Field Crops Research 120 (2011) 338–344

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Faba bean root growth in a Vertisol: Tillage effects

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ARTICLE INFO

Article history:
Received 30 July 2010
Received in revised form
10 November 2010
Accepted 11 November 2010

Keywords:
Vicia faba
No tillage
Conventional tillage
Root length
Root diameter
Root biomass
Minirhizotron

ABSTRACT

Studies on the growth of faba bean (*Vicia faba* L.) root systems in Vertisols under Mediterranean climates are practically non-existent. A three-year field study (2003–2004, 2005–2006 and 2006–2007) was conducted on a typical Vertisol (in southern Spain) to determine, using a minirhizotron system, the effects of tillage on root growth in faba bean grown in continuous rotation with wheat (*Triticum aestivum* L.) as part of the long-term "Malagón" experiment that started in 1986. Tillage treatments were no-tillage (NT) and conventional tillage (CT). The parameters measured were root length (RL), root diameter (RD), root biomass (RB), seed yield and aboveground biomass. Root growth measures with minirhizotron were carried out at six soil depths for five growth stages throughout the faba bean growing season. For the calculation of RB, soil cores were collected during flowering from the same six soil depths. NT was more favorable for the development of the faba bean root system when compared with CT. This can be attributed to improved physical properties of the soil under NT, which improves the water conditions of the soil.

1. Introduction

Root function is very important to plant health and yield. Quantifications of root growth and root distributions are necessary to understand plant–soil interactions. The depth and distribution of roots are important parameters governing water and nutrient uptake by faba bean plants (Manschadi et al., 1998), especially in semiarid climates. Dardanelli et al. (1997) argue that during drought periods, a crop's capacity to extract soil water depends on the uniformity and depth of its root system. Smit and Groenwold (2005) suggest that rooting depth can be considered an inherent crop characteristic even though it can be influenced strongly by local conditions, for example, soil compaction or bulk density.

Faba bean (*Vicia faba* L.) is a crop with a shallow root system with little osmoregulation and is very sensitive to high temperatures and water stress, particularly during anthesis and pod filling (Bond et al., 1994; Xia, 1994). When under water stress, faba beans have coping mechanisms that allow them to mitigate potential negative effects on the crop. According to Husain et al. (1990), these mechanisms consist of reducing its rate of height increase, decreasing its rate of leaf-area expansion slightly, greatly increasing root growth, producing leaves of smaller specific area and shedding leaves. Reid (1990) states that the increase in root growth of faba bean under limited water supply is the most effective of the above-mentioned adaptations to drought stress.

The effects of tillage systems on faba bean crops have been studied by López-Bellido et al. (2003) for rainfed Mediterranean conditions. However, these authors mainly refer to the effects on crop yield and the aboveground part of the plant. It is known that tillage systems influence soil properties such as bulk density, aggregation and pore continuity, temperature, aeration and moisture levels, which can affect root growth (Probert et al., 1987; Coulombe et al., 1996). On the other hand, roots also modify the structure and chemistry of the soil around them. Roots physically displace soil particles as they make their way through soil layers, and they alter the concentration gradients of water and nutrients within the soil as they take these up (Pierret et al., 2007). Roots can also perforate compact soil layers and create easily accessible pathways for the roots of succeeding crops (Henderson, 1989), which can also increase water movement and gaseous diffusion. Legume crops having the most extensive root development generally produce the greatest improvement in soil aggregation and stability (Stone and Buttery, 1989). Rochester et al. (2001) observed soil structural improvements as reduced soil strength where legume crops were grown, compared with non-legume crops. Haynes and Beare (1997) suggest that some legume roots deposit material of higher N content which enhance aggregate stability through greater exploration of those aggregates by fungal hyphae.

Vertisols are fine-textured soils that contain swelling clay minerals and develop wide and deep cracks during prolonged dry seasons. When dry, these soils have a hard consistency. They are plastic and sticky when wet, however (Lal, 1989). This soil has a large water holding capacity that allows crops to survive mid-season drought periods and grow long after rains have ended

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doi:10.1016/j.fcr.2010.11.008

Table 1
The properties of the Vertisol used in field experiments. Córdoba (Spain).

	Depth[a] (cm)		
	0–30	30–60	60–90
Fine sand (g kg^{-1})	127 (17)	143 (19)	187 (21)
Silt (g kg^{-1})	179 (20)	152 (20)	26 (5)
Clay (g kg^{-1})	694 (35)	705 (37)	787 (39)
pH (1:2.5 soil–water)	7.7 (0.15)	7.6 (0.15)	7.6 (0.1)
Organic matter (g kg^{-1})	10.2 (0.11)	7.4 (0.17)	5.3 (0.2)
Calcium carbonate equivalent (g kg^{-1})	75 (13)	93 (41)	71 (5)
CEC (cmol kg^{-1})	46.5 (3.7)	36.6 (5.4)	30(6.9)
Bulk density (t m^{-3})			
No tillage	0.95(0.06)	1.06(0.06)	1.10(0.08)
Conventional tillage	0.90(0.01)	1.05(0.04)	1.04(0.04)

[a] Standard errors of the means are given in parentheses.

(Probert et al., 1987); however, they are also characterized by low infiltration rates and impeded internal drainage (Lal, 1989). Vertisols have particular management requirements, as well as specific problems due to tillage. Coulombe et al. (1996) extensively studied the degradation suffered by Vertisols by the effect of CT. In contrast, minimum or zero tillage systems and the retention of stubble can improve soil structure, increase organic matter content (Blair and Crocker, 2000) and soil water storage capacity (OĭLeary and Connor, 1997), improve chemical fertility (Chan et al., 1999) and conserve water (Carroll et al., 1997). Mouldboard ploughing was and continues to be a common practice among farmers in our region. However, in recent years conservation tillage is gaining importance, as minimum tillage or no tillage.

The minirhizotron technique is becoming increasingly appreciated as a non-destructive method for studying the root dynamics of cultivated plants. However, the use of this technique has certain shortcomings, as pointed out by Johnson et al. (2001) and Hendricks et al. (2006), that should be investigated for each crop and each type of soil by contrasting it with traditional destructive methods.

The objective of this study is to determine the response of faba bean root growth to tillage when grown in a Vertisol under rainfed Mediterranean conditions, using minirhizotrons to estimate root length, root diameter and root biomass 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, 2005–2006 and 2006–2007), 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, wheat–chickpea, wheat–faba bean 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 m × 5 m).

Since this study was conducted to independently evaluate the influence of tillage system on faba bean 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 disk 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.

Faba bean (cv. Alameda) was planted in 50 cm-wide rows in November at a seeding rate of 278,000 seed ha^{-1} with an average thousand seeds weight of 612 g. Nitrogen fertiliser (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 disk 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 fertiliser as calcium superphosphate at a rate of 65 kg ha^{-1}; the fertiliser 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 faba bean plot was sampled. From this sample, aboveground biomass was measured by drying plants at 80 °C to a constant weight. The faba bean 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

Soil water content was determined with two measurements per faba-bean plot at planting and at harvesting to a depth of 0.9 m in 0.3-m increments using a ThetaProbe mL2x soil moisture sensor (AT Delta-T Devices, Cambridge, UK).

The pedestrian traffic was the normal amount for this type of experiment and we understand that no special perturbations or compaction occurred as a result.

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 center 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 core 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 six depths (0–15, 15–30, 30–50, 50–65, 65–80 and 80–100 cm). Sampling was carried out during full flowering of the faba bean (65 days) (Lancashire et al., 1991). 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. Distinguishing live from dead roots can be difficult and, no universal standard is applied. The criteria 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 always separated by a same experienced operator, which established a colour and flexibility criterion that followed along