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# 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.



## 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; Gan 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

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(35/18 °C, 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 randomised 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 (*C. arietinum* L.), wheat–faba bean (*Vicia faba* L.) and wheat–fallow and continuous wheat; sub-subplots were N fertiliser 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 randomised 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 2× 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 (0–90 cm) 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 randomised 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 $P \leq 0.05$. 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).

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