Chickpea water use efficiency as affected by tillage in rainfed Mediterranean conditions

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ABSTRACT

Under rainfed Mediterranean conditions, chickpea production can be increased by improving the soil water content (SWC). This study was conducted on a Vertisol in southern Spain over a period of ten years (2000-2009) to determine the effects of the tillage system on the SWC and the water use (WU) of the chickpea (*Cicer arietinum* L.) crop. The study was performed as part of a long-term experiment called “Malagón” that started in 1986; the tillage systems treatments were no-tillage (NT) and conventional tillage (CT). The NT treatment recorded more water at sowing in all soil depths studied (0-30 cm, 30-60 cm and 60-90 cm). However, the CT treatment had higher SWC at harvest in the deeper layers (30-60 cm and 60-90 cm). The NT treatment improved the grain yield significantly compared with the CT treatment (1180 kg ha^{-1} and 1082 kg ha^{-1}, respectively). The greatest WU occurred under the NT treatment, with 375 mm, compared with 355 mm under the CT treatment. This difference could be related to a higher nodule biomass in NT treated crops. However, the influence of the tillage system on the precipitation use efficiency (PUE) and the water use efficiency (WUE) was not clear.

Keywords: No-tillage; conventional tillage; soil water content; precipitation use efficiency; vertisol.

1. INTRODUCTION

The chickpea (Cicer arietinum L.) is a major food crop and is the world's third most widely grown legume after the bean (*Phaseolus vulgaris* L.) and the pea (*Pisum sativum* L.) (Yau, 2005). In northern latitudes chickpeas are cultivated in semi-arid environments, including northwest Europe, northeast Eurasia, the Siberian steppes and the northern Great Plains of North America (Gan et al., 2010). In recent years, human chickpea consumption has become more prevalent. This trend is particularly true in those countries where, because of economic, ethical or diet-related reasons, chickpeas are a central part of the diet. The world's chickpea crop surface area, according to the Food and Agricultural Organization of the United Nations Statistics (FAOSTAT, 2010), was 12 million ha in 2010, an 18% increase compared with that in 2000. In the Mediterranean region, the cultivated area decreased by 11% between 2000 and 2005 and has remained relatively stable since then, with an estimated area of 677,000 ha in 2010. Spain is the top European cultivator of the chickpea in the Mediterranean region, with approximately 30,700 ha (Ministerio, Alimentación y Medio Ambiente 2011. Anuario de Estadística 2011).

Another reason behind the increasing prevalence of chickpea cultivation is an increased interest in sustainable agricultural systems, where legumes can be introduced during crop rotations to reduce the use of N-based fertilisers (Jensen and Hauggaard-Nielsen, 2003). In addition, the legumes can be recommended for the recovery of marginal zones, where the physical and chemical properties of the soil have been deteriorated over the years (Johansen et al., 2003).

Several authors have examined chickpea yield, plant density and nitrogen fixation (Saxena, 1987; Gant et al., 2009; López-Bellido et al., 2011), but little is known about how tillage systems affect the soil water content (SWC) or how they affect water use efficiency (WUE) in Mediterranean dryland conditions.

In Mediterranean climates, the chickpea can be sown during autumn/winter (López-Bellido et al., 2008) but it is traditionally sown in early spring. The chickpea grows and completes its life cycle on stored soil moisture, and is often exposed to progressively increasing drought. According to Soltani et al. (2006), soil moisture and temperature are the major factors that influence the time between chickpea sowing and emergence. A key phase during chickpea growth is the period between flowering and grain maturity. This period generally occurs during months with high temperatures and high rates of soil water evaporation in the Mediterranean, thus resulting in yield reduction. The reproductive growth of the chickpea suffers considerably in hot environments (35/18 ºC, day/night). According to López-Bellido et al. (2007), the greatest loss of water from the profile occurs though direct evaporation from the soil, with drainage being negligible.

Due to weather conditions during the growth period, the chickpea yield is highly variable over the years. For this reason, chickpea crops are often transferred to marginal areas and, therefore, produce even lower grain yields. In this context, the no-tillage (NT) system is an important tool that could increase the SWC and decrease the evaporation rate during the warmest months, improving grain yield.

Hatfield et al. (2001) have reported that the water holding capacity can be increased by varying a single component that affects the evaporation processes, either above or below the surface, which would modify the energy and available water in the soil profile or alter the exchange rate between the soil and the atmosphere. Tillage practices can improve the mechanical impedance of soil, but they also affect the macropore space by increasing the evaporation rate. On the contrary, non-tillage practices increase precipitation infiltration by protecting the soil surface from raindrop impacts and subsequent crusting and reduce evaporation by decreasing the air movement immediately above the soil (López-Bellido et al., 2007).

Tillage practices can alter some parameters related to water use (WU) and the precipitation use efficiency (PUE) by modifying the level of water infiltration and decreasing the level of evaporation. According to Bandyopadhyay et al. (2003), the soil-crusting pattern can also be altered by tillage and by organic soil amendments. Only a few studies have been conducted on the contribution of non-tillage practices to the soil water holding capacity for chickpeas on Vertisols. It is important to consider that this type of soil presents particular problems and requirements for tillage practices (Probert et al., 1987; Coulombe et al., 1996).

The aim of this study is to compare in the framework of a 2-year, wheat-chickpea rotation, the effects of the tillage system on soil water storage and water utilisation by chickpeas grown on a Vertisol in rainfed Mediterranean conditions.

2. MATERIALS AND METHODS

2.1. Site and experimental design

Field experiments were conducted in Córdoba, southern Spain (37°46´N, 4°31´W, 280 m a.s.l.), on a Vertisol (Typic Haploxererts) typical of the Mediterranean region, where rainfed cropping is the standard practice (Table 1). The study took place over a 10-year period (2000-2009) in which February to June were the studied months. In 2005, weather conditions owing to rainfall shortage no harvest was obtained and no soil water measurement was done. The study was conducted within the framework of a long-term experiment named “Malagón”, started in 1986, and designed as a randomized complete block with a split–split plot arrangement and four replications. Main plots were tillage system [no-tillage (NT) and conventional tillage (CT)]; subplots were crop rotation, with four 2-year rotations wheat (*Triticum aestivum* L.)–sunflower (*Helianthus annuus* L.), wheat–chickpea (*Cicer arietinum* L.), wheat–faba bean (*Vicia faba* L.) and wheat–fallow) and continuous wheat; sub-subplots were N fertilizer rate (0, 50, 100, and 150 kg N ha^{-1}) applied to wheat (López-Bellido et al., 2007). Each rotation was duplicated in reverse crop sequence in order to obtain data for all crops on a yearly basis. The area of each sub-subplot was 50 m^2 (10 by 5 m). The study was conducted to independently evaluate the influence of tillage system on chickpea water use in continuous rotation with wheat. Thus the design was a randomized complete block with three replications.

2.2. Crop management

No-tillage plots were seeded with a no-tillage seed drill. Weeds were controlled with glyphosate + 2-methyl-4-chlorophenoxyacetic acid (MCPA), at a rate of 0.5 + 0.5 L active ingredient ha^{-1}, prior to sowing. The conventional tillage (CT) treatment included mouldboard ploughing (25–30 cm depth) and disc harrowing and/or vibrating tine cultivation (10–15 cm depth) several times to grind clods. The crop residues were not removed by either tillage treatment. Residues remained as mulch on NT treatments and were incorporated in CT treatments. Chickpeas (cv. Zoco) were planted in 48-cm wide rows in early February at a seeding rate of 39 seed m^{-2}, with an average thousand seed weight of 260 g. Nitrogen fertiliser was applied to the preceding wheat plots as ammonium nitrate. Each year, the preceding wheat plots were also supplied with P fertiliser as calcium superphosphate at a rate of 65 kg ha^{-1}. The fertiliser was incorporated into CT soil and banded with a drill in the NT plots. Soil-available K was adequate (530 mg kg^{-1}). Preventive treatments against Ascochyta blight (*Didymella rabiei)* were performed when the humidity and temperature were favourable for disease development, using chlorothalonil [2,4,5,6-tetra-chloroisophthalonitrile] at a rate 0.75 a.i. ha^{-1}. The chickpeas were harvested in early June each year by using a 1.5-m wide Nurserymaster elite plot combine (30 m^2 per plot).

2.3. Measurements and calculations

Soil water content was determined with two measurements per chickpea plot at sowing and harvest to a depth of 0.9 m in 0.3 m increments, using a ThetaProbe ML 2x soil moisture sensor (AT Delta-T Devices, UK) (Huang et al., 2004). The precipitation use efficiency (PUE) was calculated by dividing grain yield by growing-season precipitation. Water use (WU) during the growing season, which includes soil evaporation and crop transpiration, was determined as $WU = R + SWC_{sowing} - SWC_{harvest}$, where R is rainfall received in the growing season (February to June), and SWC is soil water content (0-90cm) at sowing and harvest. Other terms in the water balance, surface runoff, and drainage were negligible. Water use efficiency (WUE) was calculated by dividing grain yield by WU.

2.4. Statistical analysis

The year was considered as a random variable, due to unpredictable weather conditions under rainfed Mediterranean conditions (Gómez and Gómez, 1984). All parameters were subjected to analysis of variance (ANOVA) using a randomized block design combined over years and an error term according to McIntosh (1983). Treatment means were compared using Fisher´s protected least significant difference (LSD) test at P≤ 0.05. Analyses of variance were performed using Analytical Software Statistix 8.1 (Analytical Software, 2005).

3. RESULTS AND DISCUSSION

3.1. Weather conditions

According to the annual mean precipitation in the area (584 mm), the years for this study are classified as follows: 2001, 2002, 2003 and 2004 were rainy; 2000 and 2009 were average; and 2006, 2007 and 2008 were dry (Fig. 1).

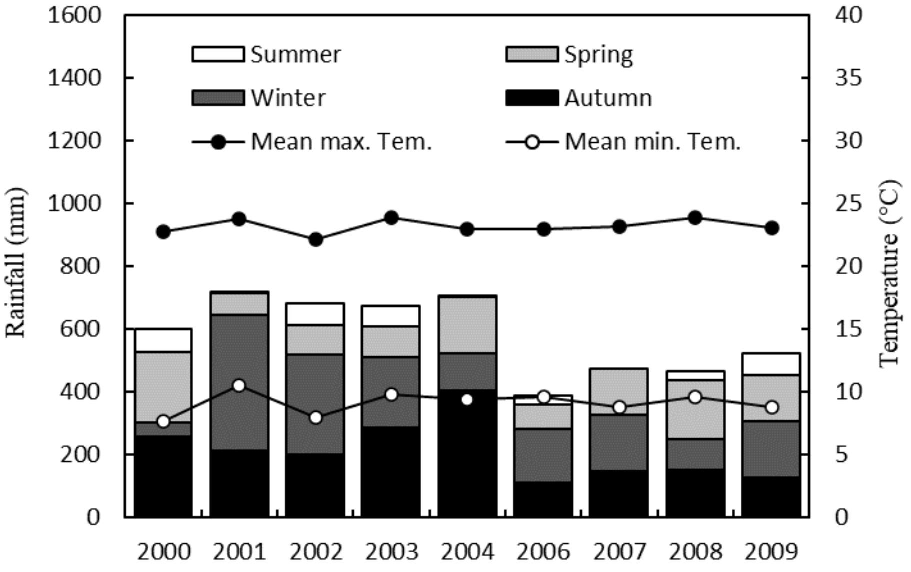

Fig.1. Seasonal and annual rainfall, mean maximum and minimum growing-season temperatures over 9 year study period at Córdoba (Spain).

Rainfall during the fall season of these years varied between 112 mm (2005-2006) and 403 mm (2003-2004), which correspond to 25% and 57% of total annual rainfall, respectively. Rainfall during the winter represented between 7% (1999-2000) and 60% (2000-2001) of total annual rainfall, while rainfall during the spring represented between 10% (2000-2001) and 40% (2007-2008) of total annual rainfall. Summer rainfall was irrelevant because it occurred after the crop season (Fig. 1). The temperature pattern was similar for all of the years in this study, with a mean temperature of 16.1 ºC, a mean minimum temperature of 9.5 ºC and a mean maximum temperature of 23.3 ºC during the crop cycle.

3.2. Soil water content (SWC)

The large variations in rainfall between years, which is characteristic of the Mediterranean climate, caused highly significant differences in the SWC during the years studied and among the depths analysed during both the sowing and harvesting seasons (Table 1).

Table 1. Effect of year and tillage system on soil water content over 9 yr in a chickpea under rainfed Mediterranean conditions.

Source	Soil water content					
	Depth at sowing (cm)			Depth at harvest (cm)		
	0-30	30-60	60-90	0-30	30-60	60-90
Year (Y)	***	***	***	***	***	***
Tillage system (T)	***	**	***	*	***	*
Y×T	***	***	***	***	***	***

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.

The SWC differed significantly among tillage systems during the sowing and harvesting seasons, as did the interactions of year x tillage system at all depths studied

(Table 1). López-Bellido et al. (2007) found no differences among tillage systems in a study on the SWC in wheat, except for the interaction of year x tillage system during the sowing and harvesting seasons at all depths.

3.2.1. Sowing

In the 0-30 cm soil layer, the SWC at sowing was significantly higher under the NT treatment than under the CT treatment (38.4 x 10^{-2} m^3m^{-3} vs. 36.1 x 10^{-2} m^3m^{-3}) over the course of the study. However, the SWC was only higher under the NT treatment in the years 2002, 2004, 2006 and 2008 (Fig. 2). Three of these four years corresponded with a winter rainfall lower than 170 mm (Fig. 1). Hatfield et al. (2001) reported that the NT treatment had a positive effect on the SWC. The other five years did not show any significant differences between the two tillage systems (Fig. 2).

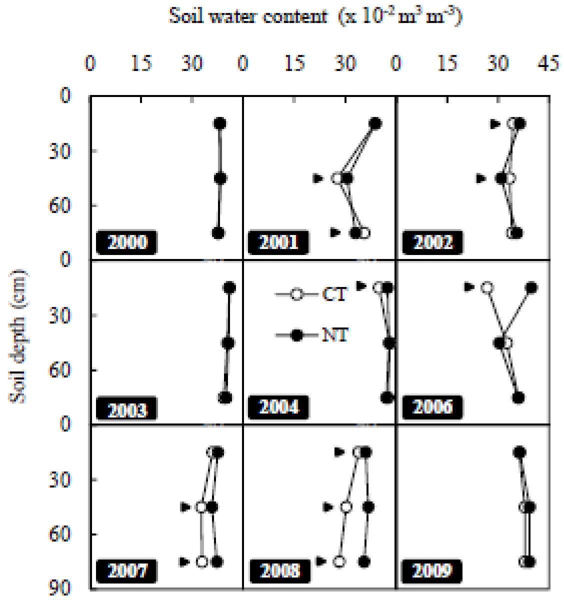

Fig.2. Soil water content at sowing in a rainfed chickpea as influenced by year and tillage system (CT: conventional tillage; NT: no-tillage) for different soil depths. The triangle (▸) represents significant differences between tillage systems.

In the 30-60 cm soil layer, the NT treatment achieved a higher SWC than the CT treatment over the course of the study (36.2 x 10^{-2} m^3m^{-3} and 35.1 x 10^{-2} m^3m^{-3}, respectively). However, the SWC for the NT treatment was higher than that of the CT treatment only during the years 2001, 2007 and 2008, while the opposite occurred in 2002 (Fig. 2).

In the deepest soil layer studied (60-90 cm), the difference in the SWC over the course of the study was the same as for the other two depths. For this soil layer, only the years 2007 and 2008 had a higher SWC for the NT treatment, while in 2001 the SWC was higher for the CT treatment (Fig. 2). The SWC did not follow the same patterns in the different soil layers, which could be attributed to variations in the distribution of rain prior to sowing and to the differences in water infiltration in the different soil horizons. The filling or recharging of water in the deepest layers is a slow and variable process that can be affected by the soil management practices on the surface. In the NT system, the crop residues are left on the soil surface, along with the pores created by the crop roots, which favours water infiltration. Hatfield et al. (2001) reported that keeping the plant residues on the surface reduces the loss of soil due to erosion and, at the same time, increases water infiltration and reduces evaporation in that horizon. Pikul and Aase (1995) found that infiltration increased due to the protection of the soil surface, while Izumi et al. (2004) indicated a noticed effect in the formation and retention of bio-pores produced by the activity of microorganisms and plant root decomposition in the soil.

3.2.2. Harvest

The SWC recorded for the 0-30 cm soil layer was higher for the NT treatment than for the CT treatment (18.9 x 10^{-2} m^3m^{-3} and 18.1 x 10^{-2} m^3m^{-3}, respectively) at harvest over the course of the study. The SWC recorded was higher for the NT treatment than for the CT treatment in 2006, while the opposite occurred in 2002 (Fig. 3). The differences between the tillage systems during these two years could have been related to the distribution of rainfall over the crop cycle. According to López-Bellido et al. (2008), the variability in chickpea production in dryland areas is related to the residual moisture and the texture of the soil and is strongly related to the precipitation during the crop cycle, which is generally irregular and scarce in the Mediterranean region.

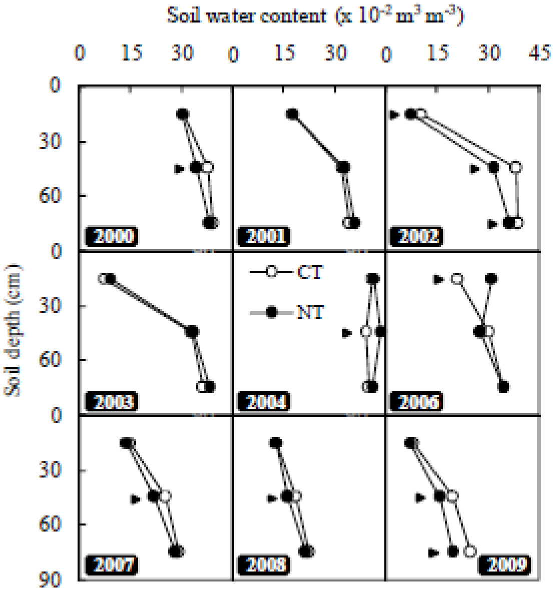

Fig.3. Soil water content at harvest in a rainfed chickpea as influenced by year and tillage system (CT: conventional tillage; NT: no-tillage) for different soil depths. The triangle (▸) represents significant differences between tillage systems.

In the 30-60 cm soil layer, the SWC was higher in the CT treatment than in the NT treatment (30 x 10^{-2} m^3m^{-3} and 29 x 10^{-2} m^3m^{-3}, respectively) over the course of the study. The SWC of the CT treatment was higher than that of the NT treatment during the years 2000, 2002, 2007, 2008 and 2009, while the opposite occurred only in 2004 (Fig. 3). There were no differences between the two tillage systems in the remaining years. The differences in SWC between the two tillage systems occurred in years when the rainfall recorded during April and May was higher than 80 mm. In this case, the SWC increased for the CT treatment in the deeper layers. Because there is no surface residue in the CT treatment, there was a greater water loss due to evaporation and, as a consequence, an increased incidence in the formation of cracks characteristic of Vertisols, which facilitate the accumulation of water in the deepest profiles. According to Bandylopadhyay et al. (2003), the soil crack pattern can be altered by the tillage system. The crevices in the soil provide a great opportunity for water recharge in the deepest layers of the Vertisols, which would normally occur at a slower rate due to a low permeability (Mitchell and Van Genuchten, 1992).

In the 60-90 cm soil layer over the course of the study, the SWC for the CT treatment was higher than for the NT treatment, even though this difference was observed only during the years 2002 and 2009 (Fig. 3). In this deepest layer, both the infiltration and the loss of water are slow processes compared to the upper layers. The absence of significant differences between tillage systems during the remaining years can be attributed not only to physical and structural soil characteristics but also to the root structure of the plants that impedes water absorption in this profile. Indeed, the chickpea root biomass remains in the first 60 cm of the soil (Muñoz-Romero et al., 2012).

3.3. Grain yield

The grain yield was significant for the year as well as for the tillage system (Table 2). The variation in rain among years, as well as its distribution, caused notable grain yield differences (Fig. 4), which varied, on average, from 632 kg ha^{-1} in 2000 to 2190 kg ha^{-1} in 2001. The grain yield was related to total precipitation during the winter and spring months ($r = 0.74$, $P \leq 0.05$). Singh et al. (1997) found a significant positive correlation between seasonal rainfall and seed yield in both seasons. Over the nine years of the experiment, the NT treatment achieved a higher grain yield than the CT treatment, with yields of 1180 kg ha^{-1} and 1082 kg ha^{-1}, respectively.

Table 2. Effects of year and tillage system on grain yield, precipitation use efficiency (PUE), water use (WU), and water use efficiency (WUE) in a chickpea crop during 9 yr under rainfed Mediterranean conditions.

Source	Grain yield (kg ha^{-1})	PUE (kg ha^{-1} mm^{-1})	WU (mm)	WUE (kg ha^{-1} mm^{-1})
Year (Y)	***	***	***	***
Tillage system (T)	*	ns†	***	ns
Y×T	***	***	***	***

* Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†ns, not significant.

The NT treatment recorded a higher grain yield than the CT treatment in three of the nine years studied (2002, 2003 and 2007); the yield of the CT treatment was higher only in 2006, even though precipitation was very similar to that in 2007 (Fig. 4). In 2006, an exceptionally strong attack by Ascochyta blight in the NT treatment was recorded. This pest could not be controlled by conventional treatment and reduced yield by more than half, compared with the CT treatment (Fig. 4). This situation could be attributed to environmental conditions, such as humidity and temperature, that are favourable for the development of the disease during the phase prior to the crop flowering. This particular fungus survives in plant residues left on the soil surface. In case of rain, it can cause infection during any of the crop growing phases, although the most severe attacks occur at the start of the flowering phase. According to Trapero and Kaiser (2007), a reduction in the chickpea yield is highly dependent on an attack by Ascochyta blight, which is strongly dependent on the environmental conditions in many of the chickpea-producing regions of the world.

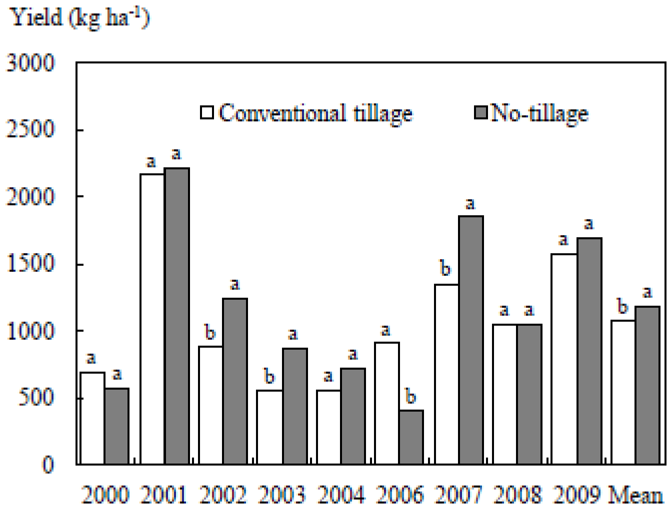

Fig.4. Effect of year and tillage system on grain yield in a chickpea crop during 9 yr under rainfed Mediterranean conditions. For each year, means followed by the same letters are not significantly different at P< 0.05 according to LSD.

3.4. *Precipitation use efficiency (PUE)*

Over the nine years of this study, the PUE was significant for the year and for the year x tillage system interaction but not significant for the tillage system (Table 2). The year exerted a strong influence on this parameter, which varied between 2 kg ha^{-1} mm^{-1} in 2000 and 10.3 kg ha^{-1} mm^{-1} in 2007 (data not shown).

The NT treatment recorded PUE values that were significantly higher than those of the CT treatment in 2003 and 2007, while in 2006, the result was the opposite (Fig. 5). Despite the similar precipitation levels in 2006 and 2007, there were differences in PUE related to the tillage system, which were due to the yield loss in the NT treatment in 2006 that was caused by Ascochyta blight, with a concomitantly low PUE compared with the CT treatment.

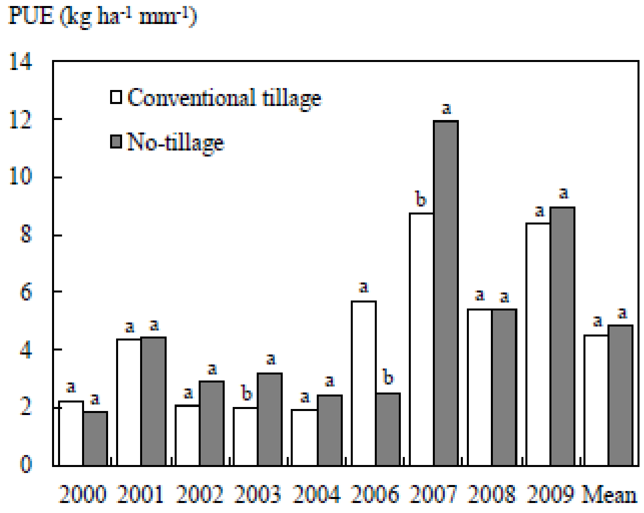

Fig.5. Effect of year and tillage system on precipitation use efficiency (PUE) in a chickpea crop during 9 yr under rainfed Mediterranean conditions. For each year, means followed by the same letters are not significantly different at P< 0.05 according to LSD.

3.5. Water use (WU)

The WU was highly significant for all variables (Table 2), varying between 185 mm in 2006 and 554 mm in 2001. Over the course of the study, WU values of 375 mm and 355 mm for the NT treatment and the CT treatment, respectively, were recorded. The NT treatment exhibited higher WU values than the CT treatment in five of the nine years studied, with no significant differences between the tillage systems during the remaining years (Fig. 6). This higher WU in the NT treatment could be related to a higher number of Rhizobium nodules in the roots per plant. López-Bellido et al. (2011) noticed a positive effect of the NT treatment on the nodular biomass and the biologically fixated nitrogen. In this regard, higher water content during the sowing season of the NT treatment could favour the symbiosis between *Rhizobium* and the legume. Ben Romdhane et al. (2009) showed that the number of nodules and the growth of the plants were affected by the water deficit.

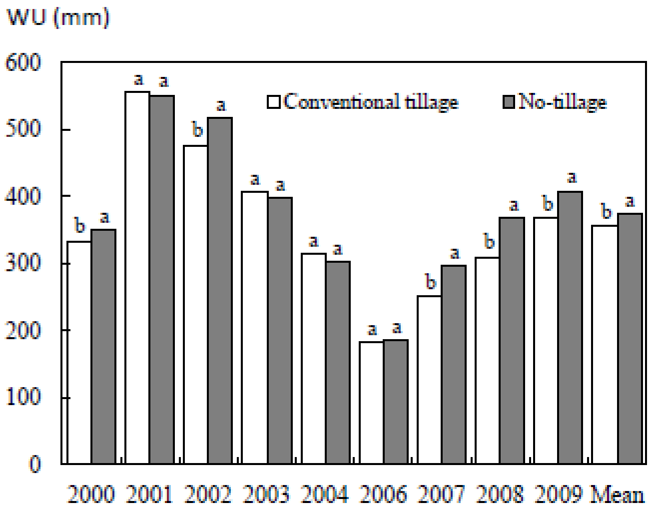

Fig.6. Effect of year and tillage system on water use (WU) in a chickpea crop during 9 yr under rainfed Mediterranean conditions. For each year, means followed by the same letters are not significantly different at $P< 0.05$ according to LSD.

3.6. Water use efficiency (WUE)

The WUE was significant for the year and for the year x tillage system interaction (Table 2). The WUE values differed considerably during the study, ranging between 1.8 kg ha^{-1} mm^{-1} in 2003 and 5.9 kg ha^{-1} mm^{-1} in 2007 (data not shown). The recorded values of the NT treatment were higher than those of the CT treatment in two of the nine years (2003 and 2007). The CT treatment had higher WUE values only in 2006 (Fig. 7), the lower WUE value under NT in this year was by Ascochyta blight attack. For this reason, it cannot be stated that either tillage system is more efficient than the other during dry years. These results differed from those reported by Gan et al. (2010), who found a higher WUE in the CT system than in the NT system under high water stress conditions.

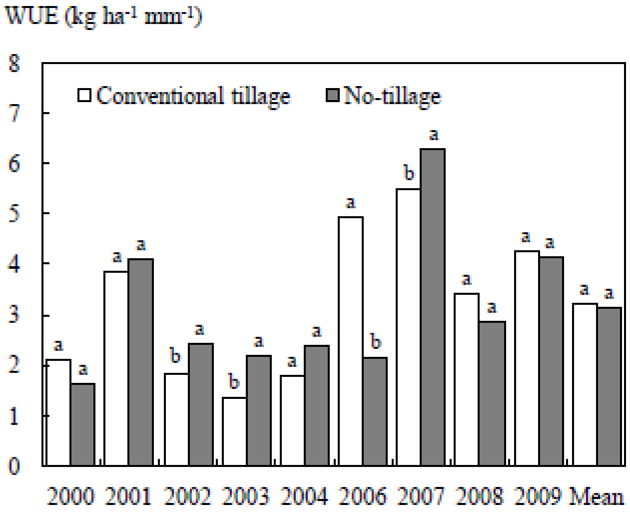

Fig.7. Effects of year and tillage system on water use efficiency (WUE) in a chickpea crop during 9 yr under rainfed Mediterranean conditions. For each year, means followed by the same letters are not significantly different at $P< 0.05$ according to LSD.

4. CONCLUSIONS

In the Mediterranean climate, annual rainfall is scarce and irregular, and there is a high solar radiation index and high temperatures that cause a high evaporation rate in soils. Under such conditions, the NT system resulted in a higher water content during the chickpea sowing seasons compared to the CT system, which improved seedbed conditions. On the contrary, the CT system retained less water due to higher water loss by evaporation.

Grain yield improved with the NT system. However, the frequent occurrence of optimal humidity and temperature during the crop cycle can favour an attack by Ascochyta blight (*Didymella rabiei)*, as inoculum remains in the mulch on the soil surface.

Among the parameters that define the use of water by the chickpea crop (WU, WUE and PUE), the WU was clearly higher in the NT system than in the CT system, which could be related to a higher development of the nodular biomass in the NT system.

The tillage system, on the other hand, did not show a clear influence on PUE or WUE.

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