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Article

The effects of five different types of combined tillage machines on soil properties and yield of maize.

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ABSTRACT
This study was conducted in silty clay loam soil and concerns the effect of tillage treatments on soil properties, the yield of maize, and economic analysis. The experiment design included five types of combined tillage machines: (T1) combined tillage machine consisting of a subsoiler operating at a depth of 60 cm, a chisel plow, disk harrow, and roller, (T2) same (T1) except subsoiler operating at a depth of 40 cm, (T3) combined tillage machine consisting of a subsoiler operating at a depth of 60 cm, a chisel plow, (T4) same (T3) except subsoiler operating at a depth of 40 cm, and (T5) combined tillage machine consisting of a chisel plow and, disk harrow. The results showed that deep tillage by T1 and T3 can significantly improve the soil structure and physical properties; the soil bulk density, EC, and penetration resistance decreased, while the saturated water conductivity and MWD of both tillage treatments (T1 and T3) increased significantly compared with T2, T4, and T5. The results revealed that the sampling period significantly affected physical properties ($p<0.05$). The soil bulk density, MWD, and EC decreased by 5.51, 14.18, and 43.60%, respectively. The soil-saturated hydraulic conductivity and penetration resistance increased by 36.17 and 43.53% when compared between the start and end seasons of maize growth. However, T1 achieved the highest grain yield compared with T2, T3, T4, and T5 by 14.18, 7.02, 36.52, and 53.17%, respectively.

Keywords: Combined tillage machine, Soil properties, Maize yield

INTRODUCTION

Farm machinery management is concerned with the effective selection, operation, maintenance, and replacement of agricultural machinery and with optimizing the equipment used for agricultural productivity. Farm machinery selection is critical for accomplishing the notion of sustainable agriculture, which has emerged as a global challenge in agricultural development [1]. Proper implementation management and implementation help to reduce costs and problems in field operations[2], increase output, protect the environment from pollution, and improve soil properties[3]. Type tillage tools may provide a better solution by minimizing the number of passes by combining two or more operations in the field with the use of type tillage implements. [3]. The combined tillage tool is important in conserving energy and time and lowering labor costs. [4] reported that utilizing a combined tillage tool positively affected time, efficiency, and costs due to reducing the number of passes in the field. [5] found that using combined plowing equipment compared to conventional deep plowing reduced the total operating costs by 48.64%.Tillage is an important part of agricultural production because it affects the soil's environmental components [6, 7]. It can improve, maintain, or deteriorate soil quality [8], to provide good soil conditions for proper growth. The most significant parameters of soil physical properties, including water capacity of plant available, air capacity, macro-porosity, bulk density, and soil structural conditions, are extremely affected by agricultural operations such as tillage methods and tractors wheel traffic [9, 10]. Improving the soil structure is one of the priorities of the tillage operation, particularly with combined tillage tools, where [11] indicated that the combined plow (chisel plow + roller) increased the mean weight diameter (MWD) at soil depths of 15–25 cm compared to the traditional chisel plow by 22.85%. [12] reported that the MWD significantly increased for combined chisel plow compared with conventional chisel plow by 48.90%. However, [4] revealed that using a combined plow (chisel plow + rigid cultivator + roller) led to a reduction in the bulk density of the soil compared to conventional tillage by 1.16 to 1.02 Mg m^{-3} (12.07%). In recent years, soil compaction due to agriculture operations has also been identified as a form of soil degradation, where the increasing tractor wheel traffic and heavy tillage tools lead to soil compaction and the formation of a hard band layer in the soil body Patel and [13, 14]. Therefore, the soil should be plowed deeply to break down the hard soil layer and improve soil physical properties such as permeability and salinity, resulting in increased production per unit area [15, 16, 17, 18]. The main objective of the current study was to evaluate the effect of a new combined tillage machine formed from four implements, a subsoiler, chisel plow, tandem disk harrow, and roller, on some soil physical properties as well as study its effect on cost and crop yield of Zea mays.

MATERIALS AND METHODS

Combined tillage machine types

Soil tillage practices were carried out by a combined tillage machine (Fig). It had five types are:

Combined tillage machine consisting of the chisel plow at a depth of 20 cm, subsoiler time at a depth of 60 cm, disk harrow at a depth of 15 cm, and roller (T1)

Combined tillage machine consisting of the chisel plow at a depth of 20 cm, subsoiler tine at a depth of 40 cm, disk harrow at a depth of 15 cm, and roller (T2).

Combined tillage machine consisting of the chisel plow at a depth of 20 cm and subsoiler tine at a depth of 60 cm (T3).

Combined tillage machine consisting of the chisel plow at a depth of 20 cm and subsoiler tine at a depth of 40 cm (T4).

Combined tillage machine consisting of the chisel plow at a depth of 20 cm and disk harrow at 15 cm (T5).

(a)

(b)

Figure 1. Combined tillage machine (a and b)

Field measurements

Field experiments site and agriculture operations

The experiment was carried out in the Research Station of the College of Agriculture at the University of Basrah by a combined tillage machine manufactured in the workshops of the Department of Agricultural Machines and Equipment, College of Agriculture, Basrah University. Soil samples were collected from the site at the soil depths of d1 (0-20), d2 (20-40), and d3 (40-60) cm to determine soil penetration resistance, soil bulk density, and EC of the saturated soil at two periods at the start and end of the corn crop season. After conducting the tillage operations, the soil was divided into boards. The length and width of each experimental unit were 1.5 and 6 m, respectively, with a 2 m gap between each plot. The chemical fertilizer was added as urea (46% N) at 160 kg N ha^{-1} for all experiments. Triple superphosphate (47% P2O2) and potassium fertilizer (52% K2O) were added as potassium sulfate. The amount was 80 kg ha^{-1} of each [31]. The corn crop (syn-maha) seeds were cultivated on July 20, 2021, with 3 seeds for each hole. The distance between the hole and the other is 25 cm. After 12 days of planting, plant thinning was conducted, where one plant was left in the hole. After 100 days of seeding, the crop was harvested. The surface irrigation system was used to irrigate corn crops. The amount of water to be added was determined by the amount of evaporation from the Class A evaporation pan. Irrigation water was added to compensate for the lack of moisture caused by evaporation, and 20% was added to it as leaching requirements [19].

Soil bulk density

The core technique was used to determine the bulk density of the soil. Using cores, soil samples were taken from the site at soil depths of (0-20), (20-40), and (40-60) cm. The soil samples were dried for 24 hours in a 105°C oven. The following equation was used to calculate the dry bulk density. [20].

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

ρb: The dry bulk density (Mg.m^{-3}) ms: The weight of the dried soil sample (Mg) is 2.2.3. the volume of the soil sample (m^3).

Penetration resistance of soil

A soil cone penetrometer (SN from Eijkelkamp, with a cone diameter of 1 cm-2, 30° cone angle, and a penetration speed of 1.5 cm sec^{-1}) was used to measure soil penetration resistance. For each tillage treatment, the soil penetration resistance was evaluated at 10 to 80 cm depth at 10 distinct places in three repetitions.

Electrical conductivity (EC)

The soil's electrical conductivity (dSm^{-1}) was measured in soil leachate (1:1) using the EC-Meter type WTW, model Cond 7110, according to the method described in [21].

Mean weight diameter (MWD)

The soil samples were taken at soil depths of 0–20, 20–40, and 40–60 cm from the test field. Soil samples were collected twice at the start and end of the growing season of corn yield. The soil samples were kept in metal containers to avoid aggregates' disorder during transport to the laboratory. A weight of 25 g of soil sample was taken from above a 4 mm sieve, and it was wetted by the poetic property 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 carried out for six minutes using the wet sieving device (model 184.80, CSC Scientific, Fairfax, VA, USA). At a vibration speed of 60 rpm, the device drains 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 oven at a temperature of 105 °C to calculate its dry weight. Then the values of the MWD were calculated, as demonstrated by [22].

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

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

2.2.4. Saturated hydraulic conductivity:

The saturated hydraulic conductivity of the soil was measured for all tillage treatments and soil depths by the following equation. [20].

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

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).

2.2.5. Grain and Biological yield of maize

The plant sampling was taken during crop harvest. The crop was grown up to maturity. The plants were harvested on October 25, 2021. The agronomic data collected includes grain yield (kg ha-1) and biological yield. After harvesting the entire plot, the grain yield was measured in kg ha-1 and adjusted to a grain moisture content of 14 percent. The biological yield of maize was calculated by weighing all the harvested plants and then converting each plot's output into Mg ha^{-1}. Ten whole plants were randomly sampled from each sub-plot of maize vegetative growth, and then the plant shoots and roots were separated and dried to estimate biomass.

Statistical analyze

A completely randomized block design (RCBD) was used in this study. Tillage was randomized within blocks. The results were statistically analyzed using the analysis of variance (ANOVA) to test the effects of tillage practices on the soil physical properties and maize yield. All calculations were performed using Gen Stat software to analyze the parameters using the least significant difference (RLSD) at a probability level of 0.05. The mean of the coefficients at the beginning and end of the planting season were compared using the t-test at the probability level (0.05).

Climate information

The trial season's climatic data were acquired from the nearest meteorological stations, as shown in table 1.

	Temperature (C °)			
	Max	Min	Humidity (%)	Rainfall (mm)
Jul	35.6	50.48	14.42	0
Aug	36.92	49.06	15.94	0
Sep	34.66	45.59	13.27	0
Oct	28.15	41.28	9.63	0
Nov	20.52	30.76	9	0
Dec	14.53	22.14	8.39	0
Jan	14.53	22.15	8.4	0

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

The initial soil properties

The test field soil's initial physical and chemical properties were measured with three replicates at soil depths of 0-20, 20-40, and 40-60 cm. The results are shown in table 2.

		Soil depths (cm)		
Soil properties	Unit	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^3 day^{-1}	0.15	0.11	0.08
Soil penetration	kN m^{-2}	2209	3574	4786
MWD	mm	0.31	0.27	0.25
Organic matter	g kg^{-1}	8.98	7.27	1.67
CEC	Coml kg^{-1}	25.89	27.42	28.77
SAR	(mmol $L^{-1})^{0.5}$	101.39	98.33	90.87
ESP	%	62.03	56.74	57.59
EC	dS m^{-1}	8.79	12.11	18.74
PH		7.20	7.61	7.86
EC of Water	dS m^{-1}	4.68		

Table 2. The initial physical and chemical properties of the test field soil

RESULTS

Bulk density

The presented data in Table 3 showed that combined tillage machine treatments had a significant ($p < 0.05$) effect on soil bulk density. The lowest bulk density (1.19 Mg m-3) was recorded by T1, followed by T2, which registered a bulk density of 1.26 Mg. While T5 had the highest bulk density value of 1.40 Mg m-3. The reason is that the installation of the combined tillage machine (T1) contains a subsoiler, which helps to loosen a large volume of soil, which leads to an increase in the pores in the body of the plowed soil, thereby reducing the bulk density. These findings are consistent with those of [4], who found that deep tillage with a combined plow (chisel plow + roller + planter) reduced soil bulk density by 12.07% compared to conventional plowing. This was attributed to the increase in the break-down soil volume, which helped increase the soil porosity and decrease the bulk density.

The results of the t-test showed a significant increase ($p<0.01$) in the values of the bulk density of the soil after the harvest of the maize crop compared to its value at the start of the season by 5.51% Figure 2. The reason for this is 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, which changes the volume distribution of the pores, thereby reducing the total soil porosity and increasing the bulk density.

Mean weight diameter (MWD)

The results indicated that combined tillage machine treatments had a significant effect ($p<0.05$) on the mean weight diameter of soil Table 3. The T1 treatment had the highest mean weight diameter of 0.69 mm, whereas T5 had the lowest mean diameter of 0.49 mm. When comparing T1, T2, T3, T4, and T5, the mean weight diameter increased by 18.97, 13.11, 27.78, and 40.82%, respectively.

The t-test results showed a significant difference ($p<0.01$) between the beginning and end-season growth of the maize crop. Figure 3 shows that the period at the end of the growing season achieved the highest mean weight diameter (MWD) of 0.62 mm. In comparison, the beginning of the season recorded a lower MWD value of 0.54 mm, which means that the weighted diameter increased by 14.18%. The reason is due to improved physical soil characteristics due to the spread of the roots of the plants of the maize, which contributed to increasing the soil aggregates stability by linking soil particles with each other.

Soil electrical conductivity (EC)

The differences in EC values of combined tillage treatments were significant, as shown in Table 3. T5 registered EC's maximum value (11.90 dSm^{-1}), while the minimum EC value was 8.21 dS.m-1 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 studied treatments on the decrease of EC took the following order: T1> T3> T2> T4> T5. This was because of a combined tillage machine containing a subsoiler, which performed tillage at a depth of reaching 60 cm, resulting in increased soil loosening in the subsurface layers, consequently improving physical properties of the soil and increasing movement of the water toward down, leading to dissolved salts leaching far away from the soil plowed layer, thereby reducing the EC.

The t-test results showed a highly significant effect ($p<0.01$) for the crop's growing season on the electrical conductivity. Figure 4 shows 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 at the end of the season decreased by 43.60%. This is due to an increase in the decomposition of organic matter in the soil as the growing season progresses and an increase in the stability of soil aggregates Figure 5. The weather, on the other hand, played a role in lowering the electrical conductivity of the soil, as lower temperatures at the end of the growing season reduced evaporation and helped increase the moisture content of the soil, consequently increasing the leaching of salts toward the lower soil layers.

Soil-saturated hydraulic conductivity (K_s)

Significant differences were found in the effect of combined tillage machine treatments on soil-saturated hydraulic conductivity (Ks) ($p<0.05$) (table 3). Deep tillage practices by T1 gave the highest Ks value of 0.55 m^3day^{-1}, followed by T3, which had a Ks value of 0.43, and the Ks decreased when using the T2 to 0.36 m^3day^{-1}. The results revealed no significant effect between T4 and T5 treatments, which had the same lowest Ks value of 0.30 m^3day^{-1}. Increasing the Ks under T1 treatment may be attributed to the fact 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 increasing the speed of 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 soil and accelerates the movement and permeation of water in the soil body. These findings accord with [26] who found that using the combined plow (subsoiler + moldboard) achieved the highest saturated water conductivity by 33.33% compared to the traditional plow.

The t-test results showed a highly significant effect ($p<0.01$) of the growing season period of the crop in the saturated water conductivity of the soil. Figure 5 shows 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}. In contrast, the saturated water conductivity of the soil decreased at the end of the growing season to reach 0.30 m^3 day^{-1}. The reason for this is due to the movement of fine particles of soil with the progression of the growing season of the crop due to the crushing of the soil masses during irrigation operations and the deposition of their fine particles in the pores, which reduces the pores 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 closure of large and medium soil pores or their transformation to small pore. This leads to a decrease in the soil's saturated water conductivity value.

Penetration resistance (PR)

The penetration resistance of the soil 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). In contrast, 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 increased the soil's loosening and decreased soil 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) significantly 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% Figure 6. The reason for this is that 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. This result is similar to the findings of [28].

Soil properties					
Tillage treatments	Bulk density (Mg m^{-3})	Mean weight diameter (mm)	Electrical conductivity (dS m^{-1})	Saturated hydraulic conductivity (m^3 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

Table 2. Effect of tillage treatments on soil properties for the average soil depth of 0-60cm.

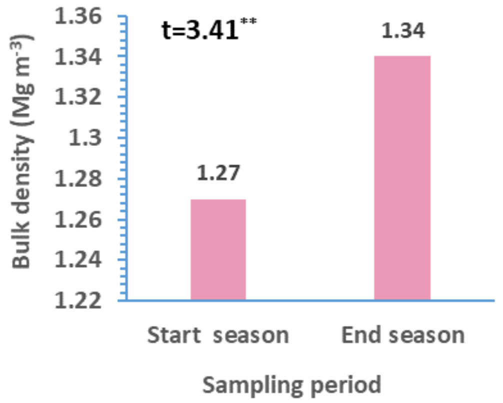

Figure 2: Effect of sampling period on bulk density

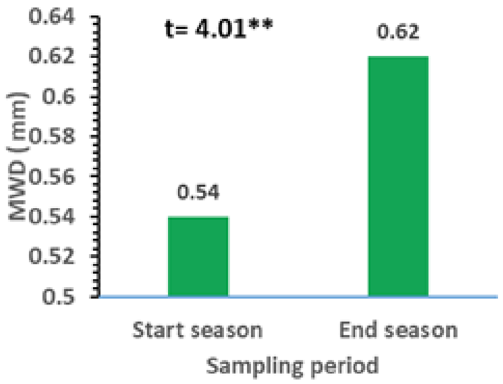

Figure 3. Effect of Sampling period on MWD

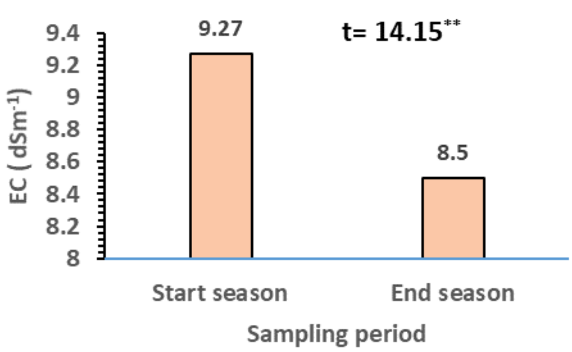

Figure 4. Effect of Sampling period on EC

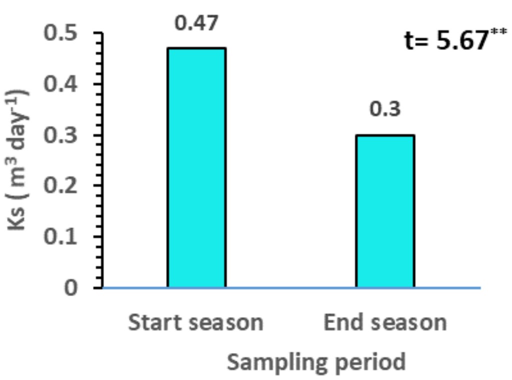

Figure 5. Effect of Sampling period on KS

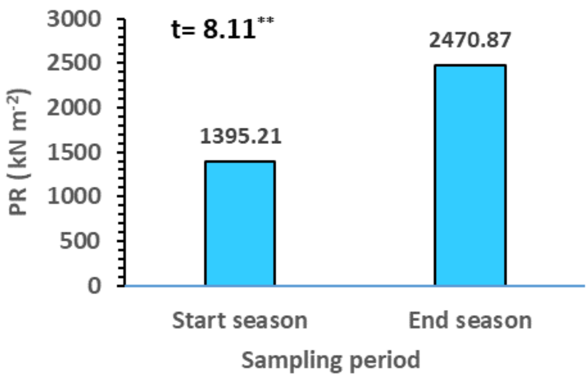

Figure 5. Effect of Sampling period on PR

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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 4. The plowing treatment with the combined tillage machine T1 achieved the highest grain yield and dry matter weight of 6.28 and 16.58 Mg ha^{-1}, followed by the T3 treatment, which recorded a grain yield and dry matter weight of 5.87 and 16.27 Mg ha^{-1}. The combined tillage machine T2 and T4 treatments recorded 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. In contrast, 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 plowing treatment with the combined tillage machine T1 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 T2, T3, T4, and T5.

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**

Table 4. Grain yield and Dry matter of maize as affected by different tillage treatments

DISCUSSION

This result is similar to the findings of [23], who found that the average bulk density increased by 4.204% at the end of the plant growing season compared to the beginning. The explanation for the increase in mean weight diameter while using T1 was ascribed to the fact that it causes the soil bulk density to decrease while increasing porosity, which improves the aggregate stability of the soil consequently, the mean weight diameter. These findings are consistent with [11], who found that the combined plow (digger + toothed roller) increased the stability of the soil aggregates in clay compared to conventional tillage by 22.85 and 25.33% for soil aggregates less than 1 mm and less than 2.5 mm, respectively. 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 cement materials. These results agreed with [24]. These findings are consistent with those of [16], 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 10 cm. The results also agree with [25], 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%. Moreover, this finding is in agreement with [27], who attributed this to the increase of soil cohesion 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. However, these results showed the role of the combined tillage machine, which works at a great plowing depth, and its positive role in increasing the 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. [29, 30].

CONCLUSION

The combined tillage machine that contains a subsoiler operating at a depth of 60 cm (T1 and T3) had a significant effect on the physical properties of the soil. The bulk soil density, EC, and penetration resistance decreased, while the saturated water conductivity and MWD of both tillage treatments (T1 and T3) increased. The sampling time significantly affected the soil bulk density, MWD, saturated water conductivity, and penetration resistance. These values were decreased at the start of the maize growth and increased at the end, while the EC was decreased compared with the start season. The highest grain yield and biological yield were recorded by the T1 treatment, followed by the T3 treatment. T5 recorded the lowest grain yield and biological yield.

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