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Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield

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ABSTRACT

The area cultivated using conservation tillage has recently increased in central Spain. However, soil compaction and water retention with conservation tillage still remains a genuine concern for landowners in this region because of its potential effect on the crop growth and yield. The aim of this research is to determine the short-term influences of four tillage treatments on soil physical properties. In the experiment, bulk density, cone index, soil water potential, soil temperature and maize (*Zea mays* L.) productivity have been measured. A field experiment was established in spring of 2013 on a loamy soil. The experiment compared four tillage methods (zero tillage, ZT; reservoir tillage, RT; minimum tillage, MT; and conventional tillage, CT). Soil bulk density and soil cone index were measured during maize growing season and at harvesting time. Furthermore, the soil water potential was monitored by using a wireless sensors network with sensors at 20 and 40 cm depths. Also, soil temperatures were registered at depths of 5 and 12 cm. Results indicated that there were significant differences between soil bulk density and cone index of ZT method and those of RT, MT, and CT, during the growing season; although, this difference was not significant at the time of harvesting in some soil layers. Overall, in most soil layers, tillage practice affected bulk density and cone index in the order: ZT > RT > MT > CT. Regardless of the entire observation period, results exhibited that soils under ZT and RT treatments usually resulted in higher water potential and lower soil temperature than the other two treatments at both soil depths. In addition, clear differences in maize grain yield were observed between ZT and CT treatments, with a grain yield (up to 15.4%) increase with the CT treatment. On the other hand, no significant differences among (RT, MT, and CT) on maize yield were found. In conclusion, the impact of soil compaction increase and soil temperature decrease, produced by ZT treatment is a potential reason for maize yield reduction in this tillage method. We found that RT could be certainly a viable option for farmers in central Spain, particularly when switching to conservation tillage from conventional tillage. This technique showed a moderate and positive effect on soil physical properties and increased maize yields compared to ZT and MT, and provides an opportunity to stabilize maize yields compared to CT.

1. Introduction

Soil moisture is vital to plant growth and is a fundamental ecosystem resource for terrestrial vegetation, providing for plant transpiration. Irrigation management practices largely depend on accurate and timely characterization of spatial and temporal soil moisture dynamics in the root zone, especially in arid and semi-arid regions.

Adoption of in-situ soil moisture conservation systems such as conservation tillage is one of the strategies for upgrading agriculture management in these environments (Ngigi et al., 2006). Conservation tillage, which includes a variety of reduced and zero tillage techniques that leave at least 30% crop residue on the soil surface, has increasingly been adopted as the agricultural best management practice to reduce soil erosion. These tillage practices dramatically affect surface hydrologic properties, leading to increased infiltration and reduced runoff (Singh et al., 2009; Van Wie et al., 2013). Healthy plant growth and development require soil conditions that have adequate soil moisture and minimal root penetration resistance

The perceived effect of conservation tillage on soil compaction, soil moisture conditions, and soil temperature, has become a major concern among producers considering adopting this tillage system (Licht and Al-Kaisi, 2005). Soil compaction is normally evaluated by measuring soil bulk density and cone index. Soil bulk density and cone index are also used to predict the depth of soil hardpans (Afzalinia and Zabihi, 2014; Mehari et al., 2005). There are some contradictory results of research

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work conducted on the effect of conservation tillage on the soil bulk density and cone index. Results of some studies show that conservation tillage methods (reduced and zero tillage) increase the soil bulk density and cone index compared to the conventional tillage (Afzalinia and Zabihi, 2014; Taser and Metinoglu, 2005). There are also some research results showing no significant effect of conservation tillage on the soil bulk density and cone index (Afzalinia et al., 2011; Rasouli et al., 2012).

In conservation tillage, the presence of crop residues on soil surface decreases evaporation (Drury et al., 1999; Jalota et al., 2006), erosion (Rhoton et al., 2002) and soil temperature fluctuations (Alletto et al., 2011). Compared to conventional tillage, generally, soil warming under conservation tillage is slower (Alletto et al., 2011; Drury et al., 1999). On the other hand, water content in the topsoil is generally higher due to increased soil water holding capacity and decreased evaporation (Bescansa et al., 2006; Xu and Mermoud, 2001). Soil moisture and soil temperature conditions in the seedbed zone can promote or delay seed germination and plant emergence (Kaspar et al., 1990).

During the maize growing season, the effects of water stress occurring at specific stages of development, for instance, delaying in irrigation during early growth stages decreased plant dry weight (Jama and Ottman, 1993). In other cases, some authors reported that the greatest sensitivity of maize yield to water stress occurred during the period bracketing flowering (Cakir, 2004; Calvino et al., 2003). Conservation tillage was found to maintain higher soil moisture during the growing period of maize (Alletto et al., 2011; Tan et al., 2002).

Therefore, quantifying the effects of conservation tillage systems on soil moisture, soil temperature, and compaction can help to explain some of the differences in plant growth and development under different tillage systems (Licht and Al-Kaisi, 2005).

Soil water status can be obtained by determining soil water content or soil water matric potential.

Soil water matric potential is often measured using tensiometers that have a maximum range of −80 kPa limited by the vapor pressure of water which is significantly below the range where many drought tolerant plants grow and they require regular refilling and degassing after a dry period (Whalley et al., 2007; Young and Sisson, 2002). In contrast resistive soil moisture tensiometers like the Watermark® soil moisture sensors are responsive to soil potentials in excess of −200 kPa. We decided to use Watermark® sensors because of their low cost, ease-of-use, and because they are widely used by the agricultural community for scheduling irrigation. Some researchers have evaluated Watermark® sensors and found them to respond well to the wetting and drying cycles for most soil types (Allen, 2000; Eldredge et al., 1993; Shock et al., 1998, 1999; Thomson et al., 2002).

Watermark® sensors' measurement can be automated allowing them to be easily integrated into soil moisture data acquisition systems and wireless data transmission networks. These networks are composed of many autonomous, cooperating, battery-powered, small-sized motes. They can be connected through wireless links and a communication gateway with a capacity to forward data from the motes to a base station with high processing and storing capacities. This makes it possible to monitor the soil water potential with the purpose of providing accurate and up-to-date knowledge of the field. To our current knowledge, there are very few studies comparing different tillage techniques that provide daily data of soil water potential at different depths. Such studies are generally helpful in the understanding of soil water dynamics throughout the growing season.

Among the different modalities of conservation tillage, zero tillage is frequently preferred worldwide by many farmers because it saves fuel and labor costs. However, there can be some constraints which appear that zero tillage does not always produce equivalent crop yields in climates with sub-optimal soil temperatures, cold springs, and poorly drained soils (Lal, 2007; López-Garrido et al., 2014). These constraints are frequent in humid temperate regions, where wet soils and crop residues lead to difficulties in soil workability, soil compaction, cooler soil temperatures at seeding and adverse effects on plant growth and crop yield (Gajri et al., 2002).

The long-term effects of conservation tillage have been well documented; however less information is available regarding the short-term effects, particularly when switching to zero tillage from conventional tillage in such soil conditions; limit crop root development due to compaction and poor water infiltration is the major initial obstacles (Chen et al., 2005). The long-term benefit from conservation tillage cannot be achieved easily, unless producers see that the system works in a short term (Chen et al., 2005).

This is a very important topic from an agronomic point of view where the adoption of zero tillage has led to difficulties in soil workability, forcing farmers to switch to other systems (López-Garrido et al., 2014). In these cases it would be desirable that farmers initially opt for other modalities of conservation tillage that are different from zero tillage, such as reservoir tillage and minimum tillage. The reservoir tillage approach was developed to provide increased levels of surface storage and it offers good prospects for infiltrating and storing more water which is then available for plant uptake (Salem et al., 2014; Ventura et al., 2005). Minimum tillage practice also, conserves soil and water resources, reduces farm energy usage and increases crop production. This practice leads to positive changes in the physical and biological properties of a soil (Alvarez and Steinbach, 2009). There is limited documentation on the short-term effects of reservoir and minimum tillage practices compared to zero tillage and conventional tillage on soil conditions in central Spain. In this region farmers frequently only consider traditional tillage with soil inversion to avoid compaction and eliminate weeds. However, less aggressive tillage practices, such as reservoir tillage and minimum tillage, could solve the problem without losing the advantages of conservation agriculture.

We hypothesized that reservoir tillage and minimum tillage could be certainly viable options that can produce beneficial effects on soil physical properties and can provide an opportunity to stabilize or increase crop yields and save production costs when switching to conservation tillage from conventional tillage. Therefore, the objectives of this study were: (i) to compare the effects of four tillage practices on soil water content, soil temperature, soil compaction, yield, and some yield components of maize, and (ii) to determine soil water potential monitoring by wireless sensors network during the maize growing season affected by tillage practices.

2. Materials and methods

2.1. Experimental field and different tillage practices tested

The experiment was performed in spring of 2013 at the Experimental Fields of the School of Agricultural Engineers (ETSIA) belonging to the Polytechnic University of Madrid (UPM), located in (40.44695, −3.73924). Before the start of the experiment, the field was under continuous conventional tillage at a site previously cropped with rainfed barley. The experimental field used is characterized by a semi-arid continental climate. The average long-term annual precipitation for the previous 50 years was 445 mm and the average temperatures during the growing season of May, June, July, August, and September 2013 were 14.5, 21.1, 26.9, 26.1, and 21.8 °C, respectively. The soils are composed by sand, silt, and clay content of 45, 34, and 21%, respectively, the soil is a loam texture, classified as Vertic Luvisol (FAO, 1988) with a low inherent fertility, organic matter of 15 g kg^{-1}, and pH of 6.1.

The four tillage practices used in this study were:

(1) CT, conventional tillage; deep ploughing to a depth of 30 cm with the help of mouldboard followed by one pass with rototiller to a depth of 10 cm;
(2) MT, minimum tillage; chisel ploughing to a depth of 20 cm followed by one pass with rototiller to a depth of 10 cm;