revealed that in conventional tillage systems, the primary energy-consuming factors for silage maize production were fuel oil, irrigation, seeds, and nitrogen fertilizers. These components accounted for 90% of the energy input, with Each component contributing 21%, 40%, 14%, and 17%, respectively. In this study, fuel-oil consumption was found to be the second most commonly used fuel in all tillage systems. A similar trend was observed in a previous study by Altunaş *et al*., (2020), which examined three different tillage systems: conventional tillage system (TS1), and conservation tillage systems (TS2 and TS3). The study reported that in terms of its contribution to the energy input, oil fuel came second after the three agricultural methods, seed energy came in third place, and the percentage of human effort was the lowest.

Energy use efficiency (%)

Table 6 shows that the energy use efficiency of different tillage strategies (CTm, CTs, DP, and RT) for maize grain production was varied. The energy use efficiency for DP had the highest energy use efficiency of 8.02%. In contrast, the energy use efficiency for tillage systems CTm, CTs, and RT reduced to 7.61, 6.93, and 6.29, respectively. This was because the total energy output was high for DP, which reached 97194 MJ ha−1 compared to the energy output for CTm, CTs, and RT which was low at 87007, 82999, and 70558 MJ ha−1 respectively. These results are consistent with Moitzi *et al*., (2021) who reported that deep tillage (DP) increased energy use efficiency by 2.60 and 10.52% compared to conventional tillage (MP) and reduced tillage (RT).

Energy productivity (kg MJ^{-1})

Table 6 shows the energy productivity values of CTm, CTs, DP, and RT. DP recorded the highest energy yield value of 0.49 kg MJ^{-1}. In comparison, RT recorded the lowest energy productivity value of 0.38 kg MJ^{-1} due to the higher output power of the deep tillage system (DP). However, CTM and CTS recorded values of 21.05 and 10.53% higher energy productivity than RT, respectively. Similar results have been reported in previous studies. According to Lopez-Vazquez *et al*., (2019), there were significant differences ($p < 0.05$) in energy productivity among tillage systems, where CT produced wheat with a 30% higher energy yield value than RT. Kumar *et al.* (2013) reported that the results agreed with the above findings.

Specific energy (MJ kg^{-1}**)**

Table 6 indicates that the impacts of tillage systems on specific energy were significant ($p<0.05$). The RT provided the greatest specific energy value of 2.65 MJ kg^{-1}, followed by CTm and CTs with 2.19 and 2.41 MJ kg^{-1}, respectively. In contrast, DP pointed to the lowest specific energy value of 2.05 MJ kg^{-1}. This may be because the decrease in grain yield (4225 kg ha-1 Table 5) is less than the reduction in energy inputs (11210.46 MJ ha^{-1} Table 5) for the reduced tillage system compared to other tillage systems, and according to Equation 8, the specific energy values for low-tillage increase. Similar findings were observed in earlier research. According to Iqbal *et al*., (2024), a reduced tillage system had a lower specific energy for wheat production of 27% than that of a conventional tillage system.

Net energy (MJ ha^{-1})

The values of the net energy of maize production for different tillage systems are given in Table 5. DP obtained the highest value of net energy compared to CTm, CTs, and RT by 12.85, 20.08, and 43.72% respectively. In contrast, the RT showed the lowest net energy value of 59347.04 MJ ha^{-1}. The reason for increasing net energy under DP might be attributed to the total output energy from maize grain yield being significantly higher than the total energy input. The findings are closer to the values reported by Saldukaite-Sribike *et al*., (2022). It was not the same as the conclusion reported by Kumar *et al*., (2013), who found that in wheat production, the net energy obtained by using a reduced tillage system (127520 MJ ha^{-1}) was higher than that of a conventional tillage system (120030 MJ ha^{-1}).

Table (6): Energy parameters in different tillage systems in maize grain production

Tillage systems	Energy efficiency (%)	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})	Net energy (MJ ha^{-1})
CTm	7.61 ± 0.94^{a}	0.46 ± 2.41^{a}	2.19 ± 1.40^{a}	75578.06 ± 1.71^{a}
CTs	6.93 ± 1.36^{b}	0.42 ± 0.86^{b}	2.41 ± 3.74^{b}	71029.96 ± 3.47^{b}
DP	8.17 ± 0.54^{c}	0.49 ± 1.32^{c}	2.05 ± 0.56^{c}	59347.04 ± 0.23^{c}
RT	6.29 ± 2.77^{d}	0.38 ± 2.16^{d}	2.65 ± 0.76^{d}	85290.93 ± 0.62^{d}

The similar letters show no significant differences ($p<0.05$) within one column based on $LSD_{0.05}$

Conclusions

Based on the study findings, the DP was the most effective in reducing soil penetration resistance, and increasing crop output, and energy efficiency. The DP had the lowest soil penetration resistance (1.15 MPa) and the highest grain output (5820 kg ha^{-1}) compared to other systems. The DP gained the maximum energy consumption efficiency and net energy values of 4225 kg ha $^{-1}$ and 6.29%. RT obtained the lowest maize grain yield and energy consumption efficiency of 4225 kg ha $^{-1}$ and 6.29%, the DP system is a good choice for sustainable farming, even though it uses more energy than the other systems (up to 10% more than the RT system) due to its greater grain output and better energy return. It can recommend applying the effect of long-term different tillage systems such as conservation tillage or zero tillage and their effect on the physical and chemical properties of the soil and crop productivity.

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Contributions of authors

S. M.: Methodology; Q. S.: Statistical analysis; A. M.: writing the original draft preparation.
M. H.: writing the review and the editing; and A.N.: responsible for data collection and conducting field experiments.

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Conflicts of interest

As for the requirements of the publishing policy, there is no potential conflict of interest for the authors

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تأثير أنظمة الحراثة على استخدام الطاقة لإنتاج الذرة وكس التربة في المناطق شبه الجافة

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المستخلص: أجريت التجارب في تربة طينية في محطة البحوث الزراعية بجامعة البصرة (حرم كرمة علي) في يوليو 2022. هدفت الدراسة إلى تقييم تأثير أنظمة الحرث المختلفة على كبس التربة وإنتاجية الحبوب وكفاءة استخدام الطاقة في إنتاج الذرة. تم تنظيم الدراسة في تصميم القطاعات العشوائية الكاملة (RCBD) وشملت أربعة أنظمة حرث وهي: (CTm)محراث مطرحي+ حادلة ذات اصابع مسننة، (CTs) محراث حفار+ مشط قرصي، (DP)محراث تحت سطح التربة + حادلة ذات اصابع مسننة، و (RT) مشط قرصي + حادلة ذات اصابع مسننة). أشارت النتائج إلى أن الحراثة العميقة (DP)أعطت أقل قيمة لمقاومة اختراق التربة مقدار 1.15 ميجا باسكال مقارنة بـ CTm وCTs وRT بنسبة 26.75 و20.69 و40.41٪ على التوالي. زادت مقاومة اختراق التربة بنسبة 46.56٪ في نهاية الموسم مقارنة بموسم البداية. أظهرت النتائج أيضًا أن DP وRT أعطيا أعلى وأدنى قيم محصول حبوب الذرة بمقدار 5820 و4225 كجم هكتار -1. أظهر تحليل الطاقة أن DP سجل أعلى كفاءة للطاقة بنسبة 8.17٪ وقيمة طاقة صافية قدرها 97194 ميجا جول هكتار -1. في المقابل، حصل نظام RT على أقل كفاءة في استهلاك الطاقة بنسبة 6.29% وقيمة صافية للطاقة بلغت 59347.04 ميجا جولهكتار-1. الري واستهلاك الوقود الزيتي هما المدخلات الأكثر استهلاكًا للطاقة. أظهرت النتائج أن نظام الري بالتنقيط فعال بشكل كبير في الإنتاجية وكفاءة استخدام الطاقة في إنتاج الذرة. كان نظام (DP) هو الاستراتيجية الأكثر فعالية لزيادة محصول الذرة وكفاءة الطاقة، مما يجعله الخيار الأفضل للأداء الحقلي في انتاج محصول الذرة.

الكلمات المفتاحية: طاقات المدخلات والمخرجات، محصول الذرة، مقاومة اختراق التربة ،الحراثة.