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Crack formation in a mediterranean rainfed Vertisol: Effects of tillage and crop rotation

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ABSTRACT

The frequency, size and development rate of Vertisols cracks influence the water, solute and heat dynamics and hence on the crop productivity. The aim of this study was to evaluate the effect of the tillage system and crop rotation on the behaviour of cracks and soil compaction in a long-term experiment that was initiated in 1986 on a Mediterranean rainfed Vertisol in southern Spain. The treatments studied were conventional tillage (CT) vs. no-tillage (NT) for five crop rotations: wheat (*Triticum aestivum* L.) - chickpea (*Cicer arietinum* L.), wheat - sunflower (*Helianthus annuus* L.), wheat - faba bean (*Vicia faba* L.), wheat - bare fallow and continuous wheat. The following parameters were measured: penetration resistance, water content at harvest, and perimeter, depth and width of crack. Soil compaction was greater in NT compared to CT in the top 10 cm of soil, with the opposite occurring between 10 and 40 cm. The surface area and volume of cracks was significantly greater in CT than in NT. The perimeter of the cracks was greater in wheat monoculture plots but with smaller crack width and depth in relation to the other studied biannual rotations. The water content at harvest recorded in the first 30 cm of soil was negatively correlated with the depth of cracks. The characterization of the cracks in Vertisols is very important for estimating losses or recharging the water in the soil profile as well as for evaluating its compaction and stability.

1. Introduction

Many studies indicate that existing cracks destroy soil integrity, diminish soil strength, and weaken its sliding ability; on the other hand, cracks provide a favourable pass for water seepage and evaporation (Shi et al., 2014). Soil crack patterns are closely related to soil properties such as swelling clay and soil organic carbon (Zhang et al., 2016). The frequency, size and development rate of cracks influence the water, solute and heat dynamics of the soil and hence influence crop productivity and the potential for ground water pollution (Bandyopadhyay et al., 2003). The cracks can also improve the air regime (Choudhary, 2015).

A large number of factors influencing soil-cracking behaviour have been studied, including temperature, wetting-drying cycles, layer thickness, soil types (Tang et al., 2010), mineral composition, soil moisture (Kishné et al., 2012) and tillage practices (Bandyopadhyay et al., 2003). Cracks are also influenced by the type of crops grown, as plant roots are known to affect cracking patterns by anchoring the soil mass and influencing soil shrinkage (Fox, 1964; Mitchell, 1991; Mitchell and Van Genuchten, 1992).

Vertisols are also well known for developing wide and deep cracking patterns, which greatly influence water flow (Novak et al., 2000) and can adversely affect crop production under rainfed conditions (Gargiulo et al., 2015). Typical cracks of Vertisols have a direct relationship with the grade and size distribution of the clods that form on its surface when it is tilled, so that the pattern of cracking affects soil tillage (Ahmad and Mermut, 1997). Soil cracks provide an opportunity for water recharge; otherwise, due to the low permeability of these soils, it would be slower (Gardner and Coughlan, 1982; Bouma, 1984; Mitchell and Van Genuchten, 1992). Conversely, cracks extend the contact surface between the ground and the air inside the profile, thereby potentially increasing water loss by evaporation (Adams and Hanks, 1964; Ritchie and Adams, 1974).

Many researchers have tried to improve the description of soil cracks through image analysis (Hoffmann and Roth, 2005; Perrier et al., 1995; Velde, 1999; Vogel et al., 2005). However, quantification of soil cracks is still a challenge because of their irregular patterns. Peng et al. (2006) introduced digital image analysis to non-destructively and continuously measure soil cracks. Liu et al. (2008) illustrated the procedures of image processing for quantifying crack patterns and proposed some parameters, including crack area density, crack width, fractal dimension, and the connectivity index.

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There is little information about how certain agricultural practices can alter the physical properties of a Vertisol in Mediterranean conditions. Therefore, the objectives of this study conducted in a Vertisol under Mediterranean rainfed conditions was i) to evaluate the effect of tillage systems and crop rotation on the behaviour of cracks and soil compaction, ii) to determine the relationships between the different crack parameters and the water content and iii) to evaluate digital photography as an alternative method to characterize the cracks.

2. Materials and methods

2.1. Site and experimental design

Field experiments were conducted in Cordoba, southern Spain (37° 46′ N and 4° 31′ W, 280 m.a.s.l.) on a Vertisol (Typic Haploxererts) typical of the Mediterranean region (Table 1), where rainfed cultivation is the standard practice. The Vertisol is found on sedimentary plain, on hill slope and piedmont plain. The Vertisol has no gilgai subsurface features. This soil presents swelling clay minerals, mainly vermiculite and montmorillonite. Parent material is very deep Miocene loam. The water table is very deep. The soil electrical conductivity was 0.44 dS m^{-1}. The study took place within the framework of a long-term experiment that was initiated in 1986, called "Malagon" that began in 1986 and was designed as a randomized complete block with a split-plot arrangement and 3 replications. The main plots tested the effects of the tillage system (no-tillage and conventional tillage); the subplots tested 2-year crop rotations [wheat (*Triticum aestivum* L.) - chickpea (*Cicer arietinum* L.), wheat - faba bean (*Vicia faba* L.), wheat - sunflower (*Helianthus annuus* L.), wheat - bare fallow and continuous wheat]. Each rotation was duplicated in a reverse crop sequence to obtain data for all crops on a yearly basis. The area of each sub subplot was 50 m^2 (10 × 5 m).

2.2. Climatic conditions

A 30-year annual average rainfall in the area was 584 ± 204 mm. Annual rainfall was 702 mm, slightly greater than the average of the study area with a distribution model typical of the Mediterranean region, with abundant rainfall in autumn, scarcer rainfall with more variability in spring and low rainfall and high temperatures in summer (Fig. 1).

2.3. Crop management

The no-tillage (NT) plots were seeded with a no-till seed drill. Weeds were controlled by applying glyphosate (N-[phosphonomethyl] glycine) + MCPA ([4-chloro-2-methylphenoxy] acetic acid) at a rate of 0.5 + 0.5 L active ingredient ha^{-1} before planting. The conventional tillage (CT) treatment included mouldboard ploughing, disk harrowing and/or vibrating tine cultivation to prepare the seedbed. Lopez-Bellido et al. (2007) provided information about the cultivars, planting, and herbicides applied during the growing season. Each year, the wheat plots were supplied with 100 kg N ha^{-1} and 65 kg P ha^{-1}. The fertilizer was incorporated according to standard conventional tillage practices and was applied in bands when drilling in the no-tillage plots.

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)
Soil-water ratio for pH 1:2.5	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)

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

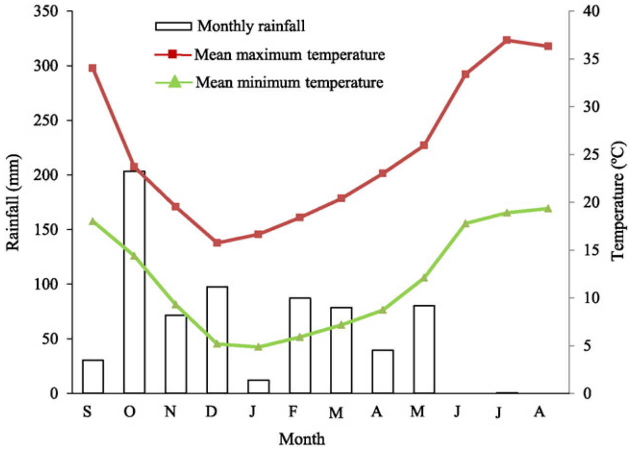

Fig. 1. Monthly and annual rainfall and mean maximum and minimum temperatures over the study period at Cordoba (Spain).

2.4. Soil measurements

2.4.1. Penetration resistance

The penetration resistance was measured in each plot of wheat and during the state of tillering by taking four random measurements using an Eijkelkamp 06.02 penetrograph to a depth of 80 cm. The readings were recorded in MPa at intervals of 15 cm, having the tip of the penetrograph use a base area of 1 cm^2 and an 11.28 mm diameter.

2.4.2. Water content in the soil at harvest

The water content was measured three times in all plots after harvesting wheat to a depth of 0.9 m and at 0.3 m intervals. Measurements were performed with a ThetaProbe ML2× (AT Delta-T Devices, UK) soil moisture sensor.

2.4.3. Manual characterization of soil cracks at harvest

a) Apparent length (m): determined with a flexible tape with a depth of 1–3 cm to avoid inaccuracies that the surface layer of these soils may cause (Dasog et al., 1988).
b) Depth (m): determined with a flexible meter stick (3 mm in diameter and 1.3 m in length). The number of measurements per crack was variable depending on the crack size, but as a rule, a measurement was taken every 30 cm of crack length. When the crack was very short, measurements were made at the ends and in the centre.
c) Width (m): determined with a calliper for inside diameters and at a depth of 1–3 cm for the same reasons as the apparent length. This measurement was made at the same points in which depths were taken following the same cadence.

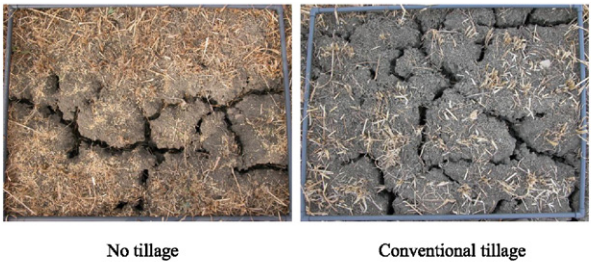
No tillage
Conventional tillage

Fig. 2. Example of photographs taken in plots of conventional tillage and no tillage.