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The effects of the tillage system on chickpea root growth

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ABSTRACT

A well-developed root system is crucial for plant growth, especially under dryland farming conditions. A two-year field study (2003–2004 and 2005–2006) was conducted to determine the effects of the tillage system on root growth in chickpea (*Cicer arietinum* L.) grown in continuous rotation with wheat (*Triticum aestivum* L.) on a typical Vertisol in southern Spain as part of the long-term "Malagon" experiment begun in 1986. The tillage treatments were either no tillage (NT) or conventional tillage (CT), and the experiment was designed as a randomized complete block with three replications. Both soil cores and a minirhizotron were used to evaluate the root system. Measurements of the root parameters were performed at different depths and included the following: root length, root biomass, root nitrogen and root length density. Root length measurements were performed during five chickpea growth stages. The CT was more favourable than NT for chickpea root development (0.34 mm cm^{-3} versus 0.18 mm cm^{-3}), which is one of the factors that induced higher yields during the drier year. The nitrogen content of the roots represented 15% of the total N extracted by the plant. The measured root lengths were larger when using the soil core method than with the minirhizotron (2.5 mm cm^{-3} versus 1.3 mm cm^{-3}), which can be attributed to the cracks that occur in Mediterranean Vertisols that can separate the tube from the soil, resulting in the underestimation of the root length.

1. Introduction

Plant roots are a fundamental component of terrestrial ecosystems and are important for balancing water and nutrients in the soil (Spedding et al., 2004). The root system, with its extensive but structured development, is considered to be an evolutionary response to the spatio-temporal variability in resource supply and the associated constraints on growth (Harper et al., 1991). Crop species differ in the rate of root growth (Liu et al., 2011) and how the roots are distributed within the soil profile.

In Mediterranean climates, chickpea is traditionally planted in early spring. Dryland chickpea production is dependent on the irregular and generally scarce rainfall and on the residual soil moisture (López-Bellido et al., 2008). Crop performance under water-related stress conditions is closely related to the root system development (Abdelhamid, 2010). Under water-limiting conditions, the morphology of crop root systems is a crucial determinant for the capacity for nutrient uptake and water extraction by crop plants (Fageria, 2004), influencing aboveground growth and biomass yield. A root that has developed during the early growth stages of the plant can effectively exploit the water in the soil, especially in semiarid areas in which plant establishment is often limited by low water availability (Lee et al., 1996; Lilley and Kirkegaard, 2007). Roots with a longer length or more tips increase the nutrient supply to the plant to a greater extent than those with shorter roots or fewer root hairs (Dong et al., 1995).

Root traits such as root depth and root biomass (RB) have been identified as the most promising plant traits in chickpea for terminal drought tolerance, as these help extract available soil moisture (Abdelhamid, 2010). However, Zaman-Allah et al. (2011) indicated that the temporal pattern of water uptake by roots, more than root growth, is critical for understanding water management and the adaption to terminal drought. Several key attributes of chickpea roots, such as their high water absorption efficiency per unit root length density, their ability to change the rooting pattern across soil depths to efficiently access the available soil moisture and their ability to produce a larger root surface area per unit root biomass, seem to make chickpea the best choice for dryland cropping systems compared with other legumes or cereals (Tilahun and Schubert, 2003; Benjamin and Nielsen, 2006).

The minirhizotron system is a non-destructive technique for studying the dynamics of crop root systems. Root system dynamics are instrumental in maintaining the biological and chemical equilibrium within the soil and modulating the changes to soil quality (Zobel, 2005). Vertisols are fine-textured soils that contain swelling clay minerals, and they can develop wide and deep cracks during prolonged dry seasons. Vertisols have particular management

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Table 1
Chickpea biomass and N uptake as affected by year and tillage in a continuous rotation with wheat at Córdoba (Spain).

Year	Tillage system	Biomass (kg ha^{-1})			N uptake (kg ha^{-1})		
		Grain	Straw	Roots	Grain	Straw	Roots
2003–2004	CT	1343a[†]	1431a	337a	52a	15a	7.8a
	NT	1104a	1258a	398a	39a	17a	10.8a
2005–2006	CT	903a	1129a	306a	32a	16a	8.0a
	NT	393b	729b	251a	12b	15a	6.4a

[†] Within treatment (year and tillage) means followed by the same letter are not significantly different at $P < 0.05$ according to LSD.

requirements as well as specific problems with tillage. The mechanical impedance and lack of aeration in soil can both be alleviated by conventional tillage, although this practice may accelerate the loss of soil moisture (Agrawal et al., 1989; Gupta and Woodhead, 1989). In contrast, minimal or zero tillage systems and the retention of stubble can improve the soil structure, increase the organic matter content (Blair and Crocker, 2000) and soil water storage capacity (O'Leary and Connor, 1997), improve chemical fertility (Chan et al., 1999) and conserve water (Carroll et al., 1997). However, crops may also suffer from the formation of soil cracks, which can accelerate the loss of soil moisture under zero or minimum tillage (Rathore et al., 1998).

The aim of the present study was to determine the response of chickpea root growth to two different tillage systems within the framework of a long-term field experiment on a rain-fed Vertisol using soil cores and a minirhizotron to estimate the root length, root biomass and root nitrogen during the period of legume growth.

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 3-year period (2003–2004 and 2005–2006); data for 2004–2005 were discarded because a severe drought prevented the installation of minirhizotrons in the soil. 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 blocks. Main plots were tillage system [no-tillage (NT) and conventional tillage (CT)]; subplots were crop rotation, with four 2-year rotations (wheat–sunflower (*Helianthus annuus* L.), wheat–chickpea, 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. 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).

Since this study was conducted to independently evaluate the influence of tillage system on chickpea root growth in continuous rotation with wheat, using only the 100 kg N ha^{-1} rate applied to wheat, the design was a randomized complete block with three replications.

2.2. Crop management

No-till plots were seeded with a no-till 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 planting. The conventional till treatment included moldboard 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.

Chickpea (cv. Zoco) was planted in 48-cm wide rows in February at a seeding rate of 384,600 seed ha^{-1} with an average thousand seeds weight of 260 g. Nitrogen fertilizer (100 kg N ha^{-1}) was applied to the preceding wheat (*Triticum aestivum* L.) plots as ammonium nitrate. Half of the N was applied before sowing (incorporated by disc harrowing in conventional till plots and surface broadcast in no-till plots). The remaining N was applied as a top dressing at the beginning of wheat tillering. Each year, the preceding wheat plots were also supplied with P fertilizer as calcium superphosphate at a rate of 65 kg ha^{-1}; the fertilizer was incorporated in conventional till soil and banded with a drill in the no-till plots. Soil-available K was adequate (530 mg kg^{-1}).

At harvest, a 1-m^2 area at the centre of each chickpea plot was sampled. From this sample, aboveground biomass was measured by drying plants at 80 °C to a constant weight. The chickpea was harvested in early June each year by using a 1.5-m wide Nursemaster elite plot combine (30 m^2 per plot).

2.3. Measurements

2.3.1. Soil coring

Cylindrical soil cores were randomly sampled and in triplicate at the centre of each plot and on planting rows, using an 8-cm diameter bi-partite root auger (Eijkelkamp, NL). The first sample was taken on a line from the centre of the plot and the other two were taken on lines separated by 2–3 m in the opposite direction. Manschadi et al. (1998) found differences between soil cores taken on the row and between rows only in the first 15 cm. We adopted the criterion of taking soil core samples from the sowing line, since this is where the minirhizotron tubes were installed and one of our objectives was to perform a comparative study of the root system using both methods. Each location was sampled at seven depths (0–10, 10–20, 20–30, 30–40, 40–55, 55–70 and 70–85 cm). Sampling was carried out during full flowering of the chickpea (growth stage 65) (Hack et al., 1992). Prior to processing, soil samples were immediately frozen at −30 °C to avoid root decomposition.

Roots were washed using Calgon (a 10% sodium hexametaphosphate and sodium bicarbonate solution) as a dispersant. After 12 h in this solution, the roots were rinsed in water and collected on a sieve with a 0.2-mm mesh screen. Debris and dead roots were manually removed from live roots. The criteria of distinguishing live from dead roots are typically based on colour (separating white or pale brown roots from darker materials) and physical appearance (e.g. branched, able to bend, some elasticity) according to Gregory (1994). The roots were scanned and the images were processed to determine length, using the specific image-processing software package CIAS version 2.0 (CID, 2002). They were then dried at 40 °C