The Effects of the Combined Tillage Machine Combinations on Some Soil Physio-Chemical Properties and Yield of *Zea mays* L.

Aqeel J. Nassir[1,*], Dakhil R. Ndawi[2], Sadiq J. Muhsin[1]

[1] Department of Agricultural Machines and Equipment, College of Agriculture, University of Basra, Basra, Iraq.
[2] Department of Soil Science and Water Resources, College of Agriculture, University of Basra, Basra, Iraq

Abstract

The investigation was carried out to evaluate the effects of tillage treatments by combined tillage machines on some soil characteristics and maize grain yield. Five combined tillage machines were used in the experiment, namely: (T_1), consisting of a subsoiler working at a depth of 60 cm, a chisel plow, a tandem disc harrow, and a grooved roller, (T_2), which is similar to (T_1) except the subsoiler works at a depth of 40 cm. (T_3), consisting of a subsoiler working at a depth of 60 cm and a chisel plow. (T_4) is similar to (T_3), except the subsoiler works at a depth of 40 cm. (T_5) consists of a chisel plow and tandem disk harrow. respectively. The experiment was laid out in a randomized complete block design (RCBD) with three replicates. The results showed that T_1 and T_3 improved soil characteristics considerably. In contrast, bulk density, EC, and penetration resistance of soil decreased, whereas saturated water conductivity and MWD increased compared to T_2, T_4, and T_5. The results showed that the sampling period had a significant effect ($p<0.01$) on soil characteristics. Bulk density, MWD, and EC of soil were reduced by 5.51, 14.18, and 43.60%, respectively, whereas the hydraulic conductivity and penetration resistance of soil, increased by 36.17 and 43.53% at the start of the maize growing season compared to after harvest. However, T_1 achieved a grain yield greater than that of T_2, T_3, T_4, and T_5 by 14.18, 7.02, 36.52, and 53.17%, respectively.

Keywords: combined tillage machine, soil properties, maize, yield.

تأثير تراكيب آلة الحراثة المركبة في بعض الخواص الفيزيائية والكيميائية للتربة وحاصل الذرة الصفراء (*Zea mays* L.)

عقيل جوني ناصر[1,*]، داخل راضي نديوي[2]، صادق جبار محسن[3]

[1] قسم المكائن والألات الزراعية، كلية الزراعة، جامعة البصرة، البصرة، العراق
[2] قسم علوم التربة والموارد المائية، كلية الزراعة، جامعة البصرة، البصرة، العراق

المستخلص

تم إجراء الدراسة لتقييم تأثير عمليات الحراثة بآلات الحراثة المركبة في خصائص التربة وحاصل الذرة. تضمن التجربة خمس تراكيب مختلفة من آلات الحراثة المركبة هي (T_1) :آلة حراثة مشتركة تشتمل على محراث تحت سطح التربة يعمل على عمق 60 سم ومحراث حفار ومشط قرصي وحادلة محززة (T_2) تشابه (T_1) ولكنه يحتوي على محراث تحت سطح التربة يعمل على عمق 40 سم (T_3) آلة حرث مركبة تتكون من محراث تحت سطح التربة يعمل على عمق 60 سم ومحراث حفار (T_4) تشابه (T_3) باستثناء محراث تحت سطح التربة يعمل على عمق 40 سم (T_5) آلة حرث مركبة تتكون من محراث حفار ومشط قرصي. تبلغ أعماق عمل المحراث الحفار المشط القرصي والحادلة المحززة في جميع تراكيب آلات الحراثة المركبة 20 و 10 و 5 سم على التوالي. استخدام تصميم القطاعات الكاملة العشوائية (RCBD) بثلاث مكررات لتصميم هذه التجربة. أشارت النتائج إلى أن T_1 و T_3 تحسن بشكل كبير من بناء التربة وخصائصها، اذ انخفضت الكثافة الظاهرية والايصالية الكهربية، ومقاومة الاختراق للتربة، بينما زادت الايصالية المائية المشبعة ومعدل القطر الموزون (MWD) لكل من معاملتي الحراثة T_1 و T_3 بشكل كبير مقارنةً مع T_2 و T_4 وT_5. أوضحت النتائج أن فترة أخذ العينات كان لها تأثير معنوي ($P < 0.05$) في خصائص التربة، اذ انخفضت الكثافة الظاهرية و MWD و EC للتربة بنسبة 5.51 و 14.18 و 43.60% على التوالي، في حين زادت الايصالية المائية المشبعة ومقاومة الاختراق للتربة بنسبة 36.17 و 43.53% عند المقارنة بين بداية ونهاية نمو الذرة. الموسم. كما اكتسبت T_1 أكبر غلة للحبوب مقارنة مع T_2 و T_3 و T_4 و T_5 بنسبة 14.18 و 7.02 و 36.52 و 53.17% على التوالي.

الكلمات المفتاحية: آلة الحراثة مركبة، خصائص التربة، الذرة الصفراء، الحاصل.

Introduction

The idea of sustainable agriculture has become a significant problem in agricultural production, and selecting the appropriate farm machinery is essential for achieving it (Puska et al., 2022, Nassir et al., 2021). Reduced costs and overcome difficulties in field operations are made possible by proper implement implementation and good management. Choosing the appropriate tillage implements leads to increased production, reduced environmental pollution, and improved soil characteristics. (Kumar et al., 2018). Combined tillage machines may provide a more

*Corresponding author.
Email: aqeel.nassir@uobasrah.edu.iq
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appropriate solution by reducing the number of passes as a result of combining two or more soil tillage operations.(Prem et al., 2016). The combined tillage machines are very important in terms of saving energy and time, as well as lowering operating costs. (Sarkar et al., 2021). Tillage operations are a crucial factor in agricultural output because affect the soil's structure. The correct soil tillage may result in improving and preventing soil characteristics from deteriorating, with the purpose of providing adequate conditions for plant growth and increasing yield (Busari et al., 2015, Gao et al., 2017). The vital soil physical characteristics, such as water holding capacity, air capacity, macro-porosity, bulk density, and soil structural, are greatly influenced by agricultural activities such as tillage techniques and tractor wheel traffic (Naderi-Boldaji and Keller 2016). Improving the soil properties is a priority of the tillage operation, particularly when using combined tillage implements, where Aday and Nassir (2009) reported that the mean weight diameter (MWD) of soil when using a combined chisel plow was 48.90% higher than for a conventional chisel plow. However, (Saber et al., 2018) observed that the use of a combined plow (chisel plow + cultivator + roller) decreased the bulk density of the soil by 1.16 to 1.02 Mg m-3 (12.07%) compared to conventional tillage. (Tverdokhlebov and Parkhomenko 2017) found that the combined plow (chisel plow + roller) increased the mean weight diameter (MWD) of soil at soil depths of 15–25 cm by 22.85% in comparison to the conventional chisel plow. In recent years, soil compaction resulting from agricultural activities has also been recognized as a type of soil deterioration. Increasing tractor wheel traffic and heavy tillage machines contribute to soil compaction and the creation of a hard pan layer inside the soil body (Jabro et al. 2021, Acquah and Chen 2022). So, the soil must be deeply tilled to break down the hard soil layer and improve the soil's physical properties, resulting in a higher yield per unit area. (Borek 2020, Ding et al., 2021, Amami et al., 2021). The main objective of the current study was to examine the impacts of five combinations of combined tillage machines on soil characteristics and identify which combinations had the most positive effect on improving soil properties and increasing maize yield.

Materials and Methods

Combined tillage machine types

The combined tillage machine consists of four parts were:

1. Chisel plow, which includes five shanks fixed on a frame of dimensions 120x180 cm. The five shanks were arranged in two rows. The front row includes three shanks the lateral distance between them is 35 cm. The rear row includes two shanks, the lateral distance between them is 35 cm, and they were fixed on the frame alternatively with the front row shanks, which made the lateral distance between the adjacent tines in the two rows 17.50 cm. This arrangement reduces the chances of leaving soil unplowed. The distance between the two rows was 35 cm. Each chisel was fixed on the frame at an angle of 60° (rake angle). The shank of the chisel was provided with a foot of 13.50 cm in length and 9.50 cm in width. The attack angle of the front of the foot was 30°. The foot was provided with wings 8.50 cm wide, and they were fixed at an inclination angle with a horizontal line of 30°, which was to facilitate the plow's penetration to the soil during the tillage operation.
2. The subsoiler consists of shanks fixed to a frame that has a position behind the frame of the chisel plow. The subsoiler frame is at an angle of 60° (rake angle). The shank of the subsoiler was provided with a foot of 29.50 cm in length and 19 cm in width. The attack angle of the front of the foot was 30°.
3. The tandem disk harrow is fixed to a frame with dimensions of 170 × 120 cm. The tandem disk harrow consists of two groups, and each group includes seven disks. The distance between disks in the same group is 18 cm. Each disk has a diameter of 22.50 cm. The distance between the front and rear disk groups is 38 cm. The frame of the tandem disk harrow had a hinged linkage with the frame of the chisel plow and subsoiler shanks, and this made the frame of the tandem disk harrow move freely.
4. Grooved Roller: The roller dimensions are 25 and 150 cm in diameter and length, respectively, and its weight is 190 kg. The roller frame featured a hinged linkage with the tandem disk harrow frame, allowing the roller frame to move freely on the soil surface. All parts of the combined tillage machine work as a single unit.

In experiments was used combined tillage machine (Figure 1) with five combinations were:

- T1: is a combined tillage machine consisting of a chisel plow, a subsoiler with a single shank that works at a depth of 60 cm, a tandem disc harrow, and the grooved roller
- T2: is a combined tillage machine similar to (T1), except a subsoiler, works at a depth of 40 cm.

- T3: is a combined tillage machine consisting of a chisel plow and a subsoiler with a single shank working at a depth of 60 cm.
- T4: is a combined tillage machine similar to (T3), except a subsoiler, works at a depth of 40 cm.
- T5: is a tillage machine that combines a chisel plow and a tandem disc harrow.

In all combined tillage machines, a chisel plow, a disk harrow, and a grooved roller work at depths of 20, 10, and 5 cm, respectively.

Figure 1. Combined tillage machine

Field measurements
Agriculture operations and a field experiment site
A combination tillage machine made in the workshops of the Department of Agricultural Machines and Machine, College of Agriculture, University of Basrah, was used in the experiment. The experiments were carried out in the Research Station of the College of Agriculture (N47°44'59"E 14'34"30) in Silty clay loam soil. The soil samples were taken from different positions at the soil depths of d1 (0-20), d2 (20-40), and d3 (40-60) cm, to evaluate penetration resistance, soil bulk density, mean weight diameter (MWD), saturated hydraulic conductivity (Ks) and electrical conductivity (Ec) of soil at two periods, at the beginning and end of the corn crop season The field was divided into plots when the tillage operations were completed. Each experimental unit had dimensions of 1.5 and 6 meters, respectively, with a 2 m space between each plot. For all plots, urea (46% N) was applied as the chemical fertilizer at a rate of 160 kg N ha^{-1}. Potassium sulfate was applied together with triple superphosphate (47% P_2O_2) and potassium fertilizer (52% K_2O). Each was present in 80 kg ha^{-1} (FAO, 2004). On July 20, 2021, the corn crop's (Al-maha) seeds were planted, and three seeds were put into each hole. There is a 25 cm distance between the hole and the next. After 12 days of planting, one plant was left in the hole during plant thinning. The crop was harvested 120 days after the seeds were sown. Corn crops were irrigated using the surface irrigation system. The rate of evaporation from the Class A evaporation pan was used to calculate the required quantity of water. In compensation for the soil moisture loss from evaporation, irrigation water was supplied, and 20% was added to it to meet leaching requirements (Pimentel et al., 2004).
Soil bulk density

It was determined using core method. Soil samples were collected by core at depths of 0 to 20 cm, 20 to 40 cm, and 40 to 60 cm. The soil samples were dried in a 105°C oven for 24 hours. Bulk density of soil can be calculated using the equation as following (Black, 1965).

$$\rho b = \frac{m_s}{V_t} \qquad (1)$$

ρb: The dry bulk density ($Mg.m^{-3}$), ms: The mass of the dried soil sample (Mg) v_t: The total volume of the soil sample (m^3).

Penetration resistance of soil

For measuring soil penetration resistance, a soil cone penetrometer (SN from Eijkelkamp, with a cone diameter of 1 cm^{-2}, cone angle of 30°, and penetration speed of 1.5 cm sec^{-1}) was used. For each tillage treatment, the soil's resistance to penetration was measured at a depth of 10 to 80 cm with three replicated at thirty different locations.

Electrical conductivity (EC)

Using the EC-Meter type WTW, model Cond 7110, and the method described in (Page et al., 1982), the electrical conductivity (dSm^{-1}) of soil was measured in soil extract (1:1).

Mean weight diameter (MWD)

The soil samples were taken at soil layers of 0–20, 20–40, and 40–60 cm from the experiment field. Soil samples were collected twice at the beginning and end of the growing season of maize yield. The soil samples were saved in metal containers during transport to the laboratory. A mass of 25 g of soil sample was taken from above a 4 mm sieve, and the capillary rise wetted it for six minutes and then transferred to a set of sieves with diameters of 0.25, 0.5, 1.0, 2.0, and 4.0 mm. The wet sieving method was conducted for a duration of six minutes using the damp sieving device (model 184.80, C.S.C Scientific, Fairfax, VA, USA). At a vibration speed of 60 rpm, the device discharge water through the device at a rate of 200 ml min^{-1}. At the end of the sieving process, the sieves were separated and the remaining soil was transferred from each sieve to a glass beaker and dried in the electrical oven at a temperature of 105 °C to calculate its dry weight. The values of the MWD were calculated using the equation mentioned by (Lamptey et al., 2018)

$$\mathrm{MWD} = \sum_{i=1}^{n} \mathrm{xiwi} \qquad (2)$$

MWD is Mean weight diameter (MWD) (mm) xi is the mean diameter (mm) of size size, and wi is the soil mass fraction remained on the sieve ($g\ g^{-1}$).

Saturated hydraulic conductivity:

The soil-saturated hydraulic conductivity (Ks) was calculated for all soil tillage treatments and soil depths by the following equation (Black, 1965).

$$\mathrm{Ks} = \frac{Q}{At} \cdot \frac{L}{h} \qquad (3)$$

Where: Ks: saturated water conductivity (cm hr^{-1}) Q: volume of water passing through the soil column (cm^3) L: length of the soil column (cm). A: Surface area of soil section (cm) t: time (hours) h: length of the soil column + the height of the water column above the soil column (cm).

Grain and Biological yield of maize

Before the maize crop was harvested, ten plants were chosen at random. This was done when the plants had reached the physiological maturity stage. The plants' heights were measured from the ground surface to the plant peak by measure tape, and the average height was calculated. On December 25, 2021, the crop was harvested manually, to estimate the dry matter for the maize crop. Ten plants were selected randomly from each plot. The harvested plants were dried in an oven (Model: WAO-610ND, USA ITW Company) at 70 °C until reaching a constant weight. After harvesting and threshing, the maize grains were cleaned by air; thereafter, the maize grains were weighed to register the quantity of the grain yield. The grain weight and dry matter of maize were adjusted to 15% moisture content and expressed in Mg ha^{-1}.

Statistical analyses

The effects of tillage strategies on soil physical characteristics and maize production were evaluated statistically using the analysis of variance (ANOVA). The parameters were examined using the least significant difference (RLSD) at a probability threshold of 0.05 using Gen Stat software to analyses the data. The mean values of soil properties at the start and end of the planting season were compared using the t-test at the probability level (0.05).

The initial soil properties

The initial physical and chemical characteristics of the experiment field soil were determined using three replicates at different layers ranging from 0 to 20 cm, 20 to 40 cm, and 40 to 60 cm. The findings were summarized Climate information (Table 1).

The trial season's climatic data were obtained from the nearest meteorological stations, as shown in table2.

Table 1. Mean precipitation, air temperature and humidity during growing seasons.

	Temperature (°C)			
	Min	Max	Humidity (%)	Rainfall (mm)
Jul	36.6	51.08	13.92	0
Aug	37.92	50.07	16.14	0
Sep	35.06	44.69	14.02	0
Oct	27.25	42.27	9.03	0
Nov	21.02	31.70	9.11	0
Dec	15.03	23.10	8.49	0
Jan	15.19	22.21	7.92	0

Table 2. The initial physical, chemical properties and irrigation water quality of the test field soil.

Soil properties	Unit	Soil layer (cm)		
		0-20	20-40	40-60
Sand	g kg^{-1}	37.27	13.5	9.56
Silt	g kg^{-1}	671.3	691.2	665.36
Clay	g kg^{-1}	291.43	295.3	325.08
Texture	g kg^{-1}	Silty clay loam	Silty clay loam	Silty clay loam
Real density Bulk	Mg m^{-3}	2.73	2.7	2.69
Bulk density	Mg m^{-3}	1.33	1.42	1.54
Total porosity	%	52.28	49.25	42.75
Moisture content	%	18.71	21.48	27.55
Ks	m day^{-1}	0.15	0.11	0.08
Soil penetration	kN m^{-2}	2209	3574	4786
MWD	Mm	0.31	0.27	0.25
EC	dS m^{-1}	8.79	12.11	18.74
		Irrigation water (Ec)		
Beginning season		5.49		
End season	dS m^{-1}	2.38		

Results and Discussion

Bulk density

The results reported in table (3) demonstrated that combined tillage machine treatments had a statistically significant ($p < 0.05$) effect on soil bulk density. T1 registered the lowest bulk density of soil at 1.19 Mg m-3 followed by T3 with a bulk density of 1.26 Mg m^{-3}. T5 has the greatest bulk density of 1.40 mg m^{-3}. This was because the combined tillage machines (T1 and T3) include a subsoiler that works at a depth of 60cm, which helps disturb a considerable volume of soil, resulting in a decreased the bulk density of soil. These results are correspondent with (Saber et al., 2018), who found that deep tillage using a combination plow (chisel plow + roller + planter) decreased soil bulk density by 12.07% in comparison to traditional plowing. This was a result of the increased volume of disturbed soil, which increased soil porosity and decreased soil bulk density.

The results of the t-test revealed a significant increase ($p<0.01$) in the soil bulk density value after the harvest compared to its value at the beginning of the season by 5.51% (Table. 4). This was because of the deposition particles of soil in the micro pores, which changes the volume pores distribution, with the advancement of the crop's growing season during irrigation processes and consequently, reducing the soil porosity and increasing the bulk density. This result is similar to the findings of (Singh et al., 2019), who reported that the value of bulk density increased by 4.20% at the end of the plant growing season compared to the start of the plant growing season.

Mean weight diameter (MWD)

The results revealed that combined tillage machine treatments had a significant effect ($p<0.05$) on the MWD of soil (Table 3). The T1 treatment recorded the highest mean weight diameter of 0.69 mm, whereas T5 recorded the lowest mean weight diameter of 0.49 mm. When comparing T1, T2, T3, and T4, with T5, the MWD increased by 18.97, 13.11, 27.78, and 40.82%, respectively. This was because of reducing the soil bulk density and increasing the total soil porosity resulting in keeping soil stability aggregate. These findings are consistent with (Alamootial and Mohammed, 2020), who found that the combined plow (digger + toothed roller) increased the stability of the soil stability aggregate compared to conventional tillage by 22.85 and 25.33% for soil aggregates less than 1 mm and less than 2.5 mm, respectively.

The results of the t-test showed a significant difference ($p<0.01$) between the two soil sampling periods at the start and end of the growing season of the maize crop. Table. 4 showed the highest value for MWD was 0.62 mm at the end of the growing season, while the beginning of the season recorded a lower MWD value of 0.54 mm, which means that the MWD increased by 14.18%. The reason was attributed to improved physical soil characteristics, as a result, the spread of the roots of the plant contributed to increasing the stability of the soil aggregates by linking soil particles with each other. In addition to the increase in the activity of microorganisms that caused an increase in the bonding of soil particles with each other through the secretion of adhesive materials, These results agree with (Obour et al., 2021).

Soil saturated hydraulic conductivity (K_s)

The results of the statistical analysis indicated that combinations of combined tillage machines had a significant effect ($p<0.05$) on the values of soil Ks (table 3). Deep tillage practices by T1 obtained the highest Ks value of 0.55 m day^{-1} followed by T3, which had a Ks value of 0.43, and the Ks decreased when using the T2 to 0.36 m^{3}day^{-1}. The results revealed that there was no significant effect between T4 and T5 treatments, which both had the same lowest Ks value of 0.30 m day^{-1}. Increasing the Ks under T1 treatment may be attributed to that the combined tillage machine (T1) consists of a subsoiler that works at a depth of 60 cm, a chisel plow at a depth of 20 cm, a disc harrow at a depth of 10 cm, and a roller that operates on the surface of the soil. This leads to disturbance of the compacted soil layers at different depths, a decrease in the soil bulk density, and an increase in the total porosity, thereby an increase in the water movement due to increasing soil permeability. The same thing happens in the case of the T3 tillage treatment, which consists of a subsoiler working at a depth of up to 60 cm and a chisel plow working at a depth of 20 cm. This increases the volume of loose soil, which encourages the formation of considerable pores in the body of a soil and accelerates the movement and permeation of water in the soil body. These findings accord with (Aday et al., 2018) who found that using the combined plow (subsoiler + moldboard) achieved the highest saturated water conductivity by 33.33% compared to the traditional subsoiler.

The results of the t-test showed a highly significant effect ($p<0.01$) of the growing season period on the saturated water conductivity of the soil. Table. 4. showed that the beginning of the growing season achieved the highest value of the saturated water conductivity of the soil, which amounted to 0.47 m^3 day^{-1}, while the saturated water conductivity of the soil decreased at the end of the growing season to reach 0.30 m day $^{-1}$. The reason may be attributed to the movement of fine particles of soil with the progression of the growing season of the crop due to the fragmentation of the soil aggregate during irrigation operations and the deposition of their fine particles in the pores, which reduces the pore's volume, as well as the action of humidification and drying cycles that cause the movement of fine particles and their deposition in the pores of the soil, which causes the large and medium soil pores to transformed into small pores. This leads to a decrease in the value of the saturated water conductivity of the soil. This finding is in agreement with (Seguel et al., 2020), who attributed this to the increase of soil bulk density with the progression of the growing season and the effect of irrigation operations on the filling and clogging of some soil pores with fine soil particles, which reduces the saturated water conductivity of the soil.

Penetration resistance (PR)

The values of soil penetration resistance varied significantly under combined tillage machine treatments (table 3). The lowest resistance of 1656.30 kN m^{-2} was recorded under T1, while the highest value of 2596.21 kN m^{-2} was recorded under tillage treatment (T5), while the penetration resistance decreased under other tillage treatments T2, T3, and T4 by 29.58, 33.28, and 28.71%, respectively, compared with T5. This means that adding subsoiler tine to the combined tillage machine led to increased loosening of the soil and decreased bulk density, thereby reducing the penetration resistance of the soil. The results agree with Tya, (2020), who indicated that the type of primary and secondary tillage (disc plow and disc harrow) reduced the penetration resistance values compared to the single use of disc plow or disc harrow by 54.04 and 44.51%, respectively, at average soil depths. 0-10, 10-20, 20-30, 30-40 cm.

The results of the t-test showed a significant increase ($p<0.01$) in the values of the penetration resistance of the soil after the harvest of the maize crop compared to its value at the start of the season by 43.53% (Table 4). This was due to the movement of fine soil particles with the progression of the crop's growing season during irrigation operations and the deposition of their fine particles in the pores changes the volume distribution of the pores, thereby reducing the total soil porosity as well as increasing soil cohesion in the after-maize harvesting period, which causes the formation of a compacted layer of soil, thereby increasing the penetration resistance of the soil.

Soil electrical conductivity (EC)

The differences in EC values of combined tillage treatments were significant, as shown in Table (3). T5 registered the maximum value (11.90 dSm^{-1}) of EC, while the minimum EC value of 8.21 dS.m-1 was recorded by T1, followed by T3, which recorded an EC value of 9.27 $dS.m^{-1}$. The deep tillage performed by T1 and T3 decreased the EC compared with the other tillage treatments, where the effect of the studied treatments on the decrease of EC took the following order: T1 > T3 > T2 > T4 > T5. This was because a combined tillage machine contained a subsoiler, which performed tillage at a depth of 60 cm, resulting in increased soil loosening in the subsurface layers, consequently improving the physical properties of the soil, and increased movement of the water toward the ground, leading to dissolved salts leaching far away from the soil plowed layer, thereby reducing the EC. These findings are consistent with those of (Ding et al., 2021), who found that deep plowing using a moldboard plow at a depth of 20 cm followed by subsoiling at a depth of 60 cm reduced soil salinity by 37% compared to using a disc harrow at a depth of 10 cm.

Table 3. Effect of tillage treatments on soil properties for the average soil depth of 0-60cm.

Tillage treatments	Soil properties Bulk density ($Mg\ m^{-3}$)	Mean weight diameter (mm)	Electrical conductivity ($dS\ m^{-1}$)	Saturated hydraulic conductivity ($m\ day^{-1}$)	Penetration resistance ($kN\ m^{-2}$)
T1	1.19	0.69	8.21	0.55	1656.30
T2	1.32	0.58	9.27	0.36	1828.14
T3	1.26	0.61	8.50	0.43	1732.14
T4	1.37	0.54	10.57	0.30	1850.82
T5	1.40	0.49	11.90	0.30	2596.21
RLSD	0.002	0.01	0.19	0.02	46.69

The results of the t-test showed a highly significant effect ($p<0.01$) of the period of the crop's growing season on the electrical conductivity. Table. 4. showed that the end of the growing season achieved the highest electrical conductivity of the soil, reaching 6.99 $dS\ m^{-1}$. While the electrical conductivity increased for the soil at the beginning of the growing season, it reached 12.39 dSm^{-1}, meaning that the electrical conductivity of the soil was reduced by 43.60 % at end of the season. The cause could be attributed to the soil leaching processes during the maize growing season, which resulted from irrigation operations in which 20% of irrigation water was added as a leaching requirement, as well as improved irrigation water in the end season (Table 1), which increased leaching efficiency, thereby decreasing (Ec) values. These results agree with Yuan et al. (2019) who indicated that the electrical conductivity values of the soil decreased at the end of the season compared to the beginning of the crop growing season by 52.68%.

Table 4. Effect of tillage treatments on soil properties for the average soil depth of 0-60 cm at two sampling periods

Sampling period	Bulk density ($Mg\ m^{-3}$)	Mean weight diameter (mm)	Electrical conductivity ($dS\ m^{-1}$)	Saturated hydraulic conductivity ($m\ day^{-1}$)	Penetration resistance ($kN\ m^{-2}$)
Begging season	1.27	0.54	9.27	0.47	1395.21
End season	1.34	0.62	8.50	0.30	2470.87

t –test (p<0.01)	3.41**	4.01**	14.15**	5.67**	8.11**

Grain Yield and Yield Components

Significant differences ($p<0.05$) in grain yields and dry matter weight were observed among combined tillage machine treatments (Table 5). The tillage treatment with the combined tillage machine T1 gained the highest grain yield and dry matter weight of 6.28 and 16.58 Mg ha^{-1}, followed by the T3 treatment, which registered a grain yield and dry matter weight of 5.87 and 16.27 mg ha^{-1}. Tillage treatments of the combined tillage machine T2 and T4 registered middle values of grain yield of 5.50 and 4.60 Mg ha^{-1}, and dry matter weight of 15.84 and 14.20 mg ha^{-1}, respectively. whereas T5 was given the lowest grain yield and dry matter weight of 4.10 and 12.90 Mg ha^{-1}. The results also showed that the tillage treatment with the combined tillage machine T_1 increased the grain yield by 14.18, 7.02, 36.52, and 53.17%, respectively, and increased the dry matter weight by 4.63, 1.89, 16.73, and 28.49%, respectively, compared with T_2, T_3, T_4, and T_5. These results showed the role of the combined tillage machine, which works at a great tillage depth, and its positive role in increasing grain yield. This was attributed to improving the physical properties of the soil, increasing the spread of roots, thereby increasing their ability to absorb nutrients. This led to an increase in plant growth and yield. (Nath et al., 2020, Ramadhan, 2021, Muhsin et al., 2021).

Table 5. Grain yield and dry matter of maize as affected by different tillage treatments

Tillage treatments	Grain yield	Dry matter
T1	6.27	16.58
T2	5.5	15.84
T3	5.86	16.27
T4	4.60	14.20
T5	4.10	12.90
RLSD	0.141	0.165

Conclusion

The results revealed that combined tillage machines (T_1 and T_3) increased grain yield and biological yield for maize more than (T_2, T_4, and T_5). The combined tillage machines (T_1 and T_3), had a positive effect on the properties of the soil. Bulk density, EC, and penetration resistance decreased, while the saturated water conductivity and MWD increased. The sampling time significantly affected the soil bulk density, MWD, saturated water conductivity, and penetration resistance. These values decreased at the start of the maize growth and increased at the end of the maize growth, while the EC decreased compared with the start season. In conclusion, the deep tillage by combined tillage machines (T_1 and T_3) improved soil physical characteristics and increased maize grain yield and biological yield. While (T_5) recorded the lowest grain yield and biological yield.

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