NON-INVASIVE INSTRUMENTAL SURVEYS FOR IRRIGATION MONITORING IN AGRICULTURE. THE CASE STUDY OF A VALUE CROP

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ABSTRACT

The impact of climate change on the ecosystem of the Mediterranean Sea basin will be manifested mainly by a significant reduction in water resources, because of rising temperatures and lower rainfall despite the increase in heavy precipitation events.
Water is a fundamental resource for the metabolic activities of plants in agriculture.
Unfortunately this resource is available in limited quantities and therefore optimizing the use of water in irrigation practice is very important for a sustainable management of it, also considering the large water volumes required for the productive cycle of crops.
In the Experimental Agricultural Companies *Pantano of Pignola* (40°33'31.34"N and 15°45'31.66"E) of ALSIA (Agency for the Agricultural Development and Innovation of Lucania), Basilicata Region (Italy), a research was performed by non-invasive geoelectrical and electromagnetic surveys on the *Rosso Scritto of Pantano of Pignola Bean* crop, for precision irrigation management.
This research illustrates the preliminary results of Time Domain Reflectometry (TDR) and Electrical Resistivity Tomography (ERT) applications on the crop, for monitoring the water content in the soil and its distribution in two different irrigation treatments.
From sowing and for the entire cultural cycle, irrigation monitoring was conducted by using these non-invasive investigations, based on measurements of physical properties of the soil Instrumental surveys have shown that the high irrigation regime increases the irrigation costs because water is lost in depth in the soil, with waste of water and energy.
In addition, the reduction of the water supply obtained using TDR and ERT technologies to control irrigation, did not result in water stress to plant and the yield was better.
A good management of water helps to cut irrigation costs, with efficient use of resources as water and energy: therefore it results that the application of technologies to irrigation management can help to achieve these objectives, for a sustainable agriculture.

Keywords: Precision irrigation management, Time Domain Reflectometry, Electrical Resistivity Tomography, "Rosso Scritto" Bean crop

1. INTRODUCTION

As reported by the World Bank in the Water Program 2008, *we can contain the water*, divert it, collect it, purify it, package it, transport it and transform it, the only thing we can't do is manufacture water which makes managing it an imperative (World Bank 2008).

Water is the major environmental factor for the metabolic activities of plants, but this resource is available in limited quantities and therefore optimizing the its use in agriculture is very important for a sustainable management of this resource, also considering the large water volumes required for the productive cycle of crops.

The impact of climate change on the ecosystem of the Mediterranean Sea basin will be manifested mainly by a significant reduction in water resources, because of rising temperatures and lower rainfall despite the increase in heavy precipitation events (Bates et al. [1]). In particular, increases in the frequency of extreme climate events during specific crop development stages (e.g., heat stress during the flowering period, rainy days during sowing), together with higher rainfall intensity and longer dry spells, are likely to reduce the yield of crops (Parry et al. [2]) therefore, in European Mediterranean regions with arid and semiarid climates, the use of irrigation systems to maintain soil moisture at optimum levels for plants, is often essential to achieve good crop productions.

Evapotranspiration (ET) is the combination of water evaporated from the soil surface and the water transpired by plants and if rainfall or irrigation does not compensate this loss of water from the soil, the level of soil moisture is reduced with plants that slow growth and eventually wilt and die. In presence of inadequate rainfalls or absence of these, irrigation is used to maintain soil moisture at optimum levels for plants of a crop. In different types of soils, the ratio soil-water is characterized by several hydrological constants as Field Capacity (FC), Wilting Point (WP) and Available Water Content (AWC). These soil moisture characteristics are constant for a given soil, but vary widely from one type of soil to another (Veihmeyer and Hendrickson [3] Salter and Williams [4]).

When water is applied on a crop, the rate at which it moves through the soil depends on the soil type, in fact, in clayey soils the rate of water is enough slow conversely, in sandy soils the rate is quite rapid. After an irrigation, if water applied for a determined depth is in excess than the soil can retain, the upper layers of the soil may become saturated, and all soil pores are filled with water.

The excess water drain into deeper layers, under the force of gravity, and after that the drainage has stopped, the soil is said to be at field capacity, with the large soil pores filled with both air and water while the smaller pores are still full of water.

At field capacity, the soil is ideal for crop growth for the water and air contents.

In fact, initially plants are easily able to draw water from the soil, successively it becomes difficult for plants to absorb water which is retained more strongly as the soil dries out, and thus the physiological activity of plants is slowed. The soil moisture at this stage is known as the critical or stress point, and is the point at which irrigation should be applied to return plants to full activities, that depends on vegetable species.

Since evaporation processes from the topsoil into the atmosphere and of uptake by the plant roots of the water stored in the soil, if no additional water is supplied, the soil gradually dries out, and the plants have difficulty to extract water from the soil and dies. At this stage the soil reaches permanent wilting point and the remaining water is no longer available to the plant. The amount of water stored in the soil between the stress point and field capacity is called water available (AW) to the plant, and it depends greatly on the soil texture and structure. The forces holding water are surface-attractive forces, in clayey or loamy soils the amount of water available is greater than in sandy soils just because clay rich or organic (loamy) soils can hold much more water than sandy soils.

The metabolic activities and then the growth of plants are not limited if the soil moistures between the stress point and field capacity are kept, and an efficient irrigation is obtained when enough water is applied to return soil moisture to a level around the field capacity.

Of course, with the use of the technologies the opportunity to know the current soil moisture status and how it is distributed in the soil is useful to determine the actual water requirement of a crop, with the result of optimizing the use of water in irrigation practice for a sustainable management of it, considering also the considerable water volumes required for the productive cycle of crops.

The objective of this study was to monitor over time the spatial distribution of the soil moisture on an irrigated bean crop with non-invasive investigations, based on measurements of physical properties of the soil using Time Domain Reflectometry (TDR) and Electrical Resistivity Tomography (ERT) applications.

2. MATERIALS AND MEASUREMENTS

2.1. Experimental procedures

A field experiment was carried out at the Experimental Agricultural Companies *Pantano of Pignola* (40°33’31.34”N and 15°45’31.66”E) of ALSIA (Agency for the Agricultural Development and Innovation of Lucania), Basilicata Region, Southern Italy (figure 1). The climate is Mediterranean, and in the 2011, the summer season (June, July and August) was characterized by good weather and a few storms in fact, there were long periods of drought and maximum temperatures exceeding 30°C, with average temperatures around 20°C.

The total rainfall for this period was 120 mm, divided as 62.2 in June, 14.6 in July and 43.2 to August; values in line with the seasonal average.

In the period September and October, there were little rainfalls with moderate temperatures, (table 1).

The soil was clay loam (sand 32.6%, silt 32.2% and clay 35.2%).

The field experiment for precision irrigation management was performed on the *Rosso Scritto of Pantano of Pignola Bean* crop.

The bean crop (Phaseolus vulgaris L) was seeded, ordered in rows, on the first days of June 2011 and harvested in the second half of October 2011, for a growing period of 140 days about.

The flat experimental plot soil was an area of about 1000 m^2, was 48 m long and 22.5 m wide.

Figure 1 Field experiment location (Google Earth 2010)

On the basis of soil water characteristic estimates (Saxton and Rawls [5]), the water content at the field capacity is equal to 35.4 % vol. and the wilting point corresponds to 21.8% vol. Then for a depth of 200 mm, corresponding to the useful layer of soil explored by bean crop, the FC and WP correspond to a column of water of 71 mm and of 43 mm respectively. While the AW calculated as FC minus WP was 27 mm.
A drip system irrigation with water that was pumped by a nearby water reserve represented by a small artificial lake, was used to irrigate.

Table 1 Meteorological data

Months	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	ET0 (mm)
June	18.2	77.9	62.2	158.7
July	20.7	72.5	14.6	185.8
August	21.8	71.3	43.2	177.2
September	19.2	84.0	80.4	118.3
October	11.8	92.5	11.8	61.8

2.2. Irrigation Monitoring

The aim of this field experimental proof was to know, using TDR and ERT techniques, the current soil moisture status and how it is distributed in the soil; that is useful to determine the actual water requirement of a crop, with the result of optimizing the use of water in irrigation practice for a sustainable management of it.
During the crop cycle, on two distinct rows, separated by two more rows, the soil moisture was determined over time by TDR, using 8 probes 0.20 m long each, installed vertically from the soil surface, at the center and at the ends of two rows. Moreover, the soil water distribution was determined by two-dimensional electrical resistivity tomography using a multielectrode method.
The experimental parcel of land was subdivided in two experimental unit, named unit A and unit B, each including the two rows of bean crop subjected to instrumental monitoring.
The number of irrigations was the same for both units while a different irrigation scheme in terms of volume of water given was adopted.

In the experimental unit A, on the basis of the obtained values of soil moisture recorded with TDR, irrigation was applied when average soil water content within top 20 cm layer has been reduced to 70% of field capacity, corresponding to the critical point of soil water content of 50 mm.
In this case the use of ERT has allowed verifying the distribution of water in the soil, allowing bettering managing the supply of water, stopping the irrigation when the water had occupied the useful layer explored by roots. In this way, it was possible to reduce the supply of water and avoid that the same could be lost in the deeper soil layers.

Instead, in experimental unit B, the amounts of water supplied during the irrigation were managed by the farmer at his discretion, as it often happens, and the instrumental monitoring recorded only the values of soil water content and its distribution.
Soil resistivity measurements using the Wenner-Schlumberger arrays, were performed with the resistivity meter Syscal R1 (Iris Instruments, Orleans, France) equipped with 32 electrodes, aligned on the soil surface along the two bean rows, with an electrode spacing of 0.2 m and a total length of 6.2 m.
To obtain 2D resistivity models, the data obtained were interpreted through the inversion algorithm, RES2DINV, proposed by Loke [6]. The measured values of apparent resistivity provide, in fact, a first preliminary image of the electrical subsurface structure denominated as the ‘pseudo-section’. In a second step, the apparent resistivity measurements were transformed into true resistivity values using the rapid inversion algorithm of Loke &Barker [7].
The inversion routine is based on a smoothness-constrained least-squares method inversion algorithm, that divides the subsurface into rectangular blocks, and the resistivity of the blocks is adjusted to minimize iteratively the difference between the computed and the measured apparent resistivity values; the root mean square (RMS) error gives a measure of this difference (Loke & Barker [7], Sasaki [8]).
Soil water infiltration and soil drying by evapotranspiration were observed by comparison of resistivity sections measured before and after the irrigation of the soil.
Soil volumetric water contents were measured during ERT acquisition with the MiniTrase TDR (Soilmoisture Equipment Corp., California, USA), using for each row, 4 probes of 0.20 m long. The relationship between relative dielectric constant and soil water content is described by a third-degree polynomial (Topp et al. [9]).

3. RESULTS AND DISCUSSION

The significant correlation between water content and the dielectric constant K of the soil measured through the use of TDR, has allowed to follow the trend of soil moisture concerning two experimental units, for the whole period in which it was irrigated.

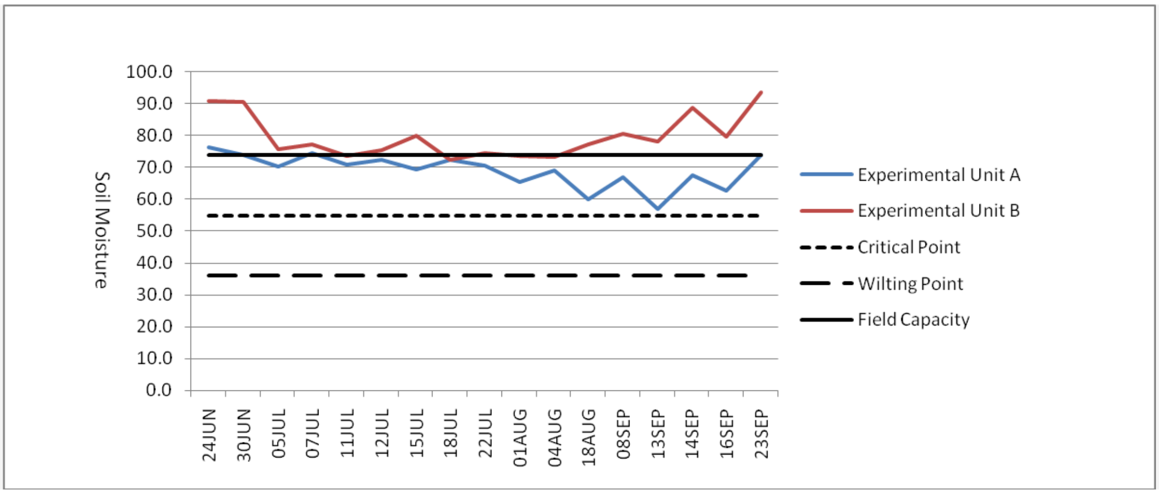

Figure 2 Soil moisture measured over time during the crop cycle

Figure 2 shows this trend, in particular we can see that in the experimental unit in which the irrigation water supply has been managed by the farmer, without the support of non-invasive technologies, the soil moisture has reached high values, overcoming the field capacity (FC) of our soil.

On the contrary, in the experimental unit where irrigation management, in terms of quantity of water given to the crop, was conducted with the support of information obtained from non-invasive investigations with ERT and TDR systems, the values of soil moisture were lower, of course. In particular in this case, the trend of the soil moisture was between Field Capacity and Critical Point.

The differences on the distribution of water in the soil, in the two experimental units with different irrigation schemes were identified with geoelectrical investigations that have produced electrical resistivity tomography.

Electrical resistivity in the soil decreases when the soil water content increases, and increases when the soil moisture decreases.

The measured resistivity sections (figure 3), show that in the controlled irrigation scheme (experimental unit A) the water is distributed, mainly in the first 20 30 cm, in contrast to what has occurred with the experimental unit B where excess water is percolated in the deeper layers not explored by the roots of the crop.

It is evident that the higher irrigation scheme increases the costs for the increased recourse to water that is lost in depth, and energy costs for irrigation.

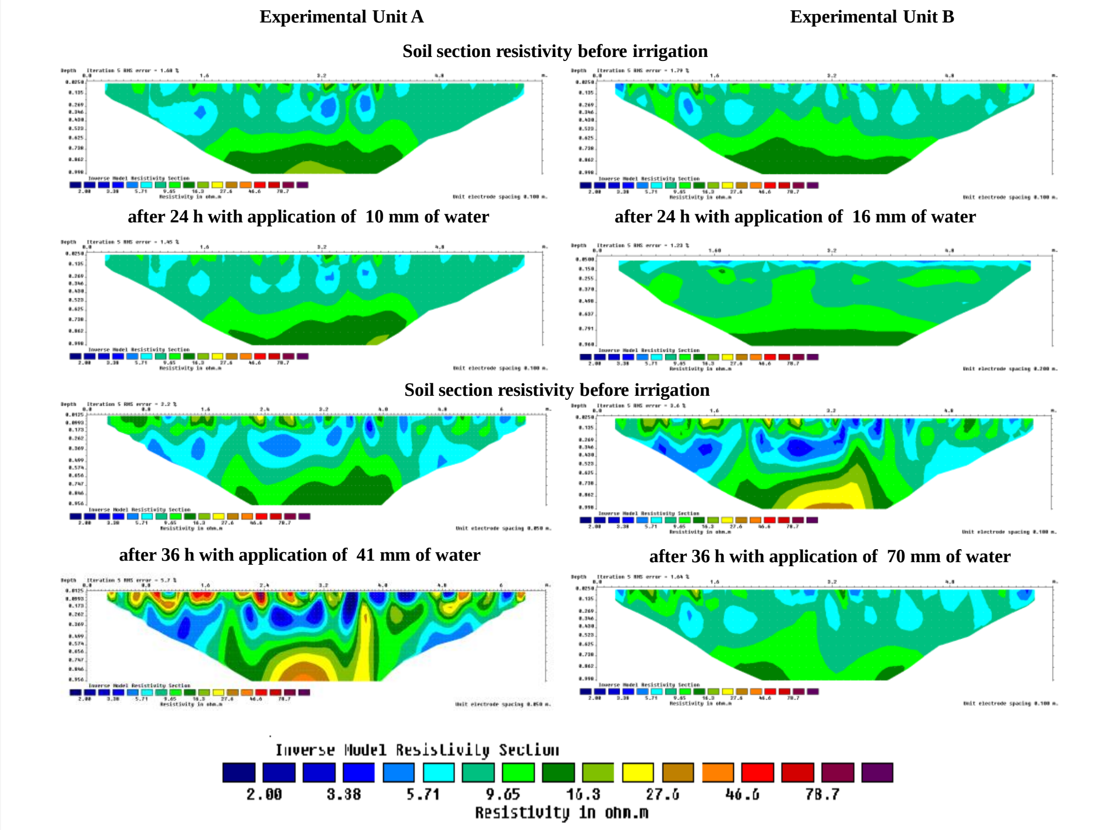

Figure 3 Soil section resistivity measured during water infiltration after drip irrigation

However the reduction of the water supply has not determined conditions of stress to the plants and the bean yield was better, in table 2 the results obtained on the crop yield are reported.

Table 2 Bean crop productivity according to irrigation scheme

	Experimental Unit A	Experimental Unit B	P value
Number of pods/plant	36.7 ± 25.15	13.7 ± 8.39	0.207302
Mean length pods	8.5 ± 1.41	7.4 ± 1.63	0.041487
N°seeds/pod	4.4 ± 1.19	3.4 ± 1.16	0.002334

4. CONCLUSIONS

Based on the results obtained with this work, we can say that a reduced water supply controlled by non-invasive surveys does not affect the bean yield, moreover a reduced water intake results in greater environmental sustainability of crop.

Therefore, the use of non-invasive technologies contributes to the achievement of these objectives; of course, more evidence is needed to confirm the many advantages of this technique and opens interesting perspectives for optimizing water use in irrigation practice for the sustainable management of it.

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