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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)