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Evaluation of soil water content in tilled and cover-cropped olive orchards by the geoelectrical technique

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ABSTRACT

Electrical Resistivity Imaging (ERI) was performed in southern Italy, under semi-arid climate, on a Haplic Calcisol soil of two rainfed olive orchards managed according to different soil management (Tillage – T, and Cover Cropping – CC), applied for 8 years. The main aim was to test the usefulness of such geoelectrical method for the assessment of spatial and temporal variability of soil water content for water balance studies. For that purpose, the quality of univariate relationships between soil electrical resistivity (ρ) and volumetric soil water content (θ_v) was tested.

Three geoelectrical measurement campaigns were performed in the autumn–spring period of 2006–2007. For each campaign, 3 two-dimensional (2-D) geoelectrical tomographies were carried out in the pole–dipole array using a fixed electrode spacing of 0.25 m. 2-D apparent resistivity pseudosection data sets have been inverted using the software TomoLab®. Each covered soil section was 3 m in depth and 11.5 m long. On 14 November 2006 and 18 April 2007 campaigns the ERI were followed by soil samplings carried out with auger directly below the respective geoelectrical profiles. Direct measurements of soil electrical conductivity and soil water content were conducted on the soil samples in situ and in the laboratory.

Volumetric soil water content, θ_v (mm mm^{-1}), was significantly related to soil electrical resistivity data, ρ (Ω m), by the exponential model $\theta_v = 1.641\,\rho^{-0.599}$ (R = 0.866, *n* = 84). This relation allowed to assess the change of soil water content in the two orchards during the autumn–spring period and to reveal that the CC plot was more efficient to intercept and store rainwater. ERI technique allowed to highlight differences between the systems in the dynamics of water distribution along the soil profile as an effect of the adopted soil management. In particular, such technique consented to easily evaluate the extent of water content of the deepest soil layers (>1.0 m) evidencing a significant water reserve in the CC plot, convenient for the root system of rainfed olive trees in the driest months. Finally, the soil water content evaluated by means of the ERI technique was used for the short-term application of soil water balance which showed interesting data on the progress of water consumption during the autumn–spring period, particularly useful as operative indications for cover crops management.

1. Introduction

The implementation of sustainable practices in agriculture is one of the main strategies adopted by many countries in the world to contrast problems such as water shortage, desertification, greenhouse effect and pollution, which are threatening the environment and the human welfare.

Sustainable soil management technologies (i.e. ground cover by sown or spontaneous vegetation) play a fundamental role in fruit growing because they are aimed a) to improve and/or maintain soil organic matter as a key factor of physical, chemical, and microbiological soil quality; b) to prevent soil erosion; c) to increase biodiversity and ecosystem stability; d) to improve CO_2 sequestration from the atmosphere by orchard systems Furthermore, in arid and semi-arid environments, where water is the most limiting factor for crop production under dryland farming, a correct water resource management requires a large knowledge of the spatial variability of soil properties (particularly, soil structure and hydraulic properties) which strongly affect the water balance (Srayeddin and Doussan, 2009).

Traditionally, soil characteristics and their spatial variations are quantified using destructive, laborious, and time-consuming direct measurements on a wide number of soil samples which are subjected to large errors (Amato et al., 2008; Böhm, 1979, Celano et al., 2010; Hagrey and Michaelsen, 2002; Lazzari, 2008; Samouëlian et al., 2005).

Otherwise, non-invasive geophysical techniques, such as Electrical Resistivity Imaging (ERI), can be rapidly and easily performed over

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wide areas to describe horizontal and vertical variability of soil structure and properties at the scale of interest also by geostatistical approach (Tabbagh et al., 2000; Besson et al., 2010). The electrical resistivity can be affected by root systems and different soil characteristics. Hence, geoelectrical surveys are often aimed to establish relationships between the resistivity values and the other soil features (texture, water content, solute concentration). In the context of soil science, electrical resistivity allows the delineation of the main soil types and, when performed repeatedly over time, also provides information on soil functioning. The information collected is very useful for agronomists, soil scientists, civil and environmental engineers, and supports them in the sustainable management of natural resources (Samouëlian et al., 2005; Celano et al., 2010).

Also in very heterogeneous tree orchard systems, ERI technique is able to map the whole rooting zone, the moisture and salinity variations, the water flows of the soils investigated starting from electrical measurements carried out on the surface (Celano et al., 2010; Hagrey and Michaelsen, 2002; Lazzari, 2008).

Geoelectrical surveys are based on the measurement of the distribution of electrical currents induced by an applied electric field. The development of the electrical potential field depends on the resistivity distribution in the subsurface. The measurements are often displayed as two-dimensional pseudosections, that provide the spatial distribution of apparent resistivity. The distribution of the true resistivity can be obtained from numerical inversion (Samouëlian et al., 2005).

In the present study, the non-destructive ERI technique, combined with conventional methods of soil investigation, was applied to heterogeneous olive orchard systems on tilled and cover cropped soils. This combined application was aimed to verify a) the quality of univariate relationships between soil electrical resistivity (ρ) and volumetric soil water content (θ_v); b) the use of the geoelectrical technique as a tool for the assessment of spatial and temporal variability of soil water content.

2. Materials and methods

2.1. The experimental set up

The experiment was performed in a mature olive grove located in southern Italy (Ferrandina – Basilicata Region, 40°29′ N, 16°28′ E) grown under rainfed conditions. Olive trees (*Olea europaea* L. – cv Maiatica, a double aptitude variety) were vase trained and planted at a distance of about 8 × 8 m.

From 2000, the olive orchard was divided into two plots managed according to different soil management systems: cover cropping (CC) and tillage (T). The soil surface of the CC plot was permanently covered by spontaneous weeds, mowed at least twice a year. In the CC plot trees were lightly pruned each year. Crop residues and pruning material were left on the ground as mulch. Tilled plot was managed by continuous tillage (milling at 10 cm soil depth) not to have any weeds on the soil during the studied period. Heavy pruning was carried out every two years, but pruned residues were burned out of the olive grove.

2.2. Climatic and pedological characterisation of the experimental site

The climate in the area is classified as semi-arid, with an annual rainfall of 561 mm (mean 1976–2006). The mean annual temperature ranges from 15 to 17 °C.

The key meteorological parameters (air temperature, rainfall, humidity, etc.) were measured daily by a standard weather station placed close to the trial area. The reference evapotranspiration (ETo), provided by SAL service of the Extension Regional Service (www.alsia.it), was the mean value coming from the application of the following methods for ETo estimation: Blaney–Criddle, radiation, and Hargreaves.

The soil of the experimental grove is a sandy loam classified as a Haplic Calcisol (FAO, WRB, 1998) with Ap1 (0.0–0.30 m) /Ap2 (0.30–0.50 m)/Bk (0.50–1.00 m)/Ck (1.00–2.00 m) profile. It has a low gravel content and shows an increasing concentration of finely divided calcium carbonate particles in the soil matrix passing from the surface horizons (Ap soil horizons, 0.0–0.50 m) to the parental material (Ck, soil layer > 0.6 m). CC and T plots belongs to the same soil unit as verified by two pedological profiles. Soil characteristics of the CC and T plots are reported in Table 1.

2.3. Soil resistivity measurements and Electrical Resistivity Imaging (ERI)

Three geoelectrical measurement campaigns were carried out in both systems, CC and T. They were performed in the autumn–winter period at the following dates: 14 November 2006, 9 January 2007, and 18 April 2007. In each survey date, three 2D geoelectrical tomographies were performed in both the systems, studying an area of 576 m^2 per plot. Data were collected using an Iris Syscal Pro resistivity meter (ten-channel receiver) connected to a 12 V battery that resulted in a DC current amplified at 100 V. A total of 48 electrodes per geoelectrical measurement, 0.25 m spaced, were used. These specific two-dimensional (2-D) quadripolar pole–dipole sequences were designed to achieve an appropriate depth of investigation (soil profile: from 0.0 to 3.0 m). 2-D inversions of soil apparent resistivity (ρ_a, Ω.m) and their graphic representation were performed using the TomoLab® software. Particularly, such software has been tested in a lot of different conditions and for different applications and the results are generally accepted (Ribolini et al., 2010). TomoLab® software uses a finite-element algorithm in order to reconstruct the resisitivity distribution. This approach, although slow and machine intense, allows a fine tuning of the inversion process, useful to appreciate small variation in soil resistivity. Information about specific characteristics of the above mentioned software is reported in LaBrecque et al. (1996) and Morelli and LaBrecque (1996).

2.4. Soil sampling and analysis

After the geoelectrical surveys, representative set of soil samples were taken directly below the geoelectrical profiles in the CC and T plots taking into account the different soil horizons (Ap1, Ap2, Bk, Ck). A total of 84 samples were collected during the field measurements of 14th of November 2006 and 18th of April 2007 at different soil depths (from 0.0 to 2.5 m, step 0.10 m) by means of a pneumatic driller or a manual auger opening holes of 40 mm. Such sampling scheme was followed in order to have a consistent number of cases and a detailed picture of the soil water distribution.

Soil volumetric water content (θ_v, mm mm^{-1}) was obtained multiplying the gravimetric water content (θ_w, g g^{-1}) by the soil bulk density (Gardner, 1986).

Electrical conductivity ($EC_{1:2.5}$) was measured in the laboratory according to Rhoades (1982) by a Crison 525 conductivimeter (Crison, Barcelona) on a thoroughly shaken mix of soil (1.0 g dry weight) and distilled water (2.5 mL).

2.5. Statistical analysis

Field and laboratory data were splitted in three groups in relation to the pedological conditions and the studied systems as follow: I) data coming from parent material horizon (Ck) for both systems, CC and T; II) data coming from A + B horizons of the CC plot; III) data coming from A + B horizons of the T plot.

In order to identify univariate association between ρ and θ_v, different statistical models were tested for each data group. Statistical regression analysis, showing minimization of the sum of square residuals, normal distribution of the data residues, and the highest significativity of coefficients, was selected.