8th International Conference on Water Resources and Arid Environments (ICWRAE 8): 743-752
22-24 January 2019*, Riyadh, Saudi Arabia*

Effect of Reservoir and Minimum Tillage Practices on Soil Physical Properties, Soil Water Tension Monitoring by Wireless Sensors Network

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Abstract: Rainfed agriculture in central Spain is mostly water limited and yields vary markedly from year to year depending on the amount and distribution of precipitation, which are both highly variable. Reservoir tillage can increase soil water content thus helping overcome most factors limiting crop production in this region. The aim of this study was to investigate the short-term effects of two tillage practices on some soil physical properties and water availability where rainfed barley was being grown. A field experiment was established on a loamy soil for comparing reservoir tillage, RT and, minimum tillage, MT. Soil bulk density, penetration resistance and volumetric water content during the entire crop growing season were measured in 5 cm increments to a depth of 30 cm. Furthermore, the soil water tension was monitored by using a wireless sensors network with sensors at 10, 20 and 30 cm depths. Yield and some yield components were determined at harvesting time. Results exhibited that no significant differences in bulk density were observed between RT and MT at all soil layers. Bulk density under RT was slightly lower than under MT in the shallow layers and the soil penetration resistance was consistent with bulk density data. Soil water tensions increased quite steadily and were consistently greatest in MT treatment and irrespective of the entire observation period RT treatment had lower water tension than MT at all soil depths. In addition, clear differences in crop yield and yield components were observed between the two tillage systems, grain yield (up to 14%) and biomass yield (up to 8.8%) were increased by RT treatment. In conclusion, reservoir tillage could be used as an alternative method for smallholder farmers in semi-arid regions to minimize risks from crop failure during the poorer rainy seasons and it showed a clear increasing in soil water retention and improving in barley yield.

Key words: Bulk density · Cone index · Precipitation use efficiency · Wireless sensors network

INTRODUCTION

In arid and semi-arid areas under rainfed agriculture water is the most limiting factor for crop production. Central Spain is a semi-arid region where rainfed crop yields are low because of limited precipitation and high evaporation [1]. The main limitation in increasing grain yields in rainfed farming systems is crop water stress caused by inefficient use of total available seasonal rainwater. Inefficient use of rainwater is often a consequence of low rainfall and uneven distribution throughout the season resulting in low root zone soil moisture and poor plant uptake of available soil moisture [2, 3]. To mitigate that stress it is essential to capture and retain the water from rainwater into the soil and to use it efficiently for optimum yield production.

In-situ rainwater harvesting and conservation tillage systems are increasingly being recognized as one of the strategies of upgrading rainfed agriculture, especially by smallholder farmers in semi-arid regions [4]. These systems involve the use of methods that conserve soil and water resources in the field and/or increase the amount of water stored in the soil profile by trapping or holding the rain where it falls [3]. However, the perceived effect of these systems on soil compaction, soil moisture conditions still a major concern among smallholder farmers considering adopting these systems [5]. Another concept related to in-situ rainwater harvesting and conservation tillage that involves different techniques is known as "Reservoir Tillage" Reservoir tillage is an alternative method defined by [6, 7, 8, 9], as a system in which numerous

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small surface depressions are formed to collect and hold water during rainfall or irrigation to prevent surface runoff.

This method of harvesting rainwater has the potential to benefit semi-arid environments [10], because the large infiltration surface area created by the depressions and the small depth of ponded water in the shallow depressions are likely to result in higher infiltration rates and therefore less surface runoff and evaporative loss [11, 9]. Much reservoir tillage research has been conducted with variations in equipment and terminology including basin tillage, micro-basin tillage, furrows diking, furrow blocking, soil pitting and tied-ridging [12, 13, 14, 15, 16, 17].

This approach was developed under the consideration that tillage can provide increased levels of surface storage and it may represent one of the most effective means of controlling both runoff and soil erosion. Furthermore, it offers good prospects for infiltrating and storing more rainwater which is then available for plant uptake during dry periods.

Minimum tillage practice also, conserves soil and water resources, reduces farm energy usage and stabilizes or increases crop production. This practice leads to positive changes in the physical, chemical and biological properties of a soil [18, 19, 20]. Knowledge is limited about the performance of reservoir tillage and minimum tillage practices and their effects on soil physical properties, soil water retention and crop yield.

Bulk density, porosity and penetration resistance, are some of the physical properties affected by any tillage systems. Changes in soil physical properties due to use of conservation tillage depend on several factors including differences in weather conditions, soil properties, history of management, intensity and type of tillage [21, 22]. Soil water tension and water content are also basic soil properties of great interest when studying the movement of water through the soil profile [23], also, when studying their availability to plants that are affected by tillage practices.

Soil water tension monitoring faces challenges of high field data monitoring costs and reliability of data acquisition systems in remote and extreme environments [24]. Resistive soil moisture tensiometers like the Watermark Soil Moisture Sensors require no field maintenance and are responsive to soil tensions in excess of -200 kPa. Other desirable properties of the Watermark sensor are its low cost, longevity and the minimal power required to sense its physical state. This low-power sensing makes them compatible with small solar powered wireless transceivers which can transport the data sampled every few minutes to where it is most useful in real-time.

In recent years, wireless sensor networks (WSNs) have emerged as a promising technology in the field of embedded systems. These networks are composed of many autonomous, cooperating, battery-powered, small-sized motes usually connected through wireless links and a communication gateway with capacity to forward data from the motes to a base station with high processing and storing capacities. This makes it possible to monitor a wide range of environments with the purpose of providing accurate and up-to-date knowledge from the field [25, 26].

To our current knowledge, there are very few studies comparing these tillage techniques that provide daily data of soil water tension at different depths. Such studies are generally helpful in the understanding of soil water dynamics throughout the growing season.

We hypothesized that reservoir tillage can minimize risks from crop failure during the poorer rainy seasons and can provide an opportunity to increase soil moisture content in soils that have lost in some degree of ability to sustain crop production, as a result of decreased physical quality. Therefore, the objectives of this study were: (i) to investigate the short-term influences of two tillage practices including minimum tillage and reservoir tillage on some soil physical properties, yield and some yield components of barley and (ii) to evaluate the impact of these tillage practices on soil moisture tension monitoring by wireless sensors network. Through this analysis, we wanted to quantify the sustainability of reservoir tillage for this semi-arid area, where water is the most limiting factor for crop production.

MATERIALS AND METHODS

Site Description and Experimental Design: A field experiment was carried out during winter season of 2012-2013 at the Experimental Fields of the School of Agricultural Engineers (ETSIA) belonging to the Polytechnic University of Madrid (UPM), which is located in (40.44695, -3.73924). The soil is a loam texture, classified as Vertic Luvisol [27] and in the 0–30 cm depth it contains 450 g kg^{-1} sand (2000–50 μm), 340 g kg^{-1} silt (50–2 μm) and 210 g kg^{-1} clay (<2 μm), organic matter 15 g kg^{-1} and a pH of 6.1. The site is 610 m above sea level with an average annual rainfall of 445 mm and an average minimum and maximum temperature of 9.8 and 19.5°C, respectively during a set of records from the 50-year time period between 1962 and 2011 (Table 1).

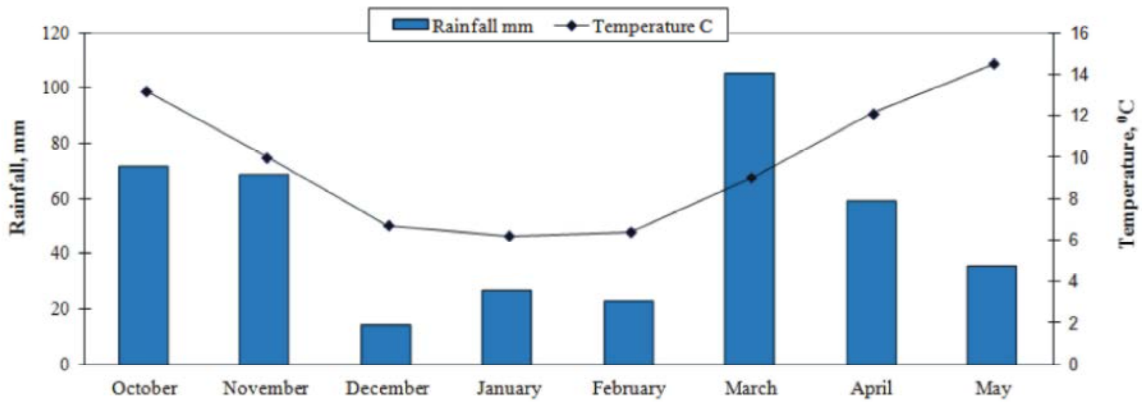

Fig. 1: Average monthly rainfall (mm) and temperature (°C) during the crop growing season

Table 1: Monthly average precipitation and air temperatures (1962-2011) at the study location.

		Temperature (°C)	
Month	Rainfall (mm)	Minimum	Maximum
January	40.9	2.8	9.7
February	41.9	3.6	11.7
March	30.6	5.7	15.3
April	47.5	7.5	17.9
May	46.2	11.1	21.9
June	25.4	15.4	27.3
July	12.0	18.5	31.4
August	9.2	18.3	30.7
September	27.1	15.1	26.0
October	56.6	10.6	19.2
November	57.9	5.9	13.1
December	49.8	3.3	9.8
Total or average	445.1	9.8	19.5

The total rainfall recorded during the crop growing season of the present study (October-May 2013) was 402 mm and the highest average rainfall occurred in March 2013 of 104.8 mm while the lowest average occurred in December of 14.4 mm (Fig. 1). These rainfall events, together with the magnitude of water uptake by crop roots, should have influenced soil water status in the growing season.

The two tillage treatments used in this study were (i) minimum tillage (MT) using a chisel plow to a depth of 20 cm, followed by one pass with rototiller to a depth of 10 cm. and (ii) reservoir tillage (RT), seedbed preparation identical to treatment (i) except that it was followed by the creation of mini-depressions or holes after planting using a hand-pushed tool with a truncated square pyramid shape to act as reservoirs tillage tool (Fig. 2), shows the hand-pushed tool and the depressions or reservoirs created on the soil surface.

The two treatments were established in a randomized block design. Three replicates per treatment were established (30 m × 5.5 m, 165 m^2 plots). The previous crop at the site was winter wheat.

Drilling was performed with a reversible tine opener conventional drill (trade mark: Gil- GT with 3.0 m working width), the sowing rate used in both treatments was 180 kg ha^{-1} for winter barley and the sowing date was 22 October 2012. Weed control was primarily made by herbicides (Glyphosate at 0.72 kg ha^{-1}) applied before sowing time. Fertilizer was broadcasted during the growing season and was applied at the same rate in both treatments, with average rate of 16-48-16 kg N-P-K per hectare.

Measurements

Soil Physical Properties: Soil bulk density of the 0–30 cm surface layer was progressively determined using the core method [28]. Intact soil cores (length 5 cm, diameter 5 cm) were collected from six depths in 5 cm increments to a depth of 30 cm. The core samples immediately weighed and then dried at 105 °C for 24 hours to a constant weight and reweighed. Volumetric water content was calculated as the product of bulk density and gravimetric water content. Soil porosity was calculated using the equation based on the relationship between the bulk density and particle density [29]. 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. Air-filled porosity was calculated as the difference between the porosity and the volumetric water content.

To characterize the degree of soil loosening between the two tillage systems, soil resistance to penetration (cone index) was measured down the soil profile to 30 cm, at intervals of 5 cm, using a soil assessment cone penetrometer (Model A2451).

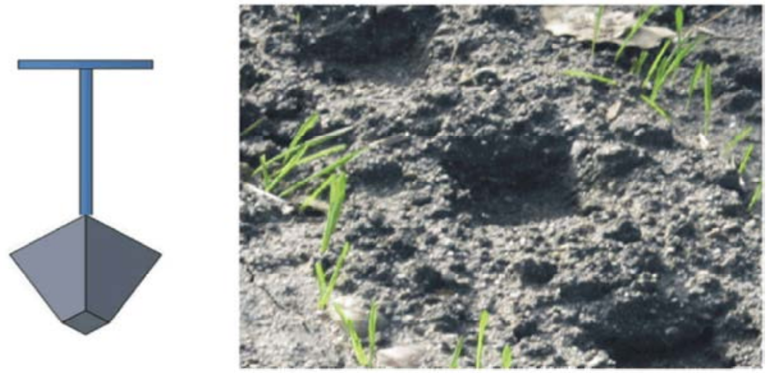

Fig. 2: The hand-pushed tool used in reservoir tillage treatment and the depression created by using it

Table 2: Physical properties of the soil measured at different layers before tillage operations. Mean ± standard deviation.

Soil depth (cm)	ρ_b	f	$\square_V$	CI
0-5	1.58 ±0.05	0.40 ±0.02	0.13 ±0.04	1.44 ±0.08
5-10	1.61 ±0.03	0.39 ±0.01	0.19 ±0.04	1.45 ±0.11
10-15	1.55 ±0.09	0.42 ±0.03	0.10 ±0.03	1.40 ±0.07
15-20	1.58 ±0.05	0.40 ±0.02	0.19 ±0.05	1.55 ±0.09
20-25	1.54 ±0.04	0.42 ±0.01	0.20 ±0.09	1.59 ±0.07
25-30	1.54 ±0.08	0.42 ±0.03	0.14 ±0.02	1.69 ±0.09

Bulk density ρ_b (g cm^{-3}); total porosity f (cm^3 cm^{-3}); volumetric moisture content $\square_V$ (cm^3 cm^{-3}) ; and cone index CI (MPa)

Soil samples and cone index were performed before tillage, during the growing season and at harvesting time and each was replicated three times in each plot. Table 2 shows some physical properties of the soil at different layers before tillage operations.

Monitoring of Soil Water Tension by Wireless Sensors Network: Soil water tension data was gathered during the growing season using a Crossbow ēKo ® Pro-Series wireless sensor network (WSN). Figure 3 shows the network consisting of a base station, two wireless nodes and each node transmitting data every 15 minutes to the base. The ēKo node integrates MEMSIC's IRIS processor/radio board and antenna that are powered by rechargeable batteries fed by a solar cell. The node is capable to cover an outdoor range up to 2 miles depending on the deployment environment. Each node was connected to three granular matrix electrical resistance sensors (Watermark®) installed in the ground. These soil moisture sensors were placed at 10, 20 and 30 cm depths in each tillage treatment.

Sensors were installed in the soil according to the manufacturer's recommendations: a deep hole was drilled into the root zone of the barley to be monitored, the sensors were placed and backfilled with a slurry of the soil extracted from the hole to minimize disturbance of the soil and roots. The purpose of these measurements was to monitor soil water tension under the two tillage treatments to help interpreting plant and soil responses to these treatments. Although readings from granular matrix sensors can be somewhat variable among individual sensors [30], these sensors are considered to be reliable for indicating relative soil wetness [31, 32].

The WSN which is capable of self-organizing and self-healing (mesh networking) requires minimum maintenance. Although the WSN uses low power radios transmitters, mesh networking technology enables transmission of data from one node to any other node in the network, without using high power radios. The mesh network allows greater flexibility in node placement since inability for two nodes to communicate (e.g. due to a physical obstruction) is handled by re-routing through any other possible alternative route within the network. Another advantage is that a failed node does not disable the network, as the other dependent nodes re-route through other available nodes (self-healing). Once the wireless sensor nodes are placed in the experiment area and the base station is activated, the sensor network is self-formed by allocating unique addresses to each node and defining the most efficient communication path to relay data from each node to the base station. The base station which processes the data also acts as a web server. Interested parties can access to the real time data by directing a standard web browser to the URL of the web server in the base station. The graphical user interface enables one to look at the real time and historical

Fig. 3: Scheme for the wireless sensors network components and the nodes deployment in the experimental site

data, download required data, backup application data and set alarms for pre-set variable values. Alarms send email alerts to notify the interested parties to warn about critical conditions.

Crop Yield Measurements: Yield and yield components of barley were determined from 1 m^2 middle area of each treatment with three replications by clipping the plants at the soil surface at the time of harvesting on 30 May 2013. The following parameters were measured: Plant height was determined by averaging the heights of 50 randomly selected plants per area from the soil surface to the highest point of the spike, spike length, grains per spike, 1000 grains weight, grain yield and the dry weight of the above-ground biomass. Grain was threshed from the straw, cleaned and weighed from three 1 m^2 areas of each treatment. Precipitation use efficiency (PUE) and PUEt was calculated by dividing dry weight of grain yield and total above-ground biomass by growing season precipitation (from October 2012 through May of 2013), respectively. Harvest index (HI) was computed by dividing the dry weight of grain yield by the above-ground biomass yield.

Statistical Analysis: For each measurement date, measured variables at selected depths, were statistically analyzed using a completely randomized bock design. Data were analyzed using ANOVA. Significant results are based on a probability level of $P = 0.05$. All statistical analyses were performed using SPSS 17.0 software.

RESULTS AND DISCUSSION

Bulk Density, Volumetric Moisture Content and Porosity: The effects of reservoir tillage (RT) and minimum tillage (MT) on soil physical characteristics were determined through measurements made (i) after seeding (6 November 2012), (ii) three months after seeding (10 February 2013) and (iii) at the time of harvesting (28 May 2013).

Bulk densities generally increased with depth and with time after tillage for both tillage treatments as the soil gradually get compacted under the influence of rainfall and particle resettlement. There were no significant differences between RT and MT in all soil layers (Table 3). After seeding, bulk density under RT was slightly greater than under MT in soil layers 0-5 and 5-10 cm, this was perhaps due to the effect of the hand-pushed tool used in the RT treatment to create depressions or mini reservoirs on the soil surface. In the shallow layers, on the other hand, the bulk density values under RT were slightly lower than the MT treatment.

The same effects were observed in the samplings made in February 2013. At the time of harvesting in May 2013, there were no significant differences between RT and MT.

In November 2012, the use of RT significantly increased the soil volumetric moisture content of the surface layers 0-5 and 5-10 cm and in shallow layer 20-25 cm. Furthermore, using RT caused significant increases in soil moisture content over MT at the 5-10, 10–15, 15-20 and 25–30 mm depths in the samplings made in February 2013, while no clear effect was found in May 2013, except in soil layers 20-25 and 25-30 cm. This is can be explained by the fact that using RT to make depressions or mini-reservoirs on the soil surface causes consolidation of depressions' internal surfaces in such a way that the water is held to percolate into the soil.

Table 4, presents the mean values of total porosity and air-filled porosity at different soil depths under RT and MT treatments. In the 10-15 and 25-30 cm depths, total porosities in RT were slightly higher than in MT treatment and no significant differences between treatments were found during the entire observation periods.

Table 3: Bulk density ρ_b (g cm^{-3}) and volumetric moisture content θ_V (cm^3 cm^{-3}) under reservoir tillage (RT) and minimum tillage (MT). Mean ± standard deviation

		6 November 2012		10 February 2013		28 May 2013	
Soil depth (cm)	Tillage treatment	ρ_b	θ_V	ρ_b	θ_V	ρ_b	θ_V
0-5	RT	1.35 ±0.12	0.32 ±0.05*	1.46 ±0.11	0.27 ±0.04	1.47 ±0.09	0.21 ±0.05
	MT	1.34 ±0.1	0.23 ±0.03	1.45 ±0.07	0.19 ±0.04	1.49 ±0.05	0.15 ±0.02
5-10	RT	1.38 ±0.06	0.35 ±0.06*	1.48 ±0.13	0.33 ±0.03*	1.58 ±0.05	0.24 ±0.06
	MT	1.36 ±0.04	0.20 ±0.04	1.49 ±0.05	0.19 ±0.04	1.63 ±0.02	0.19 ±0.04
10-15	RT	1.37 ±0.04	0.29 ±0.08	1.50 ±0.16	0.34 ±0.07*	1.48± 0.09	0.20 ±0.05
	MT	1.44 ±0.11	0.23 ±0.06	1.53 ±0.1	0.22 ±0.02	1.54 ±0.1	0.16 ±0.04
15-20	RT	1.45 ±0.05	0.28 ±0.12	1.56 ±0.03	0.31 ±0.04*	1.54 ±0.02	0.21 ±0.06
	MT	1.50 ±0.08	0.21 ±0.04	1.57 ±0.11	0.20 ±0.03	1.56 ±0.06	0.20 ±0.11
20-25	RT	1.47 ± 0.04	0.34 ±0.07*	1.61 ±0.1	0.33 ±0.08	1.62 ±0.08	0.27 ±0.06*
	MT	1.57 ±0.09	0.23 ±0.01	1.57 ±0.08	0.29 ±0.08	1.62 ±0.09	0.14 ±0.01
25-30	RT	1.43 ±0.09	0.28 ±0.05	1.55 ±0.09	0.39 ±0.04*	1.65 ±0.07	0.24 ±0.06*
	MT	1.56 ±0.09	0.23 ±0.02	1.59 ±0.04	0.25 ±0.06	1.66 ±0.05	0.11 ±0.03

Values in the same column followed by asterisk (*) are significantly different at P= 0.05 according to ANOVA.

Table 4: Total porosity f (cm^3 cm^{-3}) and air-filled porosity f_a (cm^3 cm^{-3}) under reservoir tillage (RT) and minimum tillage (MT). Mean ± standard deviation.

		6 November 2012		10 February 2013		28 May 2013	
Soil depth (cm)	Tillage treatment	f	f_a	f	f_a	f	f_a
0-5	RT	0.49 ±0.05	0.17 ±0.09	0.45 ±0.04	0.18 ±0.07	0.44 ±0.03	0.24 ±0.06
	MT	0.50 ±0.04	0.27 ±0.01	0.45 ±0.03	0.26 ±0.05	0.44 ±0.02	0.29 ±0.03
5-10	RT	0.48 ±0.03	0.13 ±0.05*	0.44 ±0.05	0.12 ±0.03*	0.40 ±0.02	0.16 ±0.07
	MT	0.49 ±0.01	0.28 ±0.06	0.44 ±0.02	0.24 ±0.03	0.38 ±0.01	0.19 ±0.04
10-15	RT	0.48 ±0.01	0.20 ±0.08	0.43 ±0.06	0.09 ± 0.01*	0.44 ±0.03	0.24 ±0.06
	MT	0.46 ±0.04	0.23 ±0.03	0.42 ±0.04	0.20 ±0.03	0.42 ±0.04	0.26 ±0.03
15-20	RT	0.45 ±0.02	0.17 ±0.11	0.41 ±0.01	0.10 ±0.03*	0.42 ±0.01	0.21 ±0.07
	MT	0.43 ±0.03	0.23 ±0.06	0.41 ±0.04	0.21 ±0.02	0.41 ±0.02	0.21 ±0.11
20-25	RT	0.44 ±0.02	0.11 ±0.06	0.39 ±0.04	0.06 ±0.05	0.39 ±0.03	0.12 ±0.09
	MT	0.41 ±0.03	0.18 ±0.03	0.41 ±0.03	0.12 ±0.09	0.39 ±0.03	0.25 ±0.04
25-30	RT	0.46 ±0.03	0.18 ±0.07	0.43 ±0.03	0.03 ±0.02*	0.38 ±0.03	0.14 ±0.08
	MT	0.41 ±0.03	0.18 ±0.05	0.40 ±0.02	0.15 ±0.06	0.37 ±0.02	0.26 ±0.05

Values in the same column followed by asterisk (*) are significantly different at P= 0.05 according to ANOVA.

At all soil depths, the values of RT and MT exhibited the lowest and highest air-filled porosity and significant differences between treatments were found in the measurements taken in February 2013 at 5-10, 10-15, 15-20 and 25-30 cm soil layers. Also, the same effect was only observed at soil layer 5-10 cm in November 2012. Otherwise, there were no significant differences between treatments regarding air-filled porosity.

Penetration Resistance: Soil penetration resistance as measured by cone index at the same time of measuring bulk density and soil moisture content, because those factors significantly affect penetration resistance [33, 34]. Cone index at different depths in response to tillage is shown in Fig. 4 (a, b and c). Generally, the soil cone index was increased with time after tillage. In November 2012, cone index was significantly greater under MT than RT for only 25-30 cm depth. No differences were observed for the upper layers. Cone index under RT was a slighter higher than under MT in soil layer 0-5 cm, followed the same pattern as bulk density in this layer. In February 2013, cone index was significantly greater in the MT than the RT treatment only in the 15-20 cm depth. Below and upper 15-20 cm no significant differences were found between treatments. In May 2013, they were no statistically significant at all of the soil depths between RT and MT on cone index. In conclusion, cone index under RT showed a uniform distribution in depth; however under MT it increased considerably between 20 and 25 cm.

Soil Water Tension: Figure 5 (a) and (b) presents daily mean soil water tension (in absolute values) in February and March 2013 under RT and MT in different soil layers. In February 2013, under RT treatment, soil water tension for all soil layers increased during the entire observation

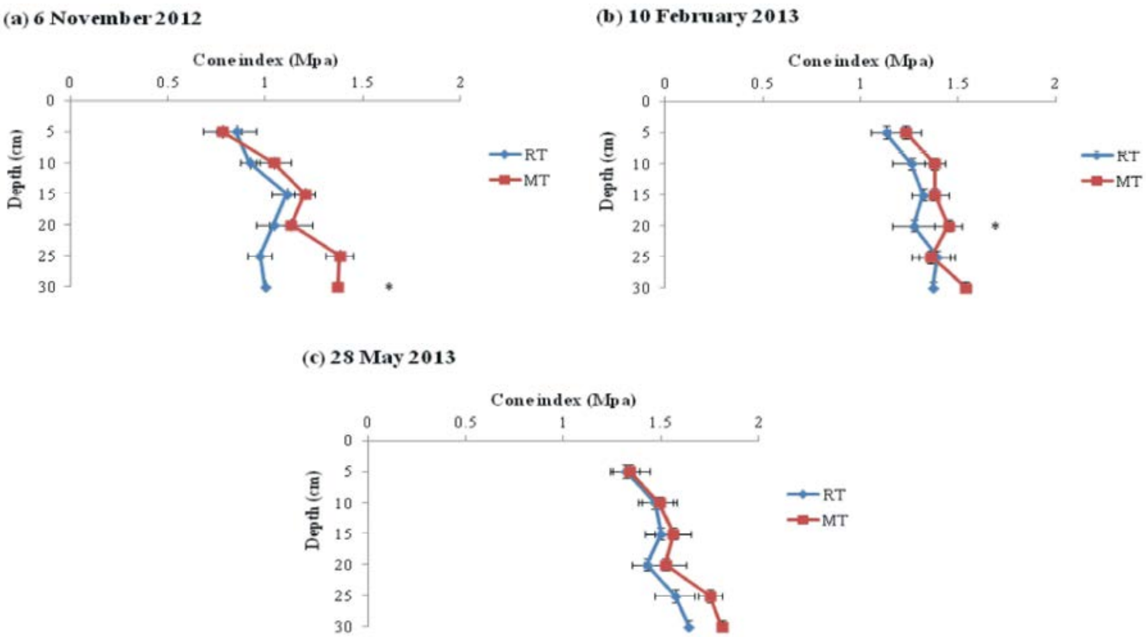

Fig. 4 (a, b and c): Effects of tillage on cone index during the growing season in November 2012 (a), February 2013 (b), May 2013 (c), RT: reservoir tillage; and MT: minimum tillage. Values followed by asterisk (*) are significantly different at P = 0.05 according to ANOVA. Error bars show standard deviation.

period and the plots exhibited the lowest soil water tensions at the beginning of this month in response to rainfall events and after 5 February, the soil water tension increased rapidly at 10 and 20 cm depths and the increasing was less pronounced at 30 cm depth. On the other hand, under MT treatment, at 10 cm depth the plot exhibited the greatest soil water tensions and increased rapidly and closely paralleled the trend of 20 cm depth. Furthermore, at 30 cm depth, soil water tension increased more rapidly than in RT treatment.

At the beginning of March 2013, the plots at all soil depths in both RT and MT were considerably dry. After 5 March 2013, soil water tension dropped dramatically in response to rainfall events.

Figure 6 (a, b and c) presents weekly mean soil water tension (in absolute values) during the entire observation period under RT and MT treatments at 10, 20 and 30 cm depths. at all soil depths, the plots of RT and MT exhibited the lowest and highest soil water tensions, respectively, during most of the period except for weeks (14, 21 and 28 March) the soil water tensions in RT were similar or slightly lower than in MT treatment.

In conclusion, soil water tensions in both treatments at all soil depths dipped significantly after most rainfall events in both months. During the whole period, soil water tensions increased quite steadily and were consistently greatest in MT treatment and irrespective of the entire observation period RT treatment had lower water tension than MT at all soil depths. This can be explained by the fact that the large infiltration surface area created by the depressions to collect and hold water during rainfall could conserve soil water by increasing infiltration. The difference in soil water tension between RT and MT treatments could also be related to the difference of plant water uptake.

Tillage Effects on Barley Grain Yield and Some Yield Components: Barley grain yields and yield components were significantly affected by tillage. The average grain yield for RT was significantly greater than MT. In other words, RT increased grain yield and biomass yield by 14 and 8.8% more than MT, respectively. The average values of plant height, spike length and grains per spike were 9.8, 20.6 and 9.2% greater respectively, under the RT than under the MT and, as a direct response of yields and yield components, PUE and PUE_t also significantly increased under the RT, while, no significant differences were observed in grain weight and harvest index between RT and MT (Table 5). The results were directly related to the improvement of the water availability and soil water retention characteristics under RT compared to MT. the higher soil moisture content under RT allowed the crop to

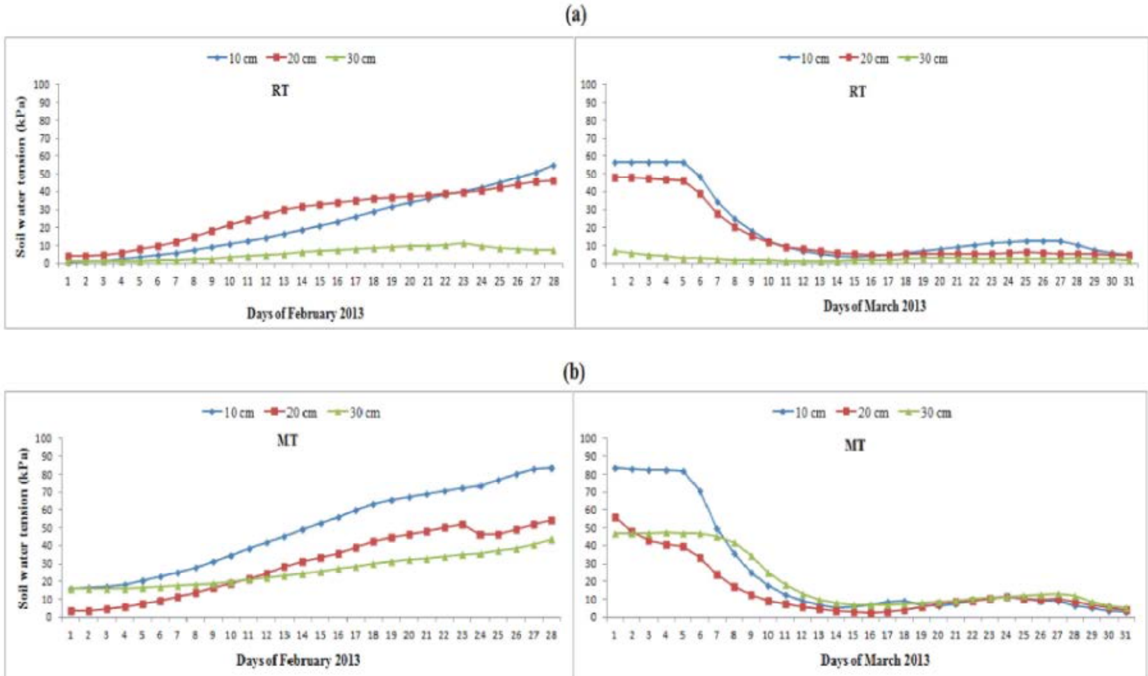

Fig. 5 (a and b): Daily soil water tension during February and March 2013 at different soil depths under RT: reservoir tillage (a) and MT: minimum tillage (b).

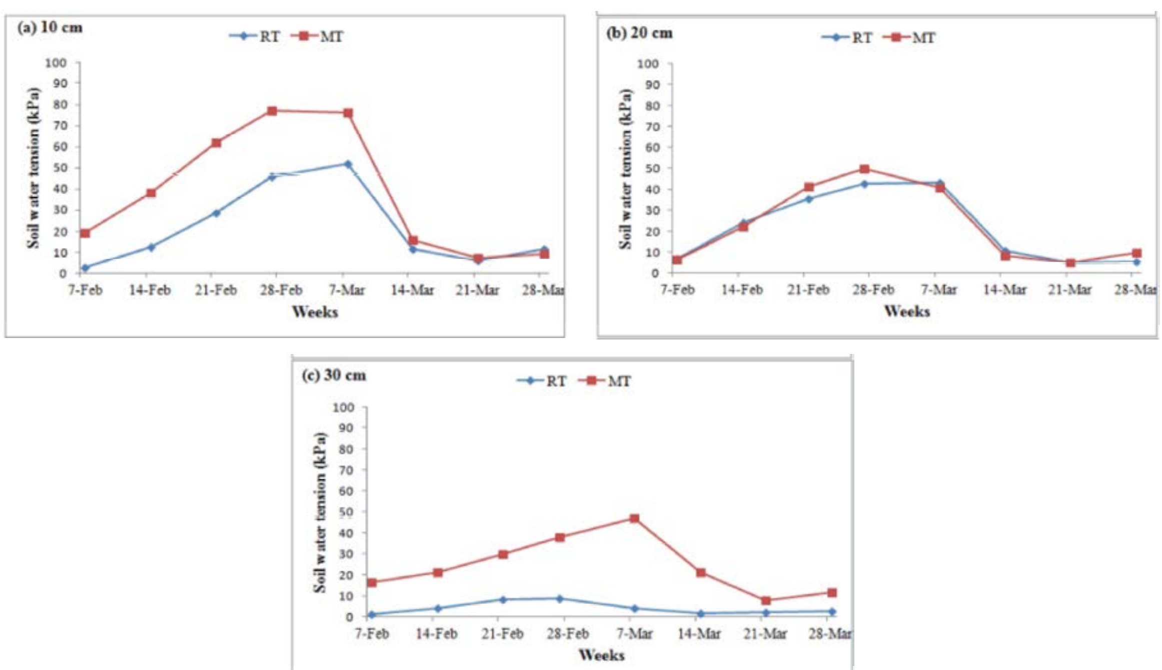

Fig. 6 (a, b and c): Weekly soil water tension under RT: reservoir tillage and MT: minimum tillage at soil depth 10 cm (a), 20 cm (b) and 30 cm (c)

grow during the drought period and increased the potential for a greater yield. The higher efficiency in retaining water in the s oil under RT also implied greater water uptake by the crop, resulting in a greater barley biomass yield in RT than MT at the time of harvesting.

Table 5: Yield components, grain yield, biomass yield, precipitation use efficiency (PUE), above-ground biomass per unit of precipitation received (PUE_t) and harvest index (HI) under tillage systems (RT : reservoir tillage; MT: minimum tillage). Mean ± standard deviation

Tillage system	Plant height (cm)	Spike length (cm)	Grains per spike	1000 grains weight (g)	Grain yield (t ha^{-1})	Biomass yield (t ha^{-1})	PUE (kg ha^{-1} mm^{-1})	PUE_t (kg ha^{-1} mm^{-1})	HI
RT	71.4 ±7.1*	8.2 ±0.9*	22.6 ±2.6*	27.7 ±3.7	3.59 ±0.1*	8.57 ±0.3*	8.9 ±0.1*	21.3 ±0.9*	0.42 ±0.01
MT	65.0 ±6.8	6.8 ±1.2	20.7 ±3.9	26.1 ±4.0	3.15 ±0.1	7.88 ±0.2	7.8 ±0.5	19.6 ±0.6	0.40 ±0.04

Values in the same column followed by asterisk (*) are significantly different at P = 0.05 according to ANOVA

CONCLUSIONS

Based on the results of this research, we draw the following conclusions:

- Using the reservoir tillage tool to perform depressions on the soil surface, the holes' internal surfaces are consolidated in such a way that the water is held to percolate into the soil and thus increasing the soil water retention. The results of the experiment showed that reservoir tillage offers higher soil moisture content and higher yield of barley than minimum tillage. Our analysis shows that reservoir tillage is certainly a viable option for smallholder farmers under rainfed conditions in semi-arid regions. Nevertheless, continued research is needed to determine the longer terms effects of these tillage practices on soil properties and crop yield.
- The methodology implemented for the evaluation of the soil water tension using the wireless sensors network in this study was suitable, adequate and comprehensive and can be considered as a helpful tool for the evaluation of any management of plant establishment in semi-arid regions.

ACKNOWLEDGMENTS

This study was supported and funded by the Rural Engineering Department, Polytechnic University of Madrid and partially with the European research project "RHEA", FP7, NMP-CP-IP 245986-2. The authors would like to thank Prof. Constantino Valero and Mr. Román Zurita Calvo for their efforts as well as material support.

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