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Integrated geophysical techniques for sustainable management of water resource. A case study of local dry bean versus commercial common bean cultivars

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ABSTRACT

This paper deals with the combined use of non-invasive technologies for a reliable and ready measures of soil physical parameters. In particular, time domain reflectometry (TDR) was deployed for soil moisture estimation in combination with geophysical investigations as electrical resistivity tomography (ERT) and ground penetrating radar (GPR).

The investigation regarded two cultivars of dry bean (*Phaseolus vulgaris* L.), a dry bean landrace and a common bean. The irrigation of these cultivars have been carried out by drip emitters placed on the bean rows, with different irrigation regimes based on crop evapotranspiration (ETc) demand calculated from the analysis of weather data. Geophysical surveys, basesd on ERT and GPR, were performed during the growth season along transects longitudinal and parallel to the bean rows with the aim to obtain soil images for the identification and characterization of crop roots locations.

Data analysis of variance indicated that a reduction in the total irrigation amount of 50% of Etc demand ensures good conditions of soil moisture and does not determine significantly decreased production in the local bean genotype, probably because of its lower sensitivity to water stress. This confirms that the choice of autochthonous varieties well adapted to the local environment, could be a winning choice for the purpose of sustainable management of irrigation water.

1. Introduction

Dry bean (*Phaseolus vulgaris* L.) is a human food high in protein, phosphorus, zinc, iron, vitamin B1, and fiber. It is the most important legume worldwide for human consumption because is a source of protein (Ramirez Builes et al., 2011). Beans play an essential role in Italian cookery and, consequently, they are grown throughout the country. Nowadays, common bean is widely cultivated in intensive agricultural systems and new cultivars have completely replaced the old landraces. In Basilicata region (Southern Italy), areas with traditional or low input agricultural systems are still present and farmers still grow autochthonous varieties not only for personal consumption, but also for sale. This represents a good example of integration between farming activities and the enhancement and preservation of the natural landscape, thanks to the bean landraces suitable to the local environment (Piergiovanni et al., 2000; Piergiovanni and Lioi, 2010).

Water irrigation in bean crop is important due to its influence on plants and pod growth (Sezen et al., 2008), thus irrigation plays a key role in the agricultural system and in the last years many problems arise due to climate change, especially in sensitive areas such as the Mediterranean one. One of the aspects of the climate change is the distribution of the rains, which even if do not substantially alter the total amount of rainfall, can induce a water lack during critical times with a detrimental effect on the achievement of a quantitatively and qualitatively excellent production (Turral et al., 2011).

The possibility to gain information on the physical and chemical characteristics of the soil, in particular on the layer of soil explored by the roots, can offer a support in the decisions to provide right irrigation water amount with a considerable saving and a more efficient use of the resource. For example, sandy soils have low water retention and therefore require frequent irrigation with low water volume to prevent losses for percolation into the deep layers, unlike the clay soils that have greater holding capacity. In addition,

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today's agriculture must review its cropping systems, both in terms of species more or less demanding in terms of water and of selection of varieties that are more resistant to water stress (Foley et al., 2011).

The efficient use of water is one of the main objectives for the sustainable management of natural resources in agriculture. In fact, the sustainability of any irrigation strategy is ensured by optimizing the water use efficiency, calculated by dividing the grain yield or the biomass, expressed as quintals for hectare, by the amount of water added, expressed as cubic meters (Stanhill, 1986).

In general, any action, aimed at reducing the amount of irrigation water by ensuring at the same time a good production, plays a key role in improving the effectiveness of water management for agricultural purposes; in this frame, drip irrigation systems have seen widespread use in the world because they allow water to drip slowly to the roots of plants (Bozkurt et al., 2006).

Sustainable crop production intensification as increased yield per volume of used water, *more crop per drop* (Kijne et al., 2003), has to be achieved in response to climate changes, which makes the water resource a limiting factor. Sustainable irrigation methods were developed particularly in semi-arid regions, characterized by an increasingly reduction of water resources, and for most crops the best irrigation deficit for an effective use of the agricultural water use has not yet been determined (Jones, 2004; Fereres and Soriano, 2007; Gonzalez et al., 2009).

As reported by Fereres et al., (2003), three main questions must be tackled for an effective irrigation management: how much water to apply, when to apply it and how to apply it.

Unfortunately, often the farmers over irrigate with the result of high water losses for percolation in the deep soil layers and low irrigation efficiencies (Yazar et al., 2002). The capability to manage efficiently irrigation without inducing significant stress in the plants is crucial for a sustainable irrigation strategy and reliable water monitoring approaches are needed. In this context, a possible technological solution is based on the combination of different methods for estimating crop water requirements also by resorting to the use of non-invasive technologies for a reliable and ready measurement of soil physical parameters.

The water requirement of a crop must be satisfied to achieve potential yields and this crop water requirement is also called crop evapotranspiration ETc. In fact, a widespread methodology to assess the irrigation requirements of crops is based on the calculation of the crop evapotranspiration.

The water requirement can be supplied by stored soil water, precipitation, and irrigation. Irrigation is required when *ETc* (crop water demand) exceeds the supply of water from soil water and precipitation.

ETc is given as the product between the reference evapotranspiration (ET_0) and the crop coefficient (Kc), a crop dependent correction factor, and accounts for the difference in evapotranspiration between the cropped and reference grass surface for the various phenological stages of a specific crop (Doorenbos and Pruitt, 1977). The evapotranspiration ET_0 is defined as the loss of water due to the simultaneous processes of evaporation from the soil surface (E) and transpiration by the vegetation cover (T); this is a very important parameter in the hydrological cycle, as it involves the return to the atmosphere of about 75% of total annual precipitation (Bates et al., 2008). The calculation of ET_0 requires daily meteorological data and there are several empirical potential equations for calculating ET_0. A standard evaluation of ET_0 is being promoted by Food and Agriculture Organization of the United Nations (FAO) and is obtained by the Penman–Monteith equation (Allen et al., 1994, 1998).

As reported by Allen et al. (1998), the calculation procedure for crop evapotranspiration, ETc, consists of identifying the crop growth stages, determining their lengths, and selecting the corresponding Kc coefficients; adjusting the selected Kc coefficients for frequency of wetting or climatic conditions during the stage; constructing the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and calculating ETc as the product of ETo and Kc.

For soil moisture estimation, time domain reflectometry (TDR) technique can be used with evapotranspiration model applied in a given environments and for a given crop. In this way, it is possible to design a proper scheduling of the amount of irrigation water for a particular crop, which is not based on the only information about the estimated evapotranspiration (Thompson et al., 2007).

Moreover, geophysical imaging obtained by electrical resistivity tomography (ERT) and ground penetrating radar (GPR) are very attractive tools for soil characterization without disturbance (Michot et al., 2003; Samouelian et al., 2003, 2005; al Hagrey 2007; Besson et al., 2010; Bitella et al., 2015). These geophysical methods are often used in combination because in the data interpretation, the ambiguity arising from the results of one survey method may often be resolved based on results from another method.

In particular, the cross-correlated analysis of the data obtained from these geophysical surveys provides information with very high detail about the soil layers and this allows at monitoring undesired water losses for percolation into the deeper layers not interested by the roots of the crop.

This paper deals the analysis of the effect of deficit irrigation treatments on the grain yield of two specific dry bean cultivars, where TDR measurements are supported by electrical resistivity tomography (ERT) and ground penetrating radar (GPR) surveys in order to estimate the soil water spatial distribution.

2. Materials and methods

A field study was made on 2013 for a dry bean crop, during the growing season between the months of May and September. The research site was the Experimental Agricultural Farm "Pantano of Pignola" (40°33′31.34″N and 15°45′31.66″E, altitude 400 m above sea level) of ALSIA (Agency for the Agricultural Development and Innovation of Lucania), Basilicata Region, Southern Italy (Fig. 1).

The research area region is characterized by a Mediterranean climate with dry summers. The amount of rainfall is significant but often not sufficient to the water needs of the crops; in fact, crop production in the dry season (June–September) is possible only with irrigation. In 2013, during the crop cycle (June through September), the total rainfall was 180 mm about and averages air temperature (minimum, maximum and average) was 11.4 °C, 27.1 °C and 19.1 °C, respectively (Table 1). Over the past five years (2010–2014), the average values in temperature (minimum, maximum, mean) and rainfall have been for the same period (June–September), equal to 12.1 °C, 27.8 °C, 19.8 °C and 181 mm, respectively.

Granulometric analysis was performed for a 60 cm soil profile by using wet sieving and sedimentation fractionated (ASTM D422-63, 2007).

The water holding capacity of soils depend on the soil hydraulic characteristics (Milly, 1994). The hydrological characteristics of each soil are described by the Field Capacity (FC) and the Wilting Point (WP); FC expresses the percentage of water present in a saturated soil after that downward gravitational drainage has stopped, while the WP expresses the percentage of water that the plant is no longer able to absorb from the soil so that the permanent wilting occurs. The fraction of water comprised in the range between the FC and the WP is the maximum available water content (AWC) and accounts for the capability of soil to store water and hence to allow the crops to resist to more or less prolonged drought (Mannini and Genovesi, 2004).