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Tillage effects on certain physical and hydraulic properties of a loamy soil under a crop rotation in a semi-arid region with a cool climate

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ABSTRACT

The purpose of this study was to research the influence of four different tillage practices [T1: Conventional tillage (moldboard plow+disk harrow+combined harrows+precision seeder); T2: Reduced tillage-I (cultivator+combined harrows+precision seeder); T3: Reduced tillage-II (rotary power harrow+precision seeder) and T4: No-till (no-till seeder)] on bulk density, total porosity, penetration resistance, field capacity, field water content and the infiltration rate of a loamy soil in a semi-arid region with a cool climate and an annual mean temperature of 5.6 °C. In particular, the effectiveness of the no-till practice was investigated. Since 1999, the experimental field has been tilled by the above-mentioned tillage practices and also applied a crop rotation (vetch–winter wheat–fallow) in dry conditions. We made assessments of selected soil properties according to the data during the sowing–germination period of winter wheat only in 2012 autumn. Therefore, the number of germinated seedlings of winter wheat was also evaluated. The data of this study carried out in three replications were statistically analyzed using the ANOVA and the regression technique.

The results indicated that the tillage treatments affected soil properties and wheat germination. The highest values in all examined parameters except for total porosity were obtained under the no-till practice for top soil layer of 30 cm. As was expected, the no-till treatment had the highest bulk density and provided the lowest total porosity. Generally, the plots tilled by conventional practice had the lowest values. Similar results were obtained for the top soil layer of 0–10 cm, which is seedbed. The penetration resistance measured to a depth of 30 cm in 5 cm increments increased as polynomial with increasing the soil depth in all treatments. The infiltration rate decreases as a function of elapsed time could be described by the Kostiakov equation. Also, significant linear relationships were obtained for penetration resistance–bulk density, field capacity–bulk density and field capacity–penetration resistance.

Although no-till treatment improved the hydraulic properties of soil, it had no positive effect on the soil physical properties. However, the linear relations with high correlation coefficients between penetration resistance and bulk density with field capacity at the no-till showed that soil physical and hydraulic properties revealed that they are connected to each other. According to the results of our study it could be concluded that the no-till practice increased winter wheat germination due to higher water content.

1. Introduction

Tillage is one of the most important practices affecting soil's physical and hydraulic properties (Jabro et al., 2009). Soil physical properties (bulk density, total porosity, pore size distribution, penetration resistance and aggregate stability) and consequently soil hydraulic properties (water retention, infiltration rate and hydraulic conductivity) change with the variation in soil structure (Gill, 2012). Changes in soil structure are due to the mechanical effect of tillage implements (Alletto and Coquet, 2009).

The most commonly measured soil physical properties under tillage conditions are soil bulk density, porosity and soil structure (Gill, 2012; Strudley et al., 2008). The effects of tillage practices on soil physical properties vary dramatically according to the type of tillage. Bulk density is one of the basic soil properties affected by tillage practices (Badalíkova, 2010). Generally, higher bulk density values were obtained in no-tillage treatments compared to other conservation or more conventional tillage systems (Aikins and Afuakwa, 2012; Lampurlanés and Cantero-Martínez, 2003; Romaneckas et al., 2009). Reduced tillage also increased bulk density in comparison with traditional tillage (Czyż and Dexter, 2008). However, Olaoye (2002) and Sekwakwa and Dikinya (2012) determined that bulk density was the lowest under no-tillage.

Higher bulk density provides lower total porosity because total porosity is inversely related to bulk density. While bulk density increases with

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compaction effects, pore volume and pore size decrease (Logsdon and Karlen, 2004). Low porosity reduces aeration and increases penetration resistance (Kuht et al., 2012; Lampurlanés and Cantero-Martínez, 2003). At the same time, the penetration resistance of soil changes with moisture content (Agherkakli et al., 2011; Badalíkova, 2010). Penetration resistance is one of the common methods used to assess soil strength (Ţopa et al., 2011). Therefore, it is considered to be a good representative indicator of soil compaction in different tillage conditions (Çelik, 2011). There was a close relationship between soil tillage and soil compaction (Badalíkova, 2010). Generally, the highest soil penetration resistances were determined under no-tillage (Aikins and Afuakwa, 2012; Lampurlanés and Cantero-Martínez, 2003). Conversely, Olaoye (2002) found that no-tillage treatment provided the lowest penetration resistance. Nkakini and Fubara-Manuel (2012) determined that different tillage treatments (plowing, plowing + harrowing, plowing + harrowing + harrowing and ridging) had no significant effect on penetration resistance and the total porosity of soil.

Water infiltration into soil is directly proportional to the soil structure, pore size and volume (Badalíkova, 2010). The results obtained from various studies showed that the no-till treatment caused lower infiltration rates (Abu-Hamdeh, 2002; Lipiec et al., 2006; Matula, 2003). However, some researchers indicated that the no-till treatment can increase infiltration due to higher surface residue and macropore connectivity between the top and bottom soil layers (Strudley et al., 2008; Subbulakshmi et al., 2009).

In dry soil conditions, lack of soil moisture during seed germination can create water stress resulting in delayed germination. For better germination, tillage should provide sufficient moisture and heat and also facilitate germination and rooting (Khan et al., 1999). Reduced tillage is one of the main applications for moisture conservation in dry land farming (Anderson and Impiglia, 2002). According to the results of various studies, non-tilled soils had the highest moisture contents (Olaoye, 2002; Romaneckas et al., 2009; Šarauskis et al., 2008). Reduced tillage also increased soil water content (Czyż and Dexter, 2008). Conversely, Aikins and Afuakwa (2012) found that the no-tillage practice provided the lowest soil moisture content. Temperature is also an important factor for seed germination in cool regions. He et al. (2010) examined the effect of different tillage systems on soil temperature in a cold and semi-arid region and found that soil temperature to 0.10 m depth increased significantly under no-tillage and ridge tillage compared to conventional tillage, and the increase was by 0.7–2.4 °C in the cold season.

Wheat is one of the main crops spread over on the world. However, wheat production in the dry and cold regions of the world is continued under environmental risks such as lower soil moisture and temperature. One of these regions is the Eastern Anatolia Region of Turkey. This region has 577.2 mm annual total precipitation and 8.7 °C annual mean temperature. The coldest and hottest months are January (−5.9 °C average) and July (22.6 °C average), respectively. Average air temperatures in the December, January and February are below zero degrees (Şimsek et al., 2012). Spring and the early summer seasons are moderate rainy, while the winter season is snowy in this region (Türkeş et al., 2007). Therefore, a cropping schema including wheat, barley and fallow is a common type of production in this region (SPO, 2000). In the Eastern Anatolia Region, the wheat–fallow cropping system covers an area on 1.5 million ha; most of the wheat production areas receive an annual precipitation of less than 500 mm (Kumlay et al., 2007). Also, vetch is one of the most common fodder crops, especially in the north eastern part of the region. Agricultural activities in the Eastern Anatolia Region are based on animal production. The widening of the cultivation of fodder and forage crops is a requirement for improvement of animal breeding, because roughage needs of the animals of this region are 15 million tons, whereas the available quantity is 6 million tons (SPO, 2000). Conversely, erosion is common over this region. At the same time, the semiarid this region soils with low organic matter have a weak structure (Kumlay et al., 2007). Cereal production on unavailable lands for cultivated agriculture and bare lands leads to serious erosion problems in these region areas. Fallow is also quite common in the region. Fallow area covers 31.9% of the cultivable land (SPO, 2000). If fodder and forage crops are integrated with cereal cultivation it is possible to reduce fallow lands in this region. Also, increased soil nitrogen in forage legume–wheat system leads to high wheat yields. Tosun et al. (1987) determined that the vetch–fallow–wheat rotation system caused high wheat yield and improved soil properties under Erzurum province conditions in the Eastern Anatolia Region. Hanay et al. (1998) investigated the effects on soil physical properties and soil–water relationships of 7 different rotation systems under Erzurum dry conditions and they indicated that rotation systems with vetch or sainfoin provided better soil properties. Karadaş et al. (2011) reported that vetch–fallow–wheat rotation system under organic agriculture in Erzurum province was the most profitable among the rotation systems of fallow–wheat, wheat–wheat and vetch–fallow–wheat. Also, this rotation system increased the soil organic matter content (Karadaş et al., 2007). Decomposition rates of organic matter in soils of regions with cooler climates are relatively slower. Tillage is one of the major practices which affects the organic matter level of soil. While traditional tillage causes rapid decomposition of organic matter, no-tillage practice provides protection and increase for the soil organic matter (Bot and Benites, 2005). Similarly, Olgun et al. (2004) determined that no-tillage under vetch–fallow–wheat crop rotation provided more organic matter in the dry and cool Eastern Anatolia Region conditions.

Therefore, applying cultural practices including tillage and rotation systems could improve soil properties for crop production, decrease soil erosion and therefore increase of economic level of farmers in cool and arid regions.

For the reasons mentioned above, we conducted a study about the effect of tillage practices on the physical and hydraulic properties of a loamy soil under a crop rotation (vetch–winter wheat–fallow) in a semi-arid region with the cool climate of Turkey. To determine the effect of different tillage practices on soil bulk density, total porosity, penetration resistance, field capacity, field water content, infiltration rate and winter wheat germination at the end of a 13-year tillage under a crop rotation is the first aim of this study. The germination of wheat seeds is mostly effected by soil moisture and cold stress. Therefore, another aim of this study was to determine whether no-tillage is the most suitable practice in terms of providing better germination conditions of winter wheat in a semi-arid region with a cool climate compared to conventional tillage.

2. Materials and methods

The experimental field was located at the Soil–Water Resources Research Station in Pasinler of East Anatolia Agricultural Research Institute approximately 30 km east of Erzurum, Turkey (39.99° N, 41.57° E, 1721 m a.s.l.) (Fig. 1).

The research region has a semi-arid climate. Long term average (2000–2012) annual total precipitation, mean temperature and mean relative humidity are 427 mm, 5.6 °C and 66.9%, respectively (DATAE, 2013). While the summers are cool and dry in the region, winters are long, cold and snowy. Soils, especially in the spring, are often exposed to freeze–thaw cycles. The number of frost days in the Pasinler region is 157.3 according to long annual average data (Geçit, 2009).

The experimental field has been tilled with four different tillage systems since 1999 (Fig. 2), with a crop rotation of vetch–winter wheat–fallow. Tillage treatments consist of;

T1: Conventional tillage (moldboard plow + disk harrow + combined harrows + precision seeder)
T2: Reduced tillage-I (cultivator + combined harrows + precision seeder)
T3: Reduced tillage-II (rotary power harrow + precision seeder)

Fig. 1. Field site location.

T4: No-till (no-till seeder).

Tillage depths at the T1, T2, T3 and T4 treatments were 20–25, 15–16, 12–13 and 5–6 cm (only seeder depth), respectively.

Experimental plots were processed by the above-mentioned practices before sowing vetch or winter wheat. Vetch seeds were sown in all plots in the second half of September during the initial stage of crop rotation, and they were harvested on the first week of July of the following year. Winter wheat after harvesting the vetch crop was sown in the last half of September of the same year. Wheat crops were harvested in the first quarter of August of the following year and then all plots were left to fallow. While the conventional tillage plots were tilled by moldboard plow in the second half of June of the following year, chemical pesticides for removing weeds were applied on the other plots in this period. Therefore, a cycle of the crop rotation completed with sowing the vetch again in the second half of September of the same year.

Fig. 2. The plots tilled by the different tillage practices.

Certain physical and hydraulic properties of soils treated with different tillage practices from long term experiment were evaluated only during the sowing–germinating period of winter wheat in 2012.

The soil type in the experimental region is Inceptisol according to the USDA soil classification (Özgül, 2003). For determining certain soil properties before tillage in 2012, soil samples were collected from three randomly selected locations at the experimental plots on the 13th of September. Some soil properties of the experimental plots determined according to the methods used by Klute (1986) and Page et al. (1982) are given in Table 1.

The experiment was planned according to a randomized complete block design with three replicates. Therefore, a total of twelve plots for four different tillage practices were arranged in the experimental field. Each plot area was 600 m^2 (width 15 m, length 40 m). Spaces between the blocks and plots were 15 and 2 m, respectively. In 2012, plots were tilled according to the trial subjects on the 26–27th of September. Also, winter wheat (*Triticum aestivum* cv. Doğu-88) seeds were sown to a depth of 5–6 cm at the amount of 200 kg ha^{-1} on these dates.

The effects of different tillage practices on the soil infiltration rate, bulk density, porosity, penetration resistance, field capacity and field water content and seed germination of winter wheat were evaluated. Infiltration measurements were conducted using the double ring infiltrometer (Bouwer, 1986) in the last half of October with three replicates in each experimental plot. Diameters of stainless steel big and small rings were 30 and 20 cm, respectively. Rings were inserted vertically into the ground to a depth of approximately 10 cm. Water heads in rings were between 5 and 15 cm during the tests. Infiltration measurements in the inner ring were continued until reaching a steady-state infiltration rate.

Undisturbed soil samples were used for determining soil bulk density and water retention at the field capacity. The soil samples were collected in the soil layers of 0–10, 10–20 and 20–30 cm using a cylindrical soil sampler (5 cm long × 5 cm in diameter). Bulk density

Table 1
Certain physical and chemical soil properties in the depth of 0–30 cm of the treatment plots before tillage in 2012.

Treatments	Clay, %	Silt, %	Sand, %	Texture	EC, dS m^{-1}	pH	CaCO$_3$, %	Organic matter, %
T1	26.0	32.7	41.3	Loam	1.450	6.91	0.59	1.52
T2	22.0	33.3	44.7	Loam	1.328	7.22	0.52	1.52
T3	24.7	34.0	41.3	Loam	1.590	7.15	0.46	1.52
T4	22.0	32.7	45.3	Loam	1.680	7.26	0.46	1.77

was calculated as mass of oven dried soil per volume of the soil sampler (Blake and Hartge, 1986). Water content at the field capacity was determined after drainage at -0.033 MPa water potential of saturated soil samples using pressure plate apparatus (Cassel and Nielsen, 1986). The water mass in the soil sample was calculated by dividing the mass of the oven dried soil sample and multiplying by 100 to give the weight percentage. The bulk density and field capacity measurement was replicated three times for all soil depths. Soil porosity was calculated using the equation based on the relationship between the bulk density and particle density (Danielson and Sutherland, 1986). Particle density is approximately 2.65 Mg m^{-3} for minerals soils. Therefore, the 2.65 Mg m^{-3} value was used in this study because the experiment area had low organic matter (Table 1).

Soil penetration resistance was measured using a cone penetrometer with a 60° cone angle (Eijkelkamp, The Netherlands) to a depth of 30 cm in 5 cm increments with three replications from each plot. The bulk density and field capacity samplings and the penetration resistance measurements were conducted between the last week of October and the first week of November.

Field water contents in the plots were measured with a neutron meter (CPN 503DR) to a 90 cm depth in 30 cm increments before tillage (24th of September) and after approximately 3 weeks from tillage (16th of October). The neutron meter was calibrated for the experimental field.

Seedling emergence on a line of 1 m selected randomly in each plot was counted totally 3 times between October 15 and 21. The number of winter wheat seedlings per square meter was then determined.

Effects on the measured variables of all tillage practices were evaluated using ANOVA. Shapiro–Wilk W test was used to test of normality. The Least Significant Difference (LSD) test was performed to rank the significance means. Bilateral relations for the measured variables using the regression technique were also investigated.

3. Results and discussion

The effects of tillage treatments on bulk density, porosity, penetration resistance, field capacity, field water content, mean infiltration rate and wheat germination were statistically significant (Table 2).

3.1. Bulk density and porosity

We conducted bulk density measurements with three replications in the soil layer of 0–10, 10–20 and 20–30 cm at all the tilled plots in 2012 (Table 3). The mean bulk density values ranged from 1.18 to 1.32 Mg m^{-3} under the conventional tillage (T1), from 1.17 to 1.29 Mg m^{-3} under reduced tillage-I (T2), from 1.21 to 1.33 Mg m^{-3} under reduced tillage-II (T3) and from 1.21 to 1.38 Mg m^{-3} under no-till (T4). In the top soil layer of 0–30 cm, the reduced tillage-I (T2) and conventional tillage (T1) treatments provided lower bulk density values compared to the reduced tillage-II (T3) and no-till (T4) treatments (Table 3). Although differences among the tillage treatments were not statistically significant for 0–30 cm soil layer, tillage practices significantly ($P < 0.05$) affected bulk density in the soil layers of 0–10 and 20–30 cm. In the soil layer of 0–10 cm, the T4 treatment provided the highest value (1.38 Mg m^{-3}) which is significantly higher than the T2 (1.17 Mg m^{-3}) and T3 (1.21 Mg m^{-3}) treatment values. The bulk densities of the T1, T2 and T3 treatments in the soil layer of 0–10 cm were lower by 4.3, 15.2 and 12.3% compared to the T4 treatment, respectively. The highest value was determined in the T3 treatment (1.33 Mg m^{-3}) in the soil layer of 20–30 cm. While the T2 and T3 treatment values were statistically similar, the T1 and T4 treatment values were significantly lower than the value of the T3 treatment. Tilled soil depth was lower than 15 cm in the T2 and T3 treatments. Higher bulk density values in the subsoil layer (20–30 cm) under the T2 and T3 treatments may be obtained because of compaction increases in untilled soil layers with mechanical effects of tillage equipment. Already, high penetration resistance values in the soil layer of 20–30 cm under the T2 and T3 treatments showed the presence of a compaction (Table 3). At the same time, the accumulation into the subsoil layers of the small soil particles transported from the upper soil layers may reduce soil porosity and also increase bulk density.

Higher bulk density causes lower total porosity. As shown in Table 3, the highest total porosity value in the 0–10 soil layer is obtained at the T2 treatment (55.71%) because bulk density at this treatment was the lowest. Total porosity at the T1, T3 and T4 treatments were 9.9%, 2.2% and 14.0% lower than the T2 treatment, respectively. In the soil layer of 0–10 cm, the T2 treatment value was statistically similar to the T3 treatment, although it was significantly higher than the values of the T1 and T4 treatments. Whereas, total porosity values of the T1 and T4

Table 2
The results of ANOVA for some soil physical and hydraulic properties and wheat germination under four different tillage practices.

Parameters	Soil layer, cm	DF	SS	F
Bulk density, Mg m^{-3}	0–10	3	0.084	6.34*
	10–20	3	0.003	0.08
	20–30	3	0.045	9.67**
	0–30	3	0.005	0.46
Porosity, %	0–10	3	119.63	6.34*
	10–20	3	3.83	0.08
	20–30	3	64.60	9.67**
	0–30	3	6.60	0.46
Penetration resistance, MPa	0–10	3	8.76	77.70**
	10–20	3	13.64	7.66*
	20–30	3	18.79	5.55*
	0–30	3	9.05	9.43*
Field capacity, mm	0–10	3	12.02	0.59
	10–20	3	6.75	0.57
	20–30	3	23.40	21.14**
	0–30	3	25.40	0.45
Field water content (before tillage), mm	0–30	3	479.35	8.43**
	30–60	3	219.51	6.38**
	60–90	3	108.60	2.23
Field water content (after tillage), mm	0–30	3	242.74	6.50*
	30–60	3	170.38	3.96
	60–90	3	160.69	3.13
	Cumulative time, min			
Mean infiltration rate, cm h^{-1}	10	3	7239.12	7.80*
	30	3	6093.17	12.44**
	60	3	4688.20	13.68**
	120	3	3192.71	12.67**
Number of wheat seedlings, plant m^{-2}		3	9346.03	4.94*

* significant at the probabilty level of 0.05.
** significant at the probabilty level of 0.01.

Table 3
The bulk density, porosity, penetration resistance and field capacity values (mean ± SEM) in the soil layers of 0–10, 10–20, 20–30 and 0–30 cm under different tillage practices after tillage in 2012.

Parameters	Soil layer, cm	Treatments			
		T1	T2	T3	T4
Bulk density, Mg m^{-3}	0–10	1.32 ± 0.06ab	1.17 ± 0.01c	1.21 ± 0.04bc	1.38 ± 0.02a
	10–20	1.25 ± 0.06	1.25 ± 0.05	1.28 ± 0.05	1.27 ± 0.07
	20–30	1.18 ± 0.02c	1.29 ± 0.04ab	1.33 ± 0.02a	1.21 ± 0.02bc
	0–30	1.25 ± 0.04	1.24 ± 0.03	1.27 ± 0.03	1.29 ± 0.03
Porosity, %	0–10	50.17 ± 2.08bc	55.71 ± 0.52a	54.46 ± 1.40ab	47.91 ± 0.77c
	10–20	52.99 ± 2.32	52.91 ± 1.76	51.59 ± 1.79	52.24 ± 2.68
	20–30	55.60 ± 0.91a	51.39 ± 1.54bc	49.73 ± 0.63c	54.32 ± 0.73ab
	0–30	52.92 ± 1.47	53.34 ± 1.11	51.93 ± 1.26	51.49 ± 1.21
Penetration resistance, MPa	0–10	0.51 ± 0.10c	0.52 ± 0.06c	1.36 ± 0.09b	2.60 ± 0.14a
	10–20	1.39 ± 0.31b	3.99 ± 0.69a	3.73 ± 0.14a	3.79 ± 0.72a
	20–30	4.38 ± 0.47b	7.91 ± 0.09a	6.14 ± 0.05ab	6.38 ± 1.15ab
	0–30	2.09 ± 0.28b	4.14 ± 0.27a	3.74 ± 0.03a	4.26 ± 0.63a
Field capacity, mm	0–10	26.03 ± 1.21	24.59 ± 1.40	25.39 ± 0.79	27.32 ± 2.14
	10–20	24.94 ± 0.91	25.04 ± 1.99	24.03 ± 1.37	26.14 ± 0.82
	20–30	22.86 ± 0.76c	26.49 ± 1.32a	25.83 ± 1.01a	24.39 ± 1.15b
	0–30	73.83 ± 0.99	76.12 ± 4.71	75.25 ± 3.15	77.85 ± 3.31

Rows marked with the same letter do not differ significantly ($P \leq 0.05$).

treatments were higher than the values of the T2 and T3 treatments in the soil layer of 20–30 cm.

Bulk density and porosity are important indicators of soil structure. Lower bulk densities or higher porosity values are desirable. According to the results of this study, while lower bulk density and resulting higher porosity values were obtained at the reduced tillage-I (T2) and reduced tillage-II (T3) treatments in the top soil layer (0–10 cm), the conventional tillage (T1) and no-till (T4) treatments provided better bulk density and porosity values in the bottom soil layer (20–30 cm) compared to the others. Especially in the soil layer of 0–10 cm, the no-till (T4) treatment provided the worst bulk density and total porosity values. It is well-known that low bulk density is a result of soil tillage. Therefore, higher bulk density values should be expected under no-tillage. In considering the soil depth of 30 cm, the reduced tillage-I (T2) and conventional tillage (T1) treatments were the best because of soil depth exposed to tillage in these treatments was higher than others.

Our bulk density results obtained from the T4 treatment are similar to the results obtained by Abu-Hamdeh (2002), who determined that no-tillage provided the highest bulk density in the upper soil layer (0–10 cm), while the bulk density in the bottom soil layer (20–30 cm) was the lowest under no-tillage compared to chisel and moldboard plowing. We also determined that bulk density of the no-till and conventional tillage treatments in all soil layers were the same statistically. Similarly, Ferreras et al. (2000) found that there were no statistical differences between the soil bulk density values of no-tillage and conventional tillage treatments. However, many researchers have expressed that bulk density values under the no-tillage practice were higher than the conventional tillage (Aikins and Afuakwa, 2012; Çelik, 2011; Fernández-Ugalde et al., 2009; Lampurlanés and Cantero-Martínez, 2003; Osunbitan et al., 2005; Rashidi and Keshavarzpour, 2011; Romaneckas et al., 2009).

3.2. Penetration resistance

The soil penetration resistances after tillage practices applied for wheat production in 2012, which were plotted against soil depth for different tillage practices, are illustrated in Fig. 3. The results showed that the penetration resistance increased with soil depth at all tillage treatments. However, the relationships between penetration resistance and soil depth were the second degree polynomial. The lowest penetration resistance values were obtained under conventional tillage (T1).

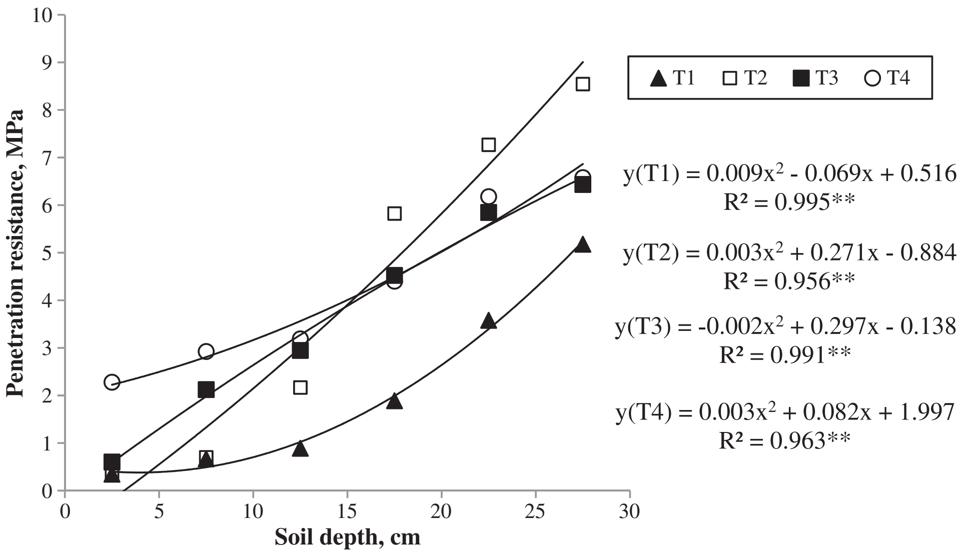

Fig. 3. Change of the penetration resistance with soil depth under different tillage practices.

While no-till (T4) provided the highest penetration resistance values from the surface to a soil depth of 15 cm, reduced tillage-I (T2) had higher values in the soil depth of 15–30 cm compared to the others. Higher penetration resistance values especially in top soil layers have been determined under no-tillage compared to the conventional or other tillage practices in studies conducted also by the several researchers (Chen et al., 2012; Fernández-Ugalde et al., 2009; Ferreras et al., 2000; Lampurlanés and Cantero-Martínez, 2003). Similarly, Çelik (2011) found that reduced and especially no-tillage treatments provided higher penetration resistance values according to conventional tillage. Also, Aikins and Afuakwa (2012) and Rashidi and Keshavarzpour (2011) indicated that soil penetration resistance was the highest in no-tillage conditions.

Tillage treatments significantly changed the soil penetration resistance in the soil layers of 0–10, 10–20 and 20–30 cm (Table 3). There were important differences among tillage treatments, especially in the soil layer of 0–10 cm. However, the differences among the T2, T3 and T4 treatments were statistically similar in the bottom soil layers. The penetration resistance value of the top soil (0–10 cm) was lower than that of the bottom soil (10–30 cm) in each tillage treatment. The T1 treatment provided statistically the lowest values in all soil layers. While the T2 treatment caused the highest penetration resistance values in soil layers of 10–20 and 20–30 cm, the T4 treatment had the highest penetration resistance value in the top soil layer (0–10 cm). Lower penetration resistance values in all soil layers under the T1 treatment could be associated with the increase in the intensity of soil loosening due to tillage. Already, Osunbitan et al. (2005), Ţopa et al. (2011) and Yavuzcan et al. (2002) also expressed that tillage creates loosening in the affected soil layer. At the same time, obtaining lower penetration resistance under the T1 treatment may be due to tillage by moldboard plow. Yavuzcan et al. (2002) concluded that tillage by moldboard plow decreased the soil strength due to greatest loosening.

Many studies reported that a relationship between penetration resistance and bulk density may be established (Dexter et al., 2007; Kılıç et al., 2004; Lampurlanés and Cantero-Martínez, 2003; Vaz et al., 2011; Whalley et al., 2007). From here, we also analyzed the relationship between the penetration resistance and bulk density for the different tillage practices using mean values in soil layers 0–10, 10–20 and 20–30 cm (Fig. 4). Significant linear relationships were obtained between the penetration resistance and bulk density in each tillage treatment. As similar with our results, some researchers also reported that there was a positive correlation between the bulk density and penetration resistance (Bengough et al., 2001; Turgut and Öztaş, 2012), whereas Chen et al. (2012) indicated that the correlation between soil penetration resistance and bulk density was not significant. Moreover, Vaz et al. (2011) reported that the relationship between penetration resistance and bulk density is not linear over a wide range of bulk densities.

In Fig. 4 it was also seen clearly that although penetration resistance increased with the increasing bulk density values in the T2 and T3 treatments, it decreased with the increasing bulk density values in the T1 and T4 treatments. This situation in the T1 and T4 treatments may be explained by the pore size distribution. Increase in porosity is an indicator of the bulk density decrease. However, while the increase in the macrospores causes soil loosening, increasing the ratio of the smaller pores in the total porosity may create a soil having more strength. Therefore, despite the decrease in bulk density the penetration resistance may increase. In terms of supporting our thesis, Şeker (1999) determined that the increase in amount of the pores lower than 0.2 micron size significantly increased the penetration resistance.

3.3. Field capacity

The field capacity values which were determined by applying a pressure of −0.033 MPa to saturated soil samples after tillage in 2012 are given in Table 3. The field capacity values were statistically similar in all tillage treatments in the soil layers of 0–10 and 10–20 cm. In these soil layers, the T4 treatment had the highest values as 27.32 mm and 26.14 mm, respectively. However, in the soil layer of 20–30 cm, while the T1 treatment provided the lowest field capacity (22.86 mm) the T2 and T3 treatments had statistically higher values. These results indicated that the no-till treatment had greater amounts of available water for plants considering the top soil depth of 30 cm. This could probably be explained with a higher amount of soil micropores in the no-till treatment. Because, Gonçalves et al. (2010) expressed that water retention at the field capacity is controlled by micropores. Similar results about high water retention under no-tilling were determined also by several researchers. Mallory et al. (2011) indicated that the no-tillage practice had a higher percentage of micropores available for water storage compared to the rotational tillage treatment. Fernández-Ugalde et al. (2009) found that field capacity in the no-tillage practice was significantly higher than conventional tillage at the three soil layers (0–5, 5–15, 15–30). Sekwakwa and Dikinya (2012) determined a higher field capacity value in non-tilled soils compared to the tilled soils. In addition, da Veiga et al. (2008) determined that the effect of different tillage practices on pore size distribution was more pronounced in larger and medium pore diameter classes.

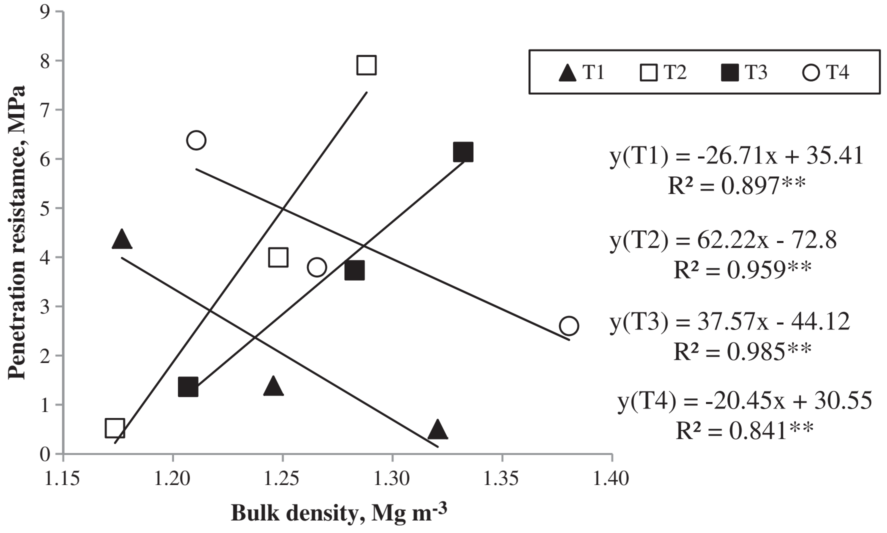

Fig. 4. The relationship of penetration resistance with bulk density under different tillage practices.

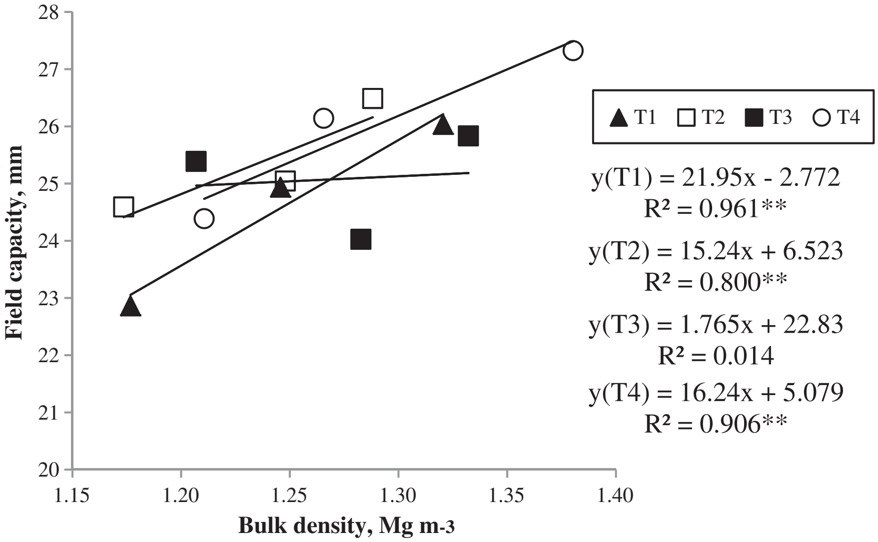

Fig. 5. The relationship of field capacity with bulk density under different tillage practices.

Soil properties such as bulk density, penetration resistance and water retention are directly affected by tillage practices. Therefore, we have also analyzed the relationships between the field capacity with bulk density and penetration resistance for all tillage treatments considering mean values in soil layers of 0–10, 10–20 and 20–30 cm. As shown in Figs. 5 and 6, the relationships between the field capacity with bulk density and penetration resistance for the T1, T2 and T4 treatments were significantly linear. However, significant linear relationships for the T3 treatment were not observed. This situation could be explained with a lower field capacity value in the soil layer of 10–20 cm compared to the soil layers of 0–10 and 20–30 cm. The cause of lower field capacity in the 10–20 cm depth may be reduction of micropores in this layer.

3.4. Field water content

Soil moisture is the source of water for plant use in non-irrigation conditions. Therefore storage of precipitation falling on the soil surface and reduction of evaporation losses from the soil are important for water conservation under dry crop production. Soil moisture values measured using a neutron probe in tilled plots by different tillage practices are given in Fig. 7 both before tillage (24th of September) and after approximately 3 weeks from tillage (16th of October). Although total precipitation in September was 72 mm, there was no precipitation between the 24th and 30th of September on the experimental area. Precipitation dates were the 1st (2 mm), 2nd (44 mm), 3rd (6 mm), 10th (8.5 mm), 11th (10 mm) and 14th (1.5 mm) of September. However, while the total precipitation for October was 45.5 mm, it was 33 mm between the 1st and 16th of October (DATAE, 2013). The number of rainy days during in this period was 7, while the highest precipitation was measured on the 8th of October as 8 mm. Field water contents in soil layers of 0–30 and 30–60 cm were the highest in the no-till treatment both before and after tillage. There were no significant differences among treatments in the soil depth of 60–90 cm. Considering the soil layer of 0–30 cm, while conventional tillage (T1) treatment before tillage had significantly lower moisture content compared to the T3 and T4 treatments, the T1, T2 and T3 treatments after tillage had statistically similar values. Before tillage, water contents of top soil depth of 30 cm at the T1, T2 and T3 treatments were 22.4, 12.8 and 7.4% lower than value of the no-till (T4) treatment, respectively. After tillage, these decreases were 21.1, 14.3 and 12.3% in the same order. Many researchers determined higher soil water contents under no-tillage. Lenssen et al. (2007) expressed that zero tillage provided better moisture conservation compared to conventional tillage. Ferreras et al. (2000) and Fernández-Ugalde et al. (2009) found that the water content was higher

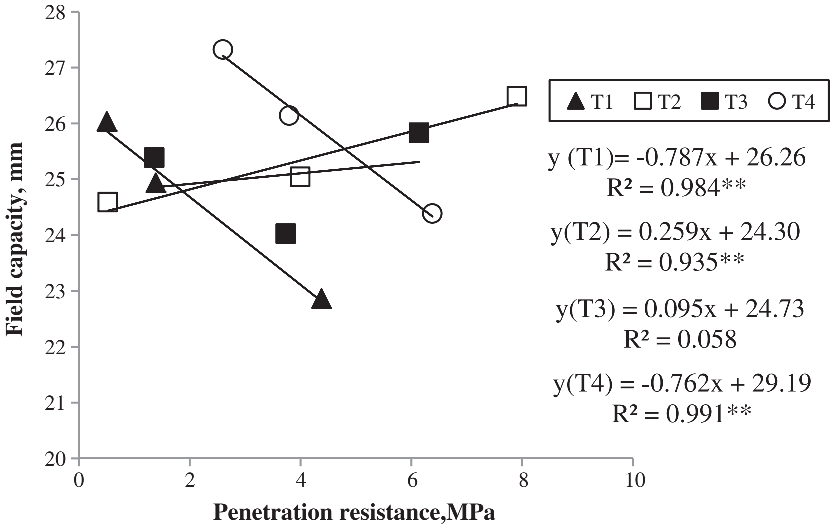

Fig. 6. The relationship of field capacity with penetration resistance under different tillage practices.

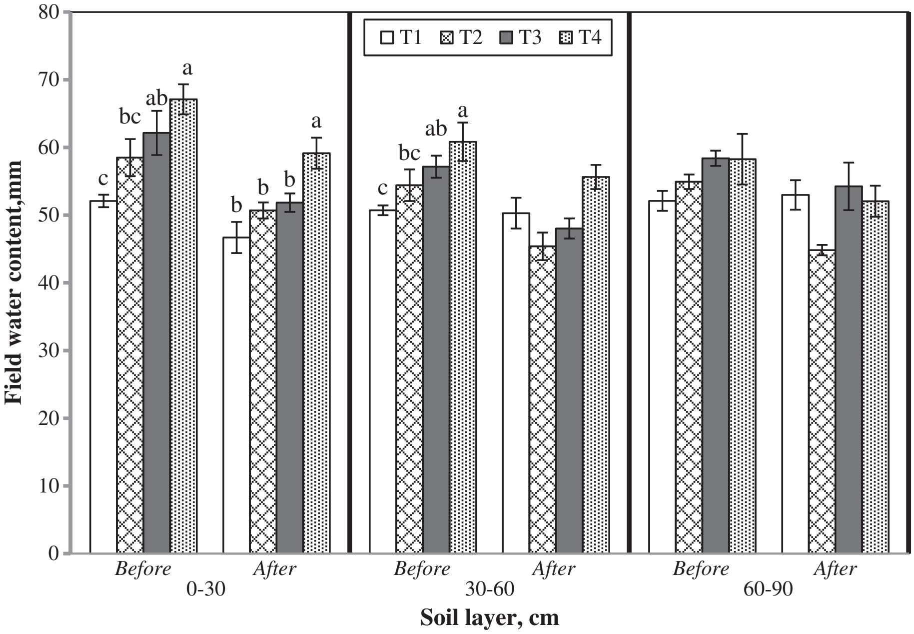

Fig. 7. The field water content values (mean ± SEM) before and after tillage treatments in the soil layers of 0–30, 30–60 and 60–90 cm. Columns marked with the same letter do not differ significantly ($P \leq 0.05$).

at with no-tillage than the conventional tillage treatment in the top soil depth of 30 cm. Also, Czyż and Dexter (2008) observed that the reduced tillage provided higher water content compared to the traditional tillage treatment.

Significant higher water content in 30 cm top soil layer under the T4 treatment could be explained with no-till treatment increased amount of micropores helping water retention against macropores. As shown in Table 3, obtaining the highest field capacity for the 30 cm soil depth under T4 treatment confirmed this fact. At the same time, the no-till practice could reduce the loss of soil moisture to the atmosphere through evaporation. Because several researchers expressed that no-till treatment provides more surface cover and so lower evaporation (Lampurlanés and Cantero-Martínez, 2006; Subbulakshmi et al., 2009).

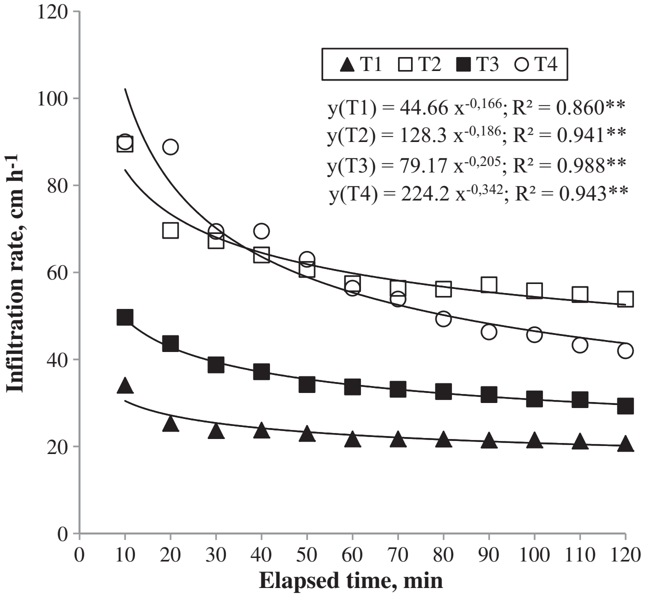

Fig. 8. The infiltration rate values under different tillage practices.

Furthermore, the T4 treatment had the highest penetration resistance compared to others in soil depth of 0–30 cm (Table 3). However, there were no significant differences among the T2, T3 and T4 treatments. Although plots under the T4 treatment were untilled, more water content in the T4 plots may provide similar penetration resistance values as the T2 and T3 treatments. In this context, previously many researchers signified that penetration resistance decreases with the increasing soil water content (Bengough et al., 2001; Kılıç et al., 2004; Turgut and Öztaş, 2012; Vaz et al., 2011).

3.5. Infiltration rate

Infiltration refers to water moving into soil from rainfall or irrigation and may be increased with favorable tillage practices. Therefore, efficiency of rainfall under dry crop production may increase, and loss of nutrients and soil by runoff may reduce. Fig. 8 shows the effect on soil infiltration rates of the different tillage practices throughout infiltration measuring time of 120 min with 10 minute intervals after tillage in 2012. Generally, all infiltration measurements reached a steady-state infiltration rate after approximately 120 min. The infiltration rates showed a decrease as a function of elapsed time was described by the Kostiakov equation. All equations had strong determination coefficients (R^2). In general, high infiltration rates in all plots were determined because sand content in the experimental soil was high (Table 1). Also, desiccation cracks or large gaps occurring with tillage practices and crop rotation may cause the increase in the infiltration rates.

The T2 and T4 treatments provided higher infiltration rates compared to the T1 and T3 treatments throughout the infiltration measuring time. The infiltration rate at the T1 treatment deep tilled was the lowest. Surface conditions have a major effect on infiltration rate. The presence of surface residues can be counteracted as a negative effect of no-tillage on infiltration (Lampurlanés and Cantero-Martínez, 2006). Therefore, changes in soil surface conditions such as surface crusting and compaction at the T1 and T3 treatments could decrease infiltration rates.

The mean infiltration rates on the 10th, 30th, 60th and 120th minutes in the different tillage practices were also calculated to evaluate a decreasing trend with time and the values are illustrated in Fig. 9. In all measuring times, T2 and T4 treatments had significantly higher mean infiltration rates compared to the T1 and T3 treatments. After

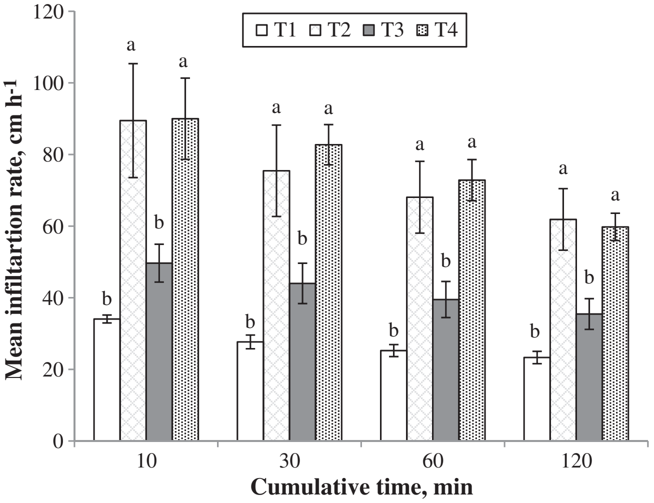

Fig. 9. The mean infiltration rate values (mean ± SEM) under different tillage practices. Columns marked with the same letter do not differ significantly (P ≤ 0.05).

10 min from water penetration, the cumulative infiltration at the T1 treatment was 5.68 cm (mean infiltration rate of 34.07 cm h^{-1}), it was lower than T2 and T4 by 61.9 and 62.1%, respectively. Similar results were also obtained for after 2 h from water entering. The cumulative infiltration at T1 was 46.64 cm (mean infiltration rate of 23.32 cm h^{-1}) and reductions according to the T2 and T4 treatments were 62.3% and 61.0%, respectively. Higher infiltration rates at T2 and T4 could be explained with strong surface aggregates and continuity of macropores along the soil depth. Subbulakshmi et al. (2009) reported that no-tillage increases the soil infiltration rate due to higher residue in surface soil, which causes fewer breakups of the aggregates during heavy rains. Also, no-tillage enhances the macropore connectivity between the soil surface and subsoil (Strudley et al., 2008; Subbulakshmi et al., 2009). In contrast, some researchers determined that the no-till practice caused lower infiltration rates (Abu-Hamdeh, 2002; Lipiec et al., 2006; Matula, 2003).

3.6. Germination of winter wheat

The seedlings of the winter wheat in the trial plots were counted between the 15th and 21st of October. As shown in Fig. 10, the T4 treatment provided the highest number of seedlings (511.6 pcs per square meter) compared to the T1, T2 and T3 treatments. The number of seedlings in the T1, T2 and T3 trial plots was 437.4, 453.1 and 458.5 pcs per square meter, respectively. While germination results of the T1, T2 and T3 treatments were statistically similar, they were statistically lower than the T4 treatment value.

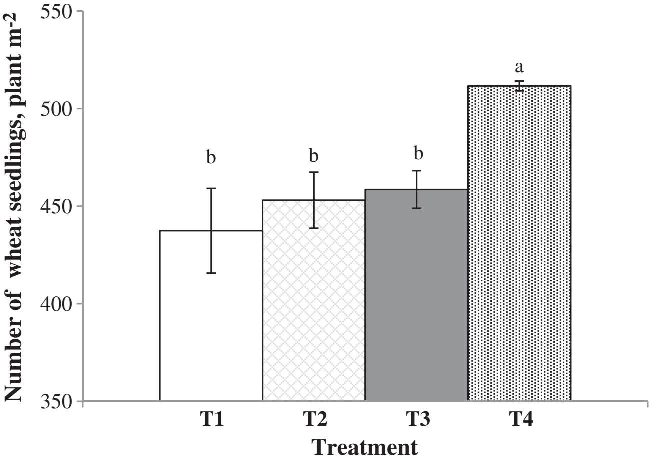

Fig. 10. The number of winter wheat seedlings (mean ± SEM) under different tillage practices. Columns marked with the same letter do not differ significantly (P ≤ 0.05).

The soil physical status changing with tillage affects the water, air, biological and thermal regimes of soil (Badalíkova, 2010). The top soil layer of 10 cm is important in terms of crop production because this layer controls many important agronomic and environmental processes, such as seed germination and early growth (Reynolds et al., 2007). Especially top soil bulk density is the most important factor to evaluate seedbed properties (Logsdon and Karlen, 2004). Higher bulk density increases the proportion of capillary pores supplying water to plants (Badalíkova, 2010). In our study we observed that a soil layer of 0–10 cm in the T4 plots had the highest bulk density (Table 3). Also, moisture content was the highest in the soil layer of 0–30 cm of the T4 plots (Fig. 7). For the period of germination and first development of the plants it is preferable that there is enough water in the soil. Therefore, it could be said that the better soil moisture conditions at the T4 treatment plots increased germination. According to the results of laboratory tests conducted by Wuest and Lutcher (2013), germination of winter wheat was rapid in soil at water potentials above − 1.1 MPa and slower at water potentials between − 1.1 MPa and − 1.6 MPa.

In addition, it is well known that temperature affects germination rates. Also, Tobeh and Jamaati-e-Somarin (2012) and Wuest and Lutcher (2013) found that temperature had an important effect on the germination of winter wheat. For germination of wheat seeds temperatures of 4 °C or higher are needed; rapid growth appears at temperatures between 12 and 25 °C (Acevedo et al., 2002). In our experimental region during the wheat sowing–germination period (26th September–21th October), the average temperatures for the air and at the soil depth of 5 cm were 11.5 and 13.8 °C, respectively (DATAE, 2013). In low temperature conditions during germination period, obtaining of higher seed germination for winter wheat under no-till could be explained that the no-till may be provide a higher soil temperature in the autumn compared to other tillage treatments. In this respect, He et al. (2010) determined that the soil temperature in a cold region increased significantly under no-tillage compared to conventional tillage. The increasing soil moisture content changes the thermal conductivity of soil because warming and cooling in wet soils is potentially slower than dry soils (Licht and Al-Kaisi, 2005). As shown in Fig. 7, the no-till had higher soil moisture during germination period compared to the other tillage practices. Similarly, Murray (2004) indicated that no-till due to conserved surface residue reduces soil moisture loss and also causes slowly cooling of air and soil temperatures near plants.

4. Conclusions

This study was conducted in soils affected by freeze–thaw processes, especially during the spring due to cool region conditions. However, high sand content in the soils could minimize the effects of this phenomenon on soil structure. Therefore, soil properties determined in this study could be explained with mechanical effects of tillage implements.

The soil's physical and hydraulic properties in the soil layers of 0–10, 10–20 and 20–30 cm were evaluated to demonstrate the effect of tillage practices. The no-till treatment increased both physical soil properties (bulk density, penetration resistance) and hydraulic soil properties (field capacity, field water content and infiltration rate). However, total porosity decreased in the plots treated with this practice. The conventional tillage treatment had lower bulk density, penetration resistance, field capacity, field water content and infiltration rate values compared to other treatments. While the conventional tillage improved the soil's physical properties, it had no positive effect on the soil's hydraulic properties. The reduced tillage-I and reduced tillage-II treatments provided better field capacity, field water content and infiltration rate values according to the conventional tillage treatment.

The aim of tillage practices is to create comfortable seedbed and growth conditions for crops. In semi-arid regions, the conservation of soil water content is of vital importance for seed germination. The no-till treatment could decrease evaporation due to higher surface residue. Therefore, water conserve in the no-till plots increased. Also, higher bulk density values of the top soil layer of 0–10 cm at the no-till practice could be decreased macropores, although increased micropores. Therefore, water conductivity increase from the soil to the seeds resulted in high germination. It could be said that the no-till practice is the most suitable practice in terms of better soil properties for crop production.

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