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Effectiveness of Conventional and Minimized Tillage Practices on Soil Quality Properties and Maize Yield Attributes

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ABSTRACT

The effects of tillage systems on soil properties and crop productivity have been the subject of many studies to ensure sustainable productivity. Aims: In the study, the effects of different tillage methods applied in the intermediate period of wheat-maize rotation on the soil quality properties and corn yield elements were investigated in the pre-planting period (PP) and plant growth period (PGP) of corn. Methods: Conventional tillage (CT), minimum tillage with subsoiling and chisel (MT1), minimum tillage with subsoiling (MT2), minimum tillage with chisel (MT3) and direct sowing (DS) methods were compared. As a result of the tillage practices, at 0-20 cm, the highest bulk density values were measured in the DS and CT methods, and 20-40 cm was determined in the CT method. The penetration resistance values of the soils measured at a depth of 0-80 cm were significantly affected by the applications made in both PP and PGP. The highest saturation value was measured in the MT3, the highest field capacity and plant available water contents were measured in the DS. The effects of the applications on the chemical properties of the soil and the nutrient content of the corn plant were limited. The effects on only grain protein ratio from yield components of corn plant were significant, the highest value was measured in CT. Considering the sustainable management of soils labour requirement and lower costs it was concluded that DS and MT methods are more applicable than CT methods in terms of yield.

1. Introduction

In order to meet the food demand on a global scale, increasing tillage practices causes faster transformations and degradations in the agro-ecosystem. Soil cultivation activities, which have increased progressively in the last fifty years, increased energy costs on the one hand and reducing profitability on the other hand, and cause deterioration in soil properties at the same time (Alskaf et al. 2021; Voorhees and Lindstrom 1984). Soil quality, which can be applied to agricultural and natural ecosystems, has attracted considerable attention worldwide in recent years (Andrews et al. 2002; Doran and Parkin, 1994; Karlen 2004). Sustainable soil management systems often require increased management activities. Instead of meeting these management activities, soil quality tests and accordingly application recommendations can reveal both selection and management functions together (Bünemann et al. 2018). Soil quality is the most practical method for the management practices, interpretation of how the soil and ecosystem are affected, and the continuation of sustainability, as well as the regularity of soil information (Beinat and Nijkamp, 1998). Physical, chemical, and biological quality characteristics of the soils impressed due to the difference in tillage methods and creates differences in plant development, root growth and product yields (Gassel 1982; Gholami et al. 2014). To ensure sustainability in agricultural activities, soil management practices such as reduced tillage or zero tillage can be selected according to the region, climate, and plant. Selection of the most suitable method helps protect soil and water resources, maintain agricultural income and to reduce soil degradation with alternative tillage (Azimzadeh et al. 2008; Blevins et al. 1971; Mujdeci et al. 2017). As a result of the application of conventional tillage methods, the physical and structural properties of the soils deteriorate (Jia et al. 2010; Ren et al. 2018; Shaokun et al 2006). While the soils are compacted due to some tillage tools and field traffic, after processing with conventional tillage tools, the penetration resistance of the top layer of soils generally decreases (Ehlers et al. 1983). However, due to repeated tillage, it is inevitable that a layer limiting the development of plant roots is formed at under the cultivation

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depth of soil. Soil porosity tends to decrease with increasing compaction due to intensification of tillage (Şeker 1999; Şeker and Işıldar 2000). Together with the it should be increase reduced soil porosity, it causes the limitation of the use of water and nutrients that plants can benefit from (Hernanz et al. 2000; Topa et al. 2021). Owing to decreasing tillage costs, increasing the amount of water stored in the soil or maintaining its current potential, reduced tillage is considered a long-term recommendation for agro-ecosystems (Li, Liao et al. 2019). Reduced tillage practices provide protection and increase in physical quality by improving soil structure, and accordingly, improve the water holding capacity of soils (Borges et al. 2018; Hellner et al. 2018). There are important interactions between the hydraulic properties and the physical properties of the soil (Li et al. 2019; Perkins et al. 2007; Wang and Shao 2013). Depending on the bulk density and aggregation change of the soils, different tillage techniques affect the hydraulic properties of the soils (Alaboz 2020; Strudley et al. 2008). Since the structure of micro and macro aggregates in soils will differ depending on the differences in tillage, it affects the pore size distribution of the soil and, accordingly, the hydrodynamic properties (Kutilek 2004). Upon evaluation of studies on soil tillage practices, although the medium and long-term effects are better known, the information about the short-term effects is limited. For this reason, in this study, the effects of 5 different tillage methods on the quality characteristics of the soil and the yield components of the corn plant were investigated in pre-planting period (PP) and plant growth period (PGP) at the wheat-corn crop rotation.

2. Materials and Methods

Site location and description

The study was carried out in the province of Aksaray, located in the central south of Turkey, in an area where wheat-corn rotation is practiced (38°24'55.3"N 33°51'01.3"E). The altitude of the study area is 936 m, and the continental climate is dominant in the region. Since the climate data for many years are examined, the temperature was measured as -3.6 °C in the lowest January, the highest in August, 30.6 °C and 12 °C as the average temperature. The region receives most of the precipitation in winter and spring due to its climatic characteristics, and the average precipitation is 361.80 mm (MGM 2020).

The soil at the experimental site area has high clay content (54.40%), medium calcareous (7.47%), low organic matter (1.66%) (Table 1). The soil type was Typic Torrifluvents (Soil Survey Staff 1999).

Experimental design and treatments

The experimental design was laid out in a randomized complete block with three replications, in 15 plots (4x25 m), after wheat harvest. Five tillage treatments and application time were compared as indicated in Table 2. Mean working depth of soil tillage tools used in the study was 20 cm for mould board plough, 60cm for subsoiling (100 cm tillage range), 40 cm for chisel, 30 cm for cultivator, 15 cm for rotatiller, 10 cm for combine rotary and 15 cm for hoeing machine.

Table 1

Basic physico-chemical properties and measurement methods of experimental soil (0-20 cm).

Soil properties		Units	Values	Methods
Texture	Sand	%	33.57	Gee, Bauder, and Klute (1986)
	Silt		12.03	
	Clay		54.40	
Texture class			Clay	
AS		%	49.66	Gugino et al. (2009)
Bulk density		g cm^{-3}	1.23	Blake and Hartge (1986)
Particle density		g cm^{-3}	2.64	
pH		-	8.28	
EC		µS cm^{-1}	536	Gugino et al. (2009)
Lime		%	7.47	McLean (1983)
OM		%	1.66	Wright and Bailey (2001)
AP		mg kg^{-1}	11.48	Olsen and Sommers (1982)
TN		%	0.113	Wright and Bailey (2001)
Fe*		mg kg^{-1}	4.38	Lindsay and Norvell (1969)
Cu*		mg kg^{-1}	1.24	
Mn*		mg kg^{-1}	4.51	
Zn*		mg kg^{-1}	0.95	

AS: Agregatte stability, EC: Electrical conductivity, OM: Organic matter, AP: Available P, TN: Total N, *: DTPA extracted.

Soil measurements and analysis

To determine the soil properties, disturbed soil samples were taken from 0-20 cm depth from different points of the trial area, and it was used in the basic analyses given in Table 1. Soil field measurements and samplings were made in two different periods (pre-plantation (PP) ve plant growth period (PGP)) to determine the effects of tillage practices on the physical quality characteristics of the soil. To determine the effects of applications on other soil quality characteristics, soil samplings were made in a single period (tassel shot time). For this purpose, at every two periods, the bulk density (BD) was determined at 0-20 cm and 20-40 cm soil depths, and the penetration resistance (PR) was measured at 0-80 cm soil depth. Digital Eijkelkamp Penetrologger with code 06.15.SA was used to determine the penetration resistance. In the PGP period, aggregate stability (AS), field capacity (FC), permanent wilting point (PWP), plant available water (PAW) contents, total porosity (TP) and macro porosity (MP) values and soil chemical properties (pH, EC, OM, TN, AP, Fe, Zn, Cu ve Mn) were measured in 0-20 cm soil depth.

Table 2
Field tillage practices planning and treatments dates

Soil tillage/treatments dates	CT	MT1	MT2	MT3	DS
01.10.2019	Moldboard plow	*	*	*	
01.10.2019	*	Subsoiling	Subsoiling	*	
28.10.2019	*	Chisel	*	Chisel	*
28.04.2020	Cultivator	Cultivator	Cultivator	Cultivator	
30.04.2020	Rototiller	Rototiller	Rototiller	Rototiller	
30.04.2020	Combine rotary	Combine rotary	Combine rotary	Combine rotary	
01.05.2020	Sowing	Sowing	Sowing	Sowing	Sowing
19.05.2020	1. Hoeing	1. Hoeing	1. Hoeing	1. Hoeing	1. Hoeing
06.06.2020	2. Hoeing	2. Hoeing	2. Hoeing	2. Hoeing	2. Hoeing

CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding

Crop management and measurements

In the experiment, a maize variety, which is in the FAO 700 death group and widely grown in the region, was sown with a pneumatic seeder with 70 cm row spacing and 16 cm plant spacing. Before planting, 13-18-15 fertilizer was applied to all plots as a basal fertilizer at 500 kg ha^{-1}. In the next periods, 270 kg ha^{-1} of urea (46%N) in the first hoe and 600 kg ha-1 of ammonium sulphate (21%N) in the second hoe were applied at the soil surface and was mixed with soil. Herbicide with 2,4-D 2-ethylhexyl ester + florasulam active ingredient in the fight against weeds and insecticides with active ingredients imidacloprid, thiamethoxam and lambda-cyhalothrin were used to combat pests.

In order to determine the effects of the treatments on the growth characteristics and yield of the corn plant; shoot emergence, nutrient content of the leaves (N, P, Fe, Zn, Cu and Mn) (Bayraklı 1987), grain protein ratio (6.25 times the grain nitrogen content) (Wright and Bailey 2001), biomass and grain yield were measured. For seedling emergency, plants at 5 meters from the three rows in the middle were counted during the post-planting shoot period. Biomass and grain yield were measured in 7 m^2 area in each plot.

Statistical Analysis

Analysis of variance was performed to test for significant differences between tillage treatments. Means were compared using the Tukey multiple comparison test at a probability level of 0,05. SPSS statistical software was used in all data analysis.

3. Results and Discussion

Bulk density (BD)

In the PP, the effects of different tillage practices on the BD measured at 0-20 cm and 20-40 cm soil depth was statistically significant (P<0.05). Accordingly, at a depth of 0-20 cm, the highest BD was measured in the DS application with 1.16 g cm-3, while the lowest BD value was measured in the MT3 application with 1.08 g cm-3. The difference between the BD values measured in other applications was statistically insignificant and were included in the same group. The highest BD value in the subsurface layer (20-40 cm) was measured in the CT application with 1.23 g cm-3, while the lowest was measured in the MT3 application with 1.13 g cm-3, however, the differences between the MT1, MT2, MT3 and DS methods were statistically insignificant (Figure 1).

In the PGP, the effects of tillage practices on BD measured at 0-20 cm and 20-40 cm soil depth were statistically significant (P<0.05). During this period, at a depth of 0-20 cm, the highest BD was measured as 1.22 g cm-3 in the CT application, while the lowest BD value was measured as 1.14 g cm-3 in the MT1 application. The difference between the BD values measured in other applications was statistically insignificant and were included in the same group. While the lowest BD values was in the DS application with 1.16 g cm-3, the BD value measured at 20-40 cm depth was determined with the highest 1.23 g cm-3 in the CT application, however, the differences between the MT1, MT2, MT3 and DS methods were statistically insignificant (Figure 2).

According to these results, DS method at 0-20 cm depth gave higher BD values due to the lack of tillage, while CT method at 20-40 cm depth gave higher results than other methods. The reason for this was evaluated to be caused by the pressure applied to the substrate during cutting and overturning of the plough and tractor traffic formed in the plough track creating a plough layer at 20 cm. The BD values also depend on the structural condition of the soils and are an indicator of soil compaction (Sutherland et al. 2001; Gomez et al. 2002; Karlen 2004; Hall and Raper 2005). The BD values measured in the treatments were below the 1.40 g cm-3 value, which limits plant root development (Lhotský et al. 1984; Badalíková 2010). As a result, although different tillage methods affected the BD values of the soils in different ways, they did not limit plant root growth. However, the effect of soil tillage treatments to be made in the long term will be more decisive (Lal 1993). In addition, it has been observed in the studies that direct sowing does not affect the bulk density much in the short term (Moraes and Benez 1996; So et al. 2009).

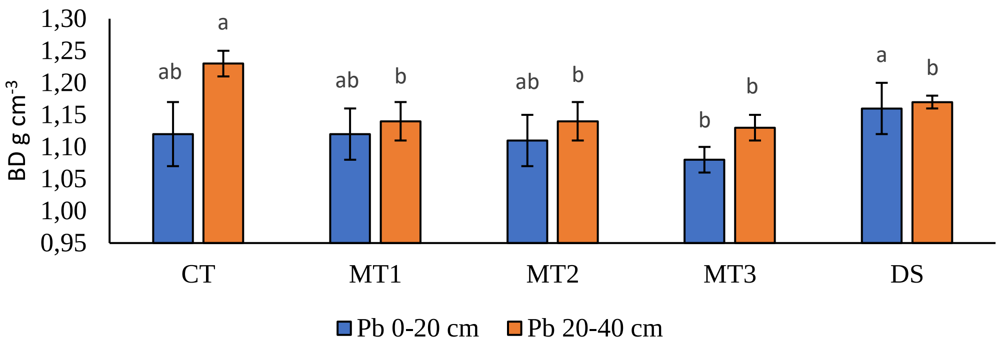

Figure 1
Bulk density (BD) changing in pre-plantation period (CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, means (*n* = 3) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

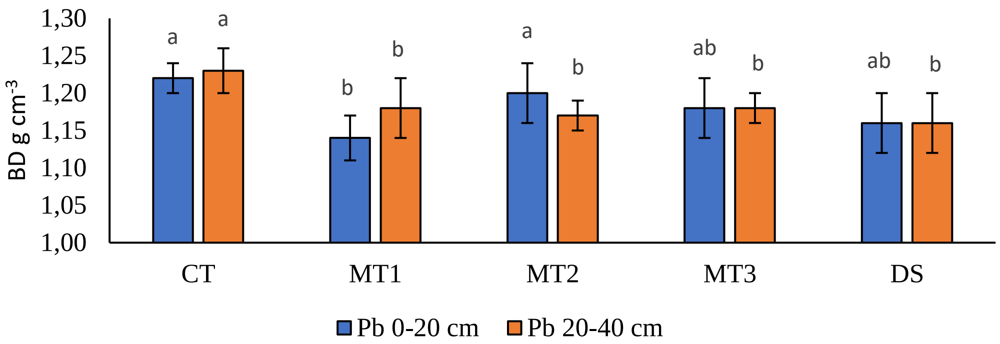

Figure 2
Bulk density (BD) changing in plant growth period (CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, means (*n* = 3) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

Penetration resistance (PR)

Tillage applications, except for 0-20 cm in PGP, had a statistically significant effect on PD measured at 0-20 cm, 20-40 cm, 40-60 cm, and 60-80 cm depths of soil in PP and PGP (P <0.05).

In the PP, at the soil depth of 0-20 cm, the highest PR value was 1.04 MPa in the MT2 method, while the lowest was 0.55 MPa in the MT1 method. While the difference between the MT2 and DS methods were insignificant, the differences between the CT, MT1 and MT3 methods were also insignificant. This situation shows that subsoiling application (MT2) alone does not create a sufficient level of loosening effect on the soil at the depth of 0-20 cm. It was determined that other applications were at the same level and more effective on loosening 0-20 cm soil (Table 3 and Figure 3). The PR values at the depth of 20-40 cm were measured at the highest 1.66 MPa in the MT2 method, while the lowest 1.29 MPa was measured in the MT1 method. While CT, MT2 and MT3 applications were in the same group with higher PR, MT1 and DS applications were also in the same group with lower PR. This shows that CT, MT2 and MT3 applications have an increasing effect on the soil at 20-40 cm depth (Table 3 and Figure 3). The highest PR value was measured at the depth of 40-60 cm with 2.33 MPa in the CT application and was in the same group with the MT3 application. The lowest was 1.87 MPa in the DS application and was in the same group with the MT1 application. MT2 application was between these two groups with a PR of 2.14 MPa (Table 3). CT and MT3 treatments caused more compaction at 40-60 cm depths, as well as at 20-40 cm depth. This situation is due to both the pressure of the plow base and the trace of the tractor in the conventional tillage method (CT). In addition, it is understood that the subsoil is compaction due to the pressure formed under the cultivation depth in the chisel application (MT3), where soil cultivation is carried out at a depth of 40 cm. Similar effects were also noted by Şeker and Işıldar (2000). Finally, in the PR values at 60-80 cm depth, the CT method gave the highest result (3.24 MPa), while the MT3 method was ranked second with 2.61 MPa and the MT2 method was ranked as the third with 2.37 MPa. With a statistically insignificant difference, the lowest values were found in MT2 and DS methods as 2.09 MPa and 2.02 MPa, respectively (Table 3).

In the PGP, while the highest PR value was measured at the depth of 20-40 cm as 2.85 MPa in the MT3 application. PR value of MT2, DS and CT methods was measured 2.48 MPa, 2.41 MPa and 2.36 MPa, respectively and statistically insignificant differences occurred between them. The lowest value was obtained from the MT1 method as 1.96 MPa (Table 3 and Figure 4). At the depth of 40-60 cm, the highest PR values of 3.13 MPa was measured in the MT3 application, which is in the same group as CT. These were followed by other applications in different groups, In the MT1, MT3 and DS applications were measured 2.54 MPa, 2.41 MPa and 2.24 MPa, respectively (Table 3). At the depth of 60-80 cm, the highest PR value was measured as 2.80 MPa in the MT3 method, and it was in the same group with MT1 and MT2 applications. DS method was in the same group with MT1 and MT2 methods, and the lowest value was measured as 2.06 MPa in the DS methos (Table 3).

In the PP, at the depth of 0-20 cm, PR values were lower in the MT1 and MT2 methods, while lower values were obtained in the MT1 and DS methods at 20-40 cm depth. While the lowest PR values, at a depth of 40-60 cm like a depth of 20-40 cm, were obtained from the MT1 and DS methods; PR values of the CT, MT2 and MT3 methods exceeded the 2 MPa limit value, which negatively affects plant root growth (McKyes 1985). At the 60-80 cm depth similar to 40-60 cm depth, at the CT, MT2 and MT3 methods measured higher PR values. The CT method also exceeded the limit value of 3 MPa, which stopped plant root growth with 3.24 MPa (Busscher and Sojka 1987; Gugino et al. 2009; Gülser and Candemir 2012). The PR values of the MT1 and DS methods like the MT2 and MT3 methods, also gave results slightly above the threshold value, although they exceeded the 2 MPa threshold value that negatively affected root growth (Gajri et al. 1994; Hall and Raper 2005).

In the PGP, PR values were higher than the pre-sowing period, especially at 0-60 cm depth. The reason for this is that the seed bed preparation, planting process and machine hoeing and pesticide applications during the plant development period create different amounts of pressure in the soil. At the 20-40 cm, except for the MT1 method, at the depth of 20-80 cm, in all tillage methods has been exceeded the 2 MPa limit value that negatively affected the root development of the plant (McKyes 1985). Except for the DS method at planting time, the reason for the compaction at the depth of 20-40 cm is that the cultivator, rototiller and combine rotary applications, creates compaction under the processing depth of the hoe machine during the plant development period. In the MT1 method, both chisel plough and subsoiler were used hence reduction of superficial and deep compression occurred and the PR values remained below the limit value of 2 MPa (McKyes 1985). At the depth of 40-60 cm, PR values in the CT and MT3 methods exceeded the limit value of 3 MPa that hinders plant root growth (Busscher and Sojka, 1987; Gugino et al. 2009; Gülser and Candemir, 2012). In the DS method, the absence of field traffic before sowing as well as the limited field traffic after sowing caused less compaction in the subsoil layers.

Table 3
The effects of different tillage practices on the penetration resistance (MPa) of the soil in two periods

Tillage practices	Pre-plantation				Plant growth period			
	0-20cm	20-40cm	40-60cm	60-80cm	0-20cm	20-40cm	40-60cm	60-80cm
CT	0.68±0.25[bc**]	1.56±0.25[a**]	2.33±0.27[a**]	3.24±0.28[a**]	1.29±0.45[*]	2.36±0.39[b**]	3.04±0.06[a**]	2.80±0.15[a**]
MT1	0.55±0.18[c]	1.29±0.33[b]	1.96±0.05[c]	2.09±0.09[d]	1.56±0.47	1.96±0.26[c]	2.54±0.10[b]	2.34±0.08[b]
MT2	1.04±0.34[a]	1.66±0.16[a]	2.14±0.07[b]	2.37±0.05[c]	1.67±0.65	2.48±0.10[b]	2.41±0.05[c]	2.29±0.12[b]
MT3	0.60±0.24[c]	1.50±0.26[a]	2.29±0.18[a]	2.61±0.06[b]	1.68±0.59	2.85±0.26[a]	3.13±0.13[a]	2.73±0.14[a]
DS	0.87±0.14[ab]	1.33±0.21[b]	1.87±0.16[c]	2.02±0.07[d]	1.71±0.57	2.41±0.05[b]	2.24±0.16[d]	2.06±0.06[c]

CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, [*]; Not significant, [**]; means (n = 3) (± standard errors) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

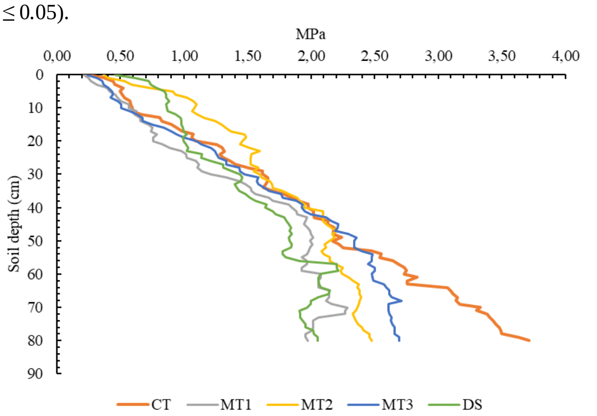

Figure 3
Penetration resistance graphs in the pre-plantation period (0-80 cm soil depth) (CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding).

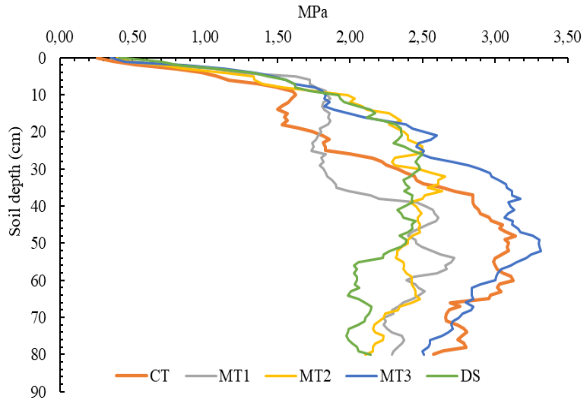

Figure 4
Penetration resistance graphs in the plant growth period (0-80 cm soil depth) (CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding).Soil water parameters

Except for permanent wilting point (θPWP), the effects of the treatments on saturation (θS), field capacity (θFC), plant available water (θPAW) and macro porosity (θMP) values were significant by statistically (P<0.05) (Table 4).

While the MT3 method gave a higher θS value compared to other applications, the lowest value (55.65%) was measured in the CT method (Table 4). Differences between CT, MT1, MT2 and DS methods and differences between MT2, MT3 and DS methods were insignificant. The highest θFC value (37.92%) was measured in the DS method, and the lowest (34.97%) in the CT method (Table 4). Only the DS method made a significant difference with the CT method, and the differences between other treatments were insignificant. An increase of approximately 8% was measured in the DS method compared to the CT method. The θFC value in the DS method was higher than others because of the structure of the pores remained intact due to the application of less pressure on the land and the preservation of the existing structure of the soil (Mitchell and Soga 2005; Burgos Hernández et al. 2019). θPWP values, as an indicator of the amount of water that can be retained on the micropores and colloid surface, varied between 24.15-25.91%. (Table 4). The reason for the insignificant change in the θPWP value is that tillage influences the macropores but not the micropore structure. The effect of applications on θPAW values, calculated as the difference of θFC and θPWP values, was significant (P<0.05) (Table 4). The plant available water content measured as 10.81% in the CT method increased by 6.84%, 6.198 and 11.10% in MT1, MT2 and DS methods, compared to CT, respectively. The θMP value of the soil varied between 20.13-23.88%, the highest value in MT3 method and the lowest value in MT3 method was measured. The θMP value, which is an indicator of the aeration level of the soil, was approximately twice of the general limiting value (10%) for plants in all tillage methods (da Silva and Kay 1997; da Silva et al. 1994).

Table 4
The effects of treatments on saturation (θ_S), field capacity (θ_{FC}), permanent wilting point (θ_{PWP}), plant available water (θ_{PAW}) and macro porosity (θ_{MP})

Tillage practices	θ_S	θ_{FC}	θ_{PWP}	θ_{PAW}	θ_{MP}
CT	55.65±2.78^{b**}	34.97±0.71^{b**}	24.16±1.35*	10.81±0.90^{b**}	20.68^{b**}
MT1	56.73±1.75^{b}	35.70±1.61^{ab}	24.15±2.74	11.55±1.85^{ab}	21.03^{ab}
MT2	57.14±0.34^{ab}	36.69±1.94^{ab}	25.21±1.90	11.48±1.91^{ab}	20.45^{b}
MT3	60.18±1.44^{a}	36.30±1.28^{ab}	25.30±1.15	11.00±1.26^{b}	23.88^{a}
DS	58.05±1.60^{ab}	37.92±1.73^{a}	25.91±1.67	12.01±1.71^{a}	20.13^{b}

CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, *; not significant, **; means (n = 3) (± standard errors) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

Chemical properties of the soil

While the effects of different tillage methods on the pH, EC, OM, TN, P and Cu contents of the soil pre-plantation period was statistically insignificant, the effect of Fe, Zn and Mn contents was limitedly significant (Table 5). In the different tillage methos, average pH, EC, OM, TN, P and Cu values of the soils were measured 8.24, 583.74 mS cm-1, 1.65%, 0.12%, 14.71 mg kg-1 and 1.80 mg kg-1 respectively. The highest and the lowest values of Fe, Zn and Mn were measured in CT and DS methods, in MT1 and MT2 methods, DS and MT3 methods, respectively (Table 5).

While the methods based on tillage (CT and MT1) had a limited effect on the Fe and Zn content of the soil, treatments had a variable effect on the Mn content, and a higher value was measured in the DS method, albeit limited. It has been evaluated that this situation may be caused by the change, increase, or decrease in soil aeration due to tillage. At the end of seven years of conventional and reduced tillage practices, soil pH and CaCO3 content were not affected by different tillage methods, while soil organic carbon, total nitrogen and plant-available phosphorus content of the soil surface layer increased partially in reduced tillage (Neugschwandtner et al. 2014). In a five-year study, it was stated that the pH was measured lower because of the mineralization of organic matter in the upper layer of the soil in the no-tillage plots compared to the plots with plough tillage (López-Fando and Pardo 2009). In this study, this effect was not observed in the short term. In the long term, the Fe content of the soil is lower in minimum tillage than in no-till agriculture, in the short-term study, the Fe content beneficial to the plant was found to be lower in the DS method (Obour et al. 2021). This shows that the duration of the tillage application has a different effect on Fe content of the soil.

Table 5
The effects of different tillage practices on the chemical properties of the soil

Tillage practices	pH	EC	OM	TN	P	Fe	Zn	Cu	Mn
		mS cm^{-1}	%	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
CT	8.25±0.13*	619.00±68.90*	1.65±0.06*	0.120±0.01*	13.38±0.22*	13.15±0.17^{a**}	1.64±0.02^{d**}	1.69±0.08*	12.41±0.46^{b**}
MT1	8.21±0.08	580.30±31.50	1.66±0.09	0.120±0.01	16.44±0.14	12.69±0.24^{ab}	2.47±0.04^{a}	1.87±0.07	13.60±1.01^{a}
MT2	8.26±0.05	570.03±28.70	1.59±0.03	0.115±0.02	14.74±0.06	12.55±0.19^{ab}	1.38±0.01^{e}	1.81±0.09	11.78±0.06^{c}
MT3	8.25±0.08	581.70±44.70	1.63±0.03	0.118±0.02	12.27±0.47	12.77±0.21^{a}	1.92±0.03^{c}	1.76±0.02	10.05±0.21^{d}
DS	8.23±0.06	567.67±16.44	1.73±0.01	0.126±0.01	16.72±0.43	12.09±0.33^{b}	2.27±0.07^{b}	1.87±0.08	13.34±0.65^{a}

EC: electrical conductivity, OM: organic matter, TN: total nitrogen, P: available phosphorus, Fe: available iron, Zn: available zinc, Cu: available cupper, Mn: available manganese, CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, *; not significant, **; means (n = 3) (± standard errors) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

Yield components of maize

Different tillage practices had a limited and statistically significant (P<0.05) effect only on grain protein proportion, among the effects of maize plant seedling emergence, grain yield, grain protein proportion, total biomass, and dry matter yield (Table 6). The number of seedling emergence, the grain yield, the total biomass amount, and the dry matter yield of the corn plant ranged between 8000-8285 plant da-1, 1252-1369 kg da-1, 8066-8466 kg da-1 and 31.03-33.41 %, respectively (Table 6). The highest protein proportion (5.06%) was measured in the CT application, while the lowest protein proportion (3.81%) was measured in the MT3 application. In terms of protein proportion, the differences between CT, MT2 and DS applications and the differences between MT1 and MT3 applications were insignificant.

Nutrient elements composition of maize leaves

While the effects of the applications on the N, Zn and Mn contents of the corn leaf were significant (P<0.05), the effects on the P, Fe and Cu contents were insignificant (Table 7). The highest N content of corn plant (2.32%) was measured in DS method, while the lowest N content (1.82%) was measured in MT1 method. In terms of N content of the corn plant, the differences between CT, MT1, MT2 and MT3 methods and CT, MT2 and DS methods were insignificant. The highest Zn content (70.10 mg kg-1) was measured in MT2 application, the lowest Zn content (51.60 mg kg-1) was measured in DS method, the differences between CT, MT1 and MT2 methods and MT1, MT3 and DS methods were insignificant. The highest Mn content (77.20 mg kg-1) was measured in MT3 method, the lowest Mn content (50.43 mg kg-1) was measured in CT method, the differences between MT2, MT3 and DS and CT and MT1 methods were insignificant. While the N content of corn cob leaves was below the deficiency limit in all applications, P, Fe, Zn, Cu and Mn contents were measured adequately (Jones Jr 1999).

Table 6
Effects of different tillage practices on yield components of maize

Tillage practices	Seedling emergence (Plants da^{-1})	Grain yield (kg da^{-1})	Protein proportion (%)	Total biomass kg da^{-1}	Dry matter %
CT	8285±285*	1252±39.10*	5.06±0.47^{a**}	8066±464*	33.41±1.32*
MT1	8095±165	1301±88.10	3.91±0.09^{b}	8466±279	31.39±0.86
MT2	8000±285	1347±56.10	4.41±0.40^{ab}	8214±429	30.59±0.13
MT3	8285±285	1280±59.50	3.78±0.37^{b}	8295±780	31.03±1.55
DS	8000±285	1369±44.70	4.43±0.34^{ab}	8338±821	31.51±1.42

CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, *; not significant, **; means (n = 3) (± standard errors) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

Table 7
Effects of different tillage practices on nutrient elements composition of maize leaves

Tillage practices	N	P	Fe	Zn	Cu	Mn
	%	mg kg^{-1}				
CT	2.01±0.23^{ab**}	0.33±1.16*	47.57±10.70*	66.40±6.44^{a**}	17.80±0.76*	50.43±3.26^{c**}
MT1	1.82±0.15^{b}	0.39±0.55	55.70±18.10	59.67±6.10^{ab}	18.56±1.20	58.57±5.84^{bc}
MT2	2.12±0.05^{ab}	0.31±2.19	70.00±4.84	70.10±6.48^{a}	19.25±1.08	68.87±8.81^{ab}
MT3	1.83±0.04^{b}	0.29±0.58	65.30±27.40	52.26±1.44^{b}	18.96±1.66	77.20±4.59^{a}
DS	2.32±0.12^{a}	0.32±0.25	62.37±11.56	51.60±2.52^{b}	17.80±0.76	71.03±2.55^{ab}

CT; conventional tillage, MT1; minimum tillage with subsoiling and chisel, MT2; minimum tillage with subsoiling, MT3; minimum tillage with chisel and DS; direct seeding, *; not significant, **; means (n = 3) (± standard errors) followed by the same letter in a column are not significantly different ($P \leq 0.05$).

4. Conclusions

Soil tillage practices can have significant effects on the efficiency and quality of crop production by affecting the physical and in some cases chemical quality properties of soils. In addition to the effect of reduced tillage practices on soil properties, the cost-reducing effects also make their application widespread. Bulk density and penetration resistance values, which are indicators of soil compaction, are periodically affected by treatments. In the pre-planting period, direct sowing and conventional tillage applications produced higher bulk density values, while the conventional tillage method created higher bulk density values in the plant development period. It has been evaluated that this situation is caused by secondary field traffic such as hoe machine and agricultural spraying. Although tillage practices had negative effects on soil compaction, the amount of macropores did not fall below the limit value, and therefore, no significant changes occurred in the yield parameters of the corn plant. Since the chemical properties of the soil and the yield and yield elements of the corn plant are less affected by the applications, it has come to the fore that soil tillage applications that create less field traffic are preferred.

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