

Impact of Different Soil-Management Systems on Soil Water Dynamics During Rainy and Drought Seasons

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Abstract: A continuous monitoring of spatial and temporal variability of soil-water content was studied under two soil-management systems: direct drilling (DD) and conventional tillage (CT), during four consecutive seasons (2003/2004, 2004/2005, 2005/2006, and 2006/2007). The soil-water content was read at different soil depths using multi-sensor capacitance probes in each soil-management treatment. During the first season (2003-2004) rainfall of 580 mm and accumulated evapotranspiration (ET_0) of 1,620 mm were registered. Soil-water content dynamics for both treatments were similar during the rainy season, although the plot under DD was able to retain more water in the soil profile, and during the maximum evapotranspirative period a faster soil-water depletion took place in the CT plot. The 2004/2005 season registered a high evapotranspiration rate with low rainfall, promoting a low soil-water recharge for both treatments. The 2005/2006 season registered an ET_0 of nearly 1,581 and 434 mm of rainfall. This increase in rainfall water led to a greater recovery of the soil-water reserve in the DD than in the CC plot. Finally, during for 2006/2007 with ET_0 and rainfall of 1,504 and 560 mm, respectively, DD again retained more soil-water content, mainly in the deeper zones, with progressive soil-water depletion during the maximum evapotranspirative period in comparison to CT. Thus, the DD was demonstrated to be a promising soil-management technique for improving the soil-water content and availability for plants in rain-fed agriculture.

Key words: Soil-water dynamic, calibration FDR probes, direct drilling, conventional tillage, vertisols

INTRODUCTION

In rain-fed agriculture in SW Spain, water availability is the major limiting factor, where weather is characterized by irregular rainfall patterns, and high evapotranspiration rates. These conditions are unfavourable for maintaining suitable water availability during the maximum evaporative period, especially when rainfall constitutes the main input (Perea et al., 2006). In this context, Hatfield et al. (2001) pointed out that the alteration of natural soil conditions affects evapotranspiration processes by changing the water availability in soil profile, or the exchange rate between the soil and the atmosphere. The greatest loss of soil water under Mediterranean conditions occurs through direct evaporation from the soil surface to the atmosphere, while drainage is generally negligible (López et al., 2007). Water

availability for the crops in the rain-fed systems determines survival and production, mainly in the case of a spring-summer crops where the soil capacity for retaining the greatest amount of water is essential. Consequently, the introduction of conservation-agriculture techniques in rain-fed farming areas under these adverse weather conditions improves physical and chemical soil properties, especially those related to maintaining the soil-water content for crop availability (Ordóñez et al., 2007). From a hydrological standpoint, water productivity depends on the ratio of the water volume used productively from an area, to the volume of water potentially available for that purpose. In this sense, all practices that enhance this factor in rain-fed agriculture can be considered essential (Ali and Talukder, 2008).

The aim of the present study was to study the response of soil-water content to direct drilling and conventional tillage in a clayey soil, for four years in the typical rotation of wheat-sunflower-field pea, and under different annual climatic conditions in SW Spain.

MATERIALS and METHODS

Experimental site

The study was carried out in the "Tomejil" experimental farm (37° 24' N, 5° 35' W) in Seville, south-western Spain. The soil, which formed on Miocene marls, is classified as a Chromic Haploxerert (Soil Survey Staff, 1999), with 69.4 g/kg of sand, 355.3 g/kg of silt and 575.3 g/kg of clay and a bulk density ranging of 1.31 g/cm³. The organic-matter content was below to 1.5 g/kg, with 0.07 g/kg of N, 0.01 mg/kg P, and 0.93 mg/kg of K. Field capacity at 0.033 and permanent wilting point at 1.5 MPa were 39.0 and 24.0 m³/m³, respectively.

The Ap culturing horizon had approximately 25 cm of depth, and the underlying Bw horizon reached as much as 65 cm. These soils had a high water-retention capacity due to high porosity and limited pore size.

The climate of the study area is typically semi-arid Mediterranean, with an annual rainfall of 495 mm and a potential evapotranspiration of 1,600 mm, with a large inter and intra-annual variability, and average winter and summer temperatures of 10° and 35° C, respectively.

Experimental design and field measurements

This trial commenced in 1982 in an area that has been continuously cropped since establishment. Specifically, the field experiment was conducted in order to study the long-term impact on soil physical and chemical soil properties exerted by different tillage systems: direct drilling (DD) and conventional tillage (CT). In DD plots, the crop debris is left on the field until it decays, and an adapted drilling machine is required. CT management consists of one pass of a mould-board plough pass and successive passes of a cultivator. The size of treatment plots was 15 m x 180 m and with four replicates, in a randomized complete-block design. The established crop system was

rotation of wheat (*Triticum durum* Desf.), sunflower (*Helianthus annuus* L.) and field pea (*Pisum sativum* L.). In each plot under CT and DD, two separate devices for measuring soil-water content were used, and each device had five multi-sensor capacitance probes (MCP) (EnviroSCAN, Sentek PTY Ltd., Kent Town, Australia) installed at 10, 20, 30, 60, and 90 cm in soil depth. The EnviroSCAN probe allows continuous and precise monitoring of soil-water content at intervals of 10 cm in depth within and below the active root system, providing critical information for monitoring soil moisture.

Finally, the potential evapotranspiration was calculated using the Penman equation (Allen et al., 1998), and climate data were recorded using an automatic weather station located in the experimental plot.

RESULTS and DISCUSSION

Table 1 shows the accumulated ET₀ and rainfall during the four-year monitoring period. The 2003/2004 and 2006/2007 corresponded to low-deficit seasons, while the 2004/2005 could be considered a season with a high water deficit. With respect to 2005/2006, water-deficit values remained within the average for a typical season in the study area.

During the first study season a potential water deficit of -1,040 mm was registered, implying an important water deficit for crops.

Table 1. General weather conditions during the monitoring period

	Season			
	2003/2004	2004/2005	2005/2006	2006/2007
ET ₀ (mm)	1,620	1,741	1,581	1,504
Rainfall (mm)	580	228	434	560
Balance (mm)	-1,040	-1,513	-1,147	-944

Figure 1 shows that the soil-water content at 30 cm of soil depth was higher in the DD than in the CT plot during the season 2003/2004.

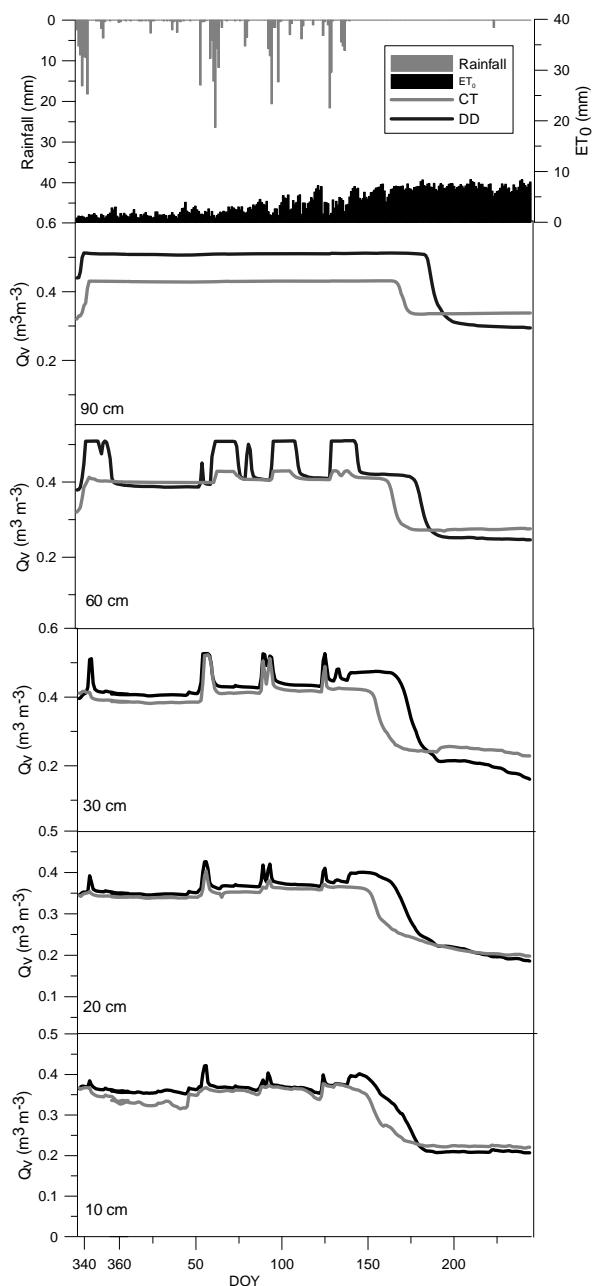


Figure 1. Temporal evolution of soil-water content at 10, 20, 30, 60, and 90 cm soil depth during 2003/2004 season. DOY, day of the year

These differences were particularly important in the first 10 cm of soil depth, diminishing gradually at greater depths. The strongest effect took place during the discharge period (low rainfall and high ET_0), the water-depletion process from soil profile in DD plot being lower than in the CT treatment, as shown in Figure 1. Therefore, the soil under the DD treatment was able to provide more available water to the crop

during the critical periods of ET_0 . According to Muriel et al. (2005) the agriculture conservation techniques allowed greater soil-water retention at 30 cm of soil depth, promoting a slower discharge rate from soil profile under DD. Similarly, Jiménez et al. (2005) reported that the crop was able to extract more water from the soil under DD than CT, especially during the high water-demand period.

For the deeper soil profile, at 90 cm of soil depth, none of the treatments showed major changes in soil-water content during the wet period, although discharge during the dry period was significantly higher in the DD plot, which showed the greater soil-water retention at greater depths. On the other hand, at 60 cm of soil depth, the largest increase in soil-water content was recorded in the DD treatment during the wet period, coinciding with the heaviest rainfalls, whereas in the CT plot these effects were almost negligible. This is presumably due to a more uniform soil structure throughout the profile without compaction areas. On average, during this period, the soil-water balance was considerably higher for the DD plot, being especially significant in the deepest zone of the profile that provided available water to the plant from stored water.

During the 2004/2005 season, the total rainfall was very low (228 mm) with ET_0 (1,741 mm) significantly higher than during the previous season (Table 1). These severe conditions did not allow a full recharge of the soil profile (Fig. 2), keeping the soil-water content at about 40% below values recorded in the period of 2003/2004. This is a typical situation under Mediterranean climate in which water remained steady at 10-20 cm of soil depth under DD treatment, whereas in the CT plot the water tended to accumulate in deeper zones (30 cm soil depth), hindering its availability for the crop. Water shortage was similar in both treatments, unlike what occurred in deeper zones. The rainfall scarcity during this season did not promote significant changes in the soil-water content in deeper zones (60-90 cm), even during the discharge period (Fig. 2), because the existing moisture in deep zones was near the wilting point and thus not available for the crop.

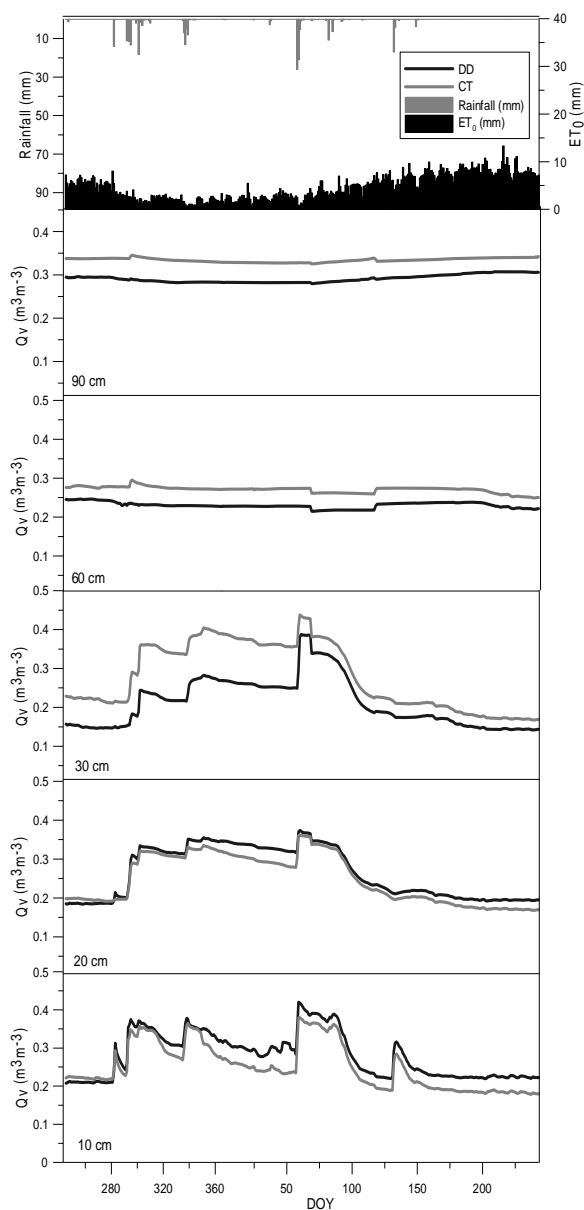


Figure 2. Temporal evolution of soil-water content at 10, 20, 30, 60, and 90 cm soil depth during 2004/2005 season. DOY, day of the year.

During 2005/2006 season, accumulated rainfall and ET_0 were about 434 and 1,581 mm, respectively (Table 1). This increase in rainfall combined with a significant drop in ET_0 with respect to the previous season, allowed a partial recovery of soil-water content. This effect was especially pronounced at 30 cm of soil depth, this effect being very noticeable under the DD treatment (Fig. 3). As was the case in 2003/2004 season during the discharge period, at 30 cm deep, the soil-water depletion under CT was more rapid than in DD treatment. In addition, soil-water

absorption in DD was higher than in the CT plot, and therefore it was able to make more water available to the crop during the period of greatest ET_0 (Fig. 3).

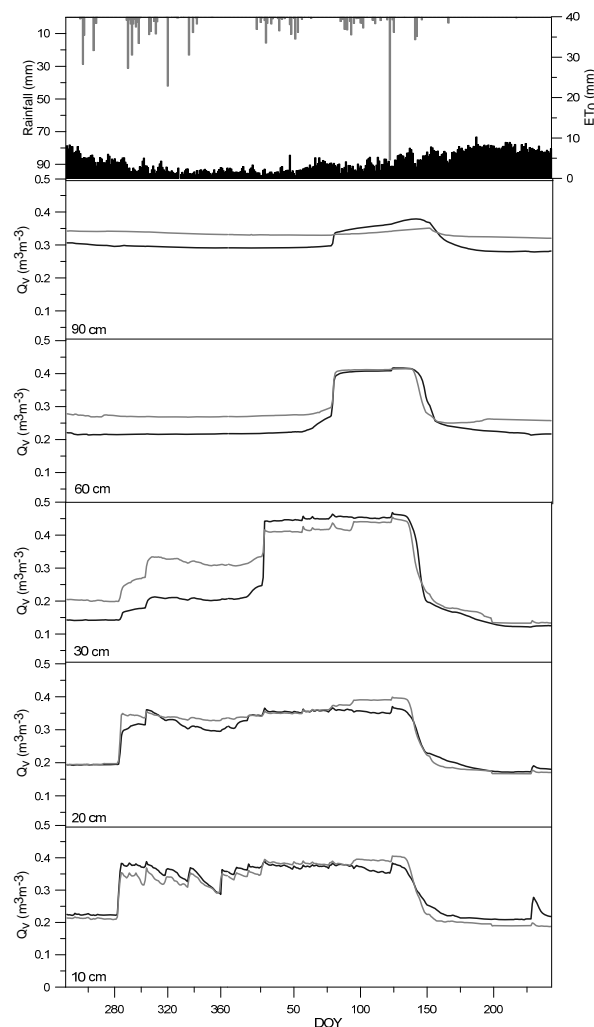


Figure 3. Time course of soil-water content at 10, 20, 30, 60, and 90 cm soil depth during the 2005/2006 season. DOY, day of the year

In addition, the rainfall enabled a recovery of the soil-water content in the deepest zones of the profile, especially in the DD plot, where, as in CT plot, the rainfall effects were less pronounced, especially at 90 cm deep. García-Tejero et al. (2007) reported a hard layer (often called plough pan) at 50 cm of soil depth, in an experimental work conducted in the plots similar to those used in the present work. This situation could promote a break in the continuity of the natural soil structure, impeding the infiltration processes and the water storage while encouraging erosion and runoff processes. Also, this situation would hamper

the capillary movement of soil water, and hence would impede the provision of the soil water stored in deeper zones. The rainfall distribution throughout this season indicated that the autumn rainfalls intercepted by the soil were stored at the soil surface (~5 cm). Consequently, when the soil profile is charged on the surface, the winter and spring rainfalls tended to be stored in deeper zones, this recharge being more significant in the DD treatment. Arshad et al. (1990) and Moreno et al. (2005) found that DD improved the soil-water status of the profile in dry seasons, promoting a significant soil recharge. Similar results were reported by Ordóñez et al. (2007) in this experimental area, these authors reporting improvements in soil-water availability of the DD in comparison to the CT treatment.

Finally, during 2006/2007 (Fig. 4) in the first 10 cm of soil depth the soil-water content was higher in the DD plot, although at 20 and 30 cm of soil depth the results of both treatments were very similar.

Notably, the largest discharge occurred in the DD plot during the maximum evapotranspirative demand period, indicating again that with this soil-management system more soil water was available for the crop (Fig. 4). The differences in soil-water content between treatments were not excessively large at shallow depths, in contrast with those found at 60-90 cm soil depth. Therefore, under DD, more than 30% of the water was recharged in comparison to the CT treatment, reaching higher values during the rainy period and increasing discharge during the dry period. Thus, according to the results of the present study, the DD treatment encouraged better physical soil conditions, improving the capability for recharge of the soil-water content for the crop in critical periods (Fig. 4).

CONCLUSIONS

Considering these results, we conclude that the direct-drilling technique provided a more favourable soil environment for crop establishment than did conventional tillage. Evidence suggests the benefits of direct drilling in conserving and providing soil water for crops during critical periods of high water demand especially during dry years. Continuous soil tillage promoted major changes in soil structure and in the water-retention characteristics, hindering preservation of natural soil pore space.

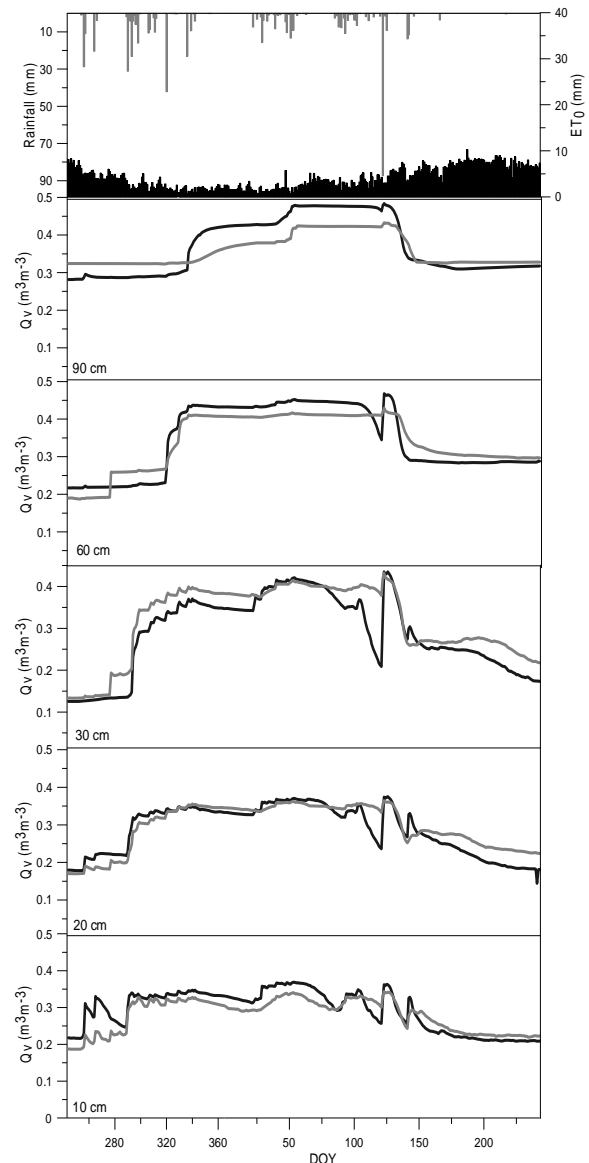


Figure 4. Time course of soil-water content at 10, 20, 30, 60, and 90 cm soil depth during 2006/2007 season. DOY, day of the year

In addition, according to the results of the present study the major differences of soil-water content are located in the first centimetres of the soil profile, although the effects of tillage are also evident in the deepest zones of soil profile for the availability of stored water. Thus, promoting and adopting conservation agricultural techniques such as direct drilling has a positive impact on agriculture by improving rainfall interception and subsequent storage in soil profile, and thus ensuring water availability for crops.

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