A CONTROL SYSTEM TO ACHIEVE OPTIMUM SOIL WATER CONDITIONS FOR PLANT GROWTH

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Abstract: In this paper, a drip irrigation control system based on measurements of soil water content has been presented. In order to achieve optimum soil water conditions, we have to place a moisture sensor within the zone of soil volume saturated by average soil water content. Concerning the deep root plants, the solution of installing two or more sensors, has been decided. The core of the control system is the unit IRCO-19. The control loop of embedded software is continually repeated, collecting new input values. In every measured value deviation from the requested limits of minimum (LVAL) and maximum (HVAL) soil water content, the control unit regulates on the electric valves of the drip irrigation system. The experimental validation of control instrumentation IRCO-19 was done in the area of Larissa (Greece) during the summer time of the years 2005 and 2006.

Keywords: Irrigation automation, soil moisture sensor, drip irrigation system.

1 Introduction

The relationship between crop production and the amount of irrigation water applied to the plants is very important. The aim of irrigation control is to avoid the detrimental effects of water stress on the plants and save water. Of course, the measurements of soil water content and the capability to control it, in order to achieve optimum water conditions for plant growth, is not a new idea. It is known and made more researchers to develop automated irrigation systems.

Since 1960 there is a continuous improvement in the efficiency of water use, which is accomplished by scheduling of the irrigation on basis of climate parameters, plant water potential and measured soil water content. Waugh and Corey (1963) describe different systems by which the plants could be grown at constant soil water content. Fischbach et al. (1970) developed an irrigation control system using tensiometers. One of the disadvantages of tensiometer is that it cannot follow rapidly changing soil water conditions. Phene et al. (1973) developed control for an automatic irrigation system with soil matric potential sensor that operates on the principle of heat dissipation rate in a porous block. Cuming (1990) developed an irrigation control system, which includes a soil moisture sensor that controls the common lines of various irrigation systems. A timer is activated whenever the soil moisture sensor placed in the root zone allows it to be watered. Frankovitch and Sarich (1991) developed an automatic plant watering system consisted of an electronic switching system that controls pumping time. The flow rate of water is controlled by a valve system. Stenitzer (1993) presented recommendations for irrigation scheduling with gypsum blocks. A pilot block placed 20-40 cm deep indicates the need for irrigation. A second control block, at a depth of 60-70 cm, signals percolation losses as a result of too high irrigation applications. Gypsum blocks have small sphere of influence and so give soil water measures in one spot. Malicki and Skierucha (1989) described the principle of operation of a simple, manually controlled Time Domain Reflectometer (TDR) for soil water measurements, which operates with needle pulse of 300 ps rise–time. Lukangu et al. (1999) obtained laboratory and field measurements of soil water content using a frequency-domain reflectrometry (FDR) sensor to predict the start and termination of irrigation.

The term "automated" irrigation applies to any irrigation system that is controlled by something other than the direct actions of a person. Typically it means any irrigation system where irrigation is initiated by a control system using operator settings and measured environmental conditions. Two general types of automated irrigation systems are used: i) open control loop systems and ii) closed control loop systems. Open control loop systems are constructed in such a way that an irrigation timer is used to start/stop irrigation. Operator makes the decision of the amount of water and the time that it should be applied. The first devices were composed of clocks that were converted to timers that controlled the electric valves. Today, several designs are commercially available with many different features and over a wide range of costs (Zazueta et al., 2002). The closed control loop systems have feedback for sensing equipments, make decisions and apply them to the irrigation systems. The general strategy is defined once by the operator and the control system takes detailed decisions on how much water to apply and when. The early generation of programmable controllers was complex and bulky. The most outstanding progress in the last decades occurred by the incorporation of integrated circuits (IC), which increased the capabilities of automation and reduced the cost. Programmable Logic Controllers (PLC) and industrial microcomputers replaced the early generation of controllers (Sne, 2005).

Numerous soil moisture-sensing instruments based on different techniques have been commercialised. Classical soil monitoring devices such as tensiometers and modified gypsum blocks are available along. The soil moisture neutron probe, based on neutron scattering by the hydrogen atoms of water, was developed about 40 years ago. However, due to the mounting pressure against the utilisation of any radioactive source, it is becoming increasingly difficult and expensive to use the neutron probe. More recently, non-radioactiv devices have been developed, including time domain reflectometry (TDR) and capacitance probes (CP). Both devices measure the dielectric capacity of moist soil in situ.

The objectives of this paper is to test whether the control system can achieve optimum soil water conditions for plant growth and close to a set point for a long period and within an acceptable range of the targeted values.

2 Materials and methods

The control system is based on data acquisition of environmental parameters, such as, soil water content and solar radiation. Therefore, this type of system requires feedback loop for sensing equipments (sensors). Depending on the feedback of the sensors, the irrigation decisions are made and actions are carried out if they are considered to be necessary. The decisions based on the comparison between the direct measurements of soil water content and a desired state. Figure 1 shows the block diagram of the automated control system, each of the hardware elements is described below.

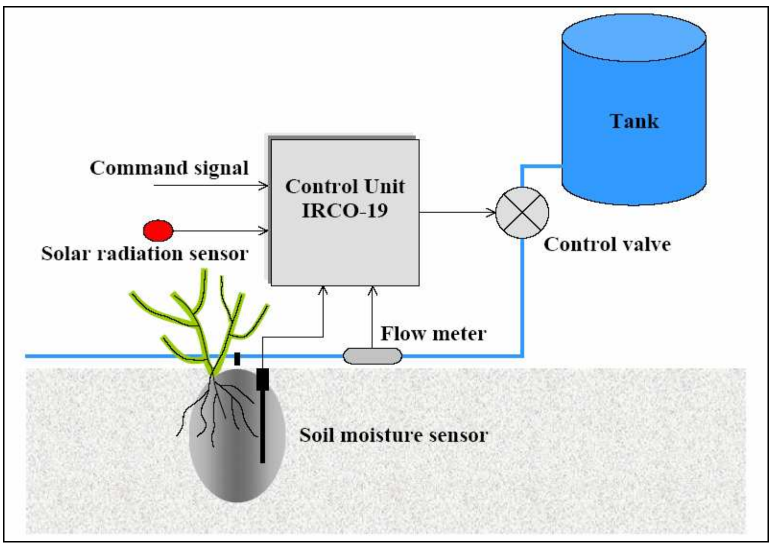

Figure 1 - Block diagram of automated control system.

The prototype of specially designed unit IRCO-19 that is solely dedicated to control task and is evolution of the device IRCO-09 is presented in Figure 2 (Gravalos, 2003). The core of the control unit is an Intel's microcontroller. It is a single CMOS 8 bits microcontroller with 128x8 RAM and 32 programmable I/O lines. Two other circuits, an address register and an external memory EPROM support the microcontroller. The control unit has 8 analog inputs and outputs for the connection of sensors and actuators respectively. Since, microcontroller works internally with digits, the analog output resulting from each soil water sensor must be converted to digital data. This is done through Analog to Digital (A/D) converter. The user can input the desired operation parameters by an array of 4 DIP switches. In those parameters, the minimum soil water limit (LVAL), the maximum soil water limit (HVAL), the solar radiation limit (INZL) and the maximum irrigation time (TZ) (defined at 6 hours) are included. If, by error, we define the minimum soil water limit larger than maximum, the right-hand decimal point on the led display automatic starts lighting. On the led display of control unit the measured values are depicted. It consists of four 7-segment units. The choice of the above electronic components was done exclusively with the criteria of the wide experimental capabilities and the low cost of the prototype device IRCO-19.

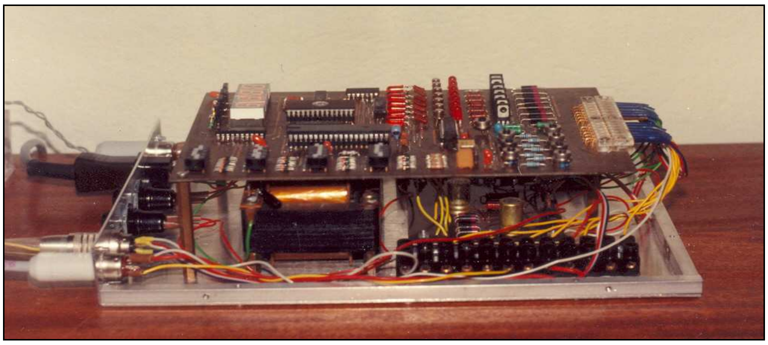

Figure 2 - The prototype of specially designed control unit (IRCO-19).

A great number of soil moisture sensors have been developed the last decades. However, the information with regard to their performance is limited, while the comparative studies that have been realised are not despite minimal. The type of soil moisture sensor, which used in this study, was Virrib (Fig. 3). The Virrib sensor selection was done between six other dielectric sensors (ECH_2O, Aquaflex, SM200, Gro-Point, Virrib και Acclima), according to their technical characteristics, the satisfactory precision of their measurements and the possibility of easy interface with electronic systems and the low cost (Gravalos, 2006). The Virrib soil moisture sensor consists of two stainless steel concentric circular rings (electrodes of diameters 28 and 20 cm). Measurements of soil water content using the Virrib sensor are made by means of an electro-magnetic wave between these two electrodes. The sensor produces an output between 5 and 55 mA, which corresponds to a soil water content range from 5 to 55 % v/v. Soil moisture measurements using the Virrib sensor are reported to be independent of the soil's chemical properties. Due to the diameter of the outer electrode and the layer thickness over which the sensor output responds (approximately 12 cm when installed parallel), the sensor provides average soil moisture measurements for a 20 l volume of soil.

Avoid the irrigation during summer cloudless days (mainly in midday hours) using a solar radiation sensor. The radiation was measured 1 m above the canopy. Solar radiation sensor was designed and constructed to be able to measure within predefined range. It is based on general-purpose photodiode IPL10020BW and its photocurrent conditions by an operational amplifier and other compensating and filtering elements. The using photodiode is not the ideal sensor but is suitable for orientation measurements and has low cost.

Figure 3 - Soil moisture sensor Virrib under laboratory conditions.

This control system can automatically collect, record and control the soil water content in the root zone of plants in real time. It is also possible to be connected with other devices such as flow meter and pressure transducer to perform technical diagnosis of irrigation system.

3 Results and discussion

Effective irrigation management requires soi1 water content data to ensure higher water use efficiencies and to achieve better yields. Thus, the sensing equipment should measure soil water quickly and accurately. In order to verify the accuracy and repeatability of commercially available soil water Virrib sensors, we have tested the ability of these sensors to provide reliable results for different soil types and water salinity levels. The experiments were conducted under controlled laboratory conditions and over more drying cycles for water contents decreasing from FC to PWP by volume. Therefore, sensors were set up in plastic boxes with soil of known physical and hydrological properties. The Virrib sensors were installed horizontally. Soil was wetted up to saturation and allowed to drain to FC and weighed periodically to determine the gravimetric water contents. Afterwards, calculated volumetric soil water contents were compared with values obtained from the sensors. Figure 4 illustrates the Virrib readings as function of calculated volumetric content. Each data point represents the mean value of the measurements from the sensor. Virrib sensors respond to soil water content variations and gave very accurate results in the 12 to 20 % range.

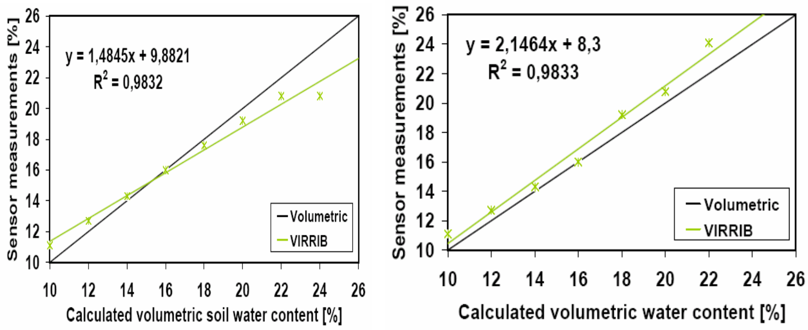

Figure 4 - Comparison of volumetric soil water content as determined by Virrib Sensor and from calculated volumetric content: a) in loam and b) in sandy loam.

The soil water sensors were placed into the root zone of plants in depth at 20 cm. The DIP switches of the control unit IRCO-19 were put into the limits of minimum soil water (LVAL) and the maximum soil water (HVAL) according to the soil type, while the measurement values are depicted on led display. The experimental validation of control system was done in the area of Larissa (Greece) during the summer time of the years 2005 and 2006. For the experiments, two different soil types were used, one with low and the other with high infiltration (table 1). The measurement recordings were done in predefined time intervals and the results are processed by diagrams (fig. 5, 6, 7).

Table 1- Physical and hydrological properties of soil types

Soil type	Sand [%]	Silt [%]	Clay [%]	Bulk density [g/cm^3]	Field capacity [% Vol.]	Permanent Wilting point [% Vol.]
A	44	40	16	1.35	24	10
B	69	22	9	1.50	18	7

From the following diagrams it is clear that soil water content was always into the desired values of LVAL and HVAL, which composes fraction of available water. At the soil B, due to high infiltration, the falling of soil water is faster in relation with the other soil type A, which is smoother. The user must give special care for the determination of operation parameters (LVAL, HVAL). The method of these parameters determination is experimental. For monitoring the soil water content in deep root zone plants two sensors were used. The first was placed at a depth of 20 cm and the second at 60 cm. By placing one soil moisture sensor in the root zone (across) and another sensor below (parallel), we have maintained crops at optimal hydration and monitor excess irrigation. The soil water in the superficial layers at depth 20 cm has high excitation due to disturbances, in contrast with deeper layers at 60 cm, when the soil water content is more stable.

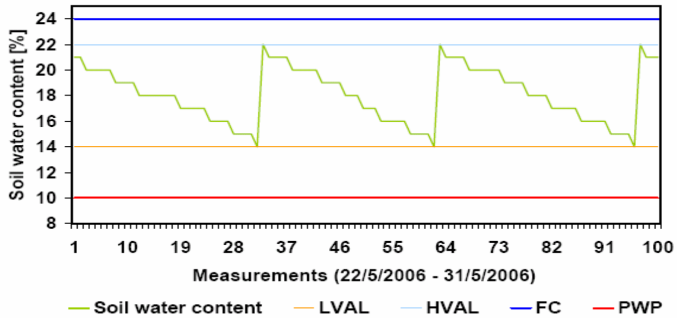

Figure 5 - The soil water change at soil type A in depth 20 cm and its regulation by control system.

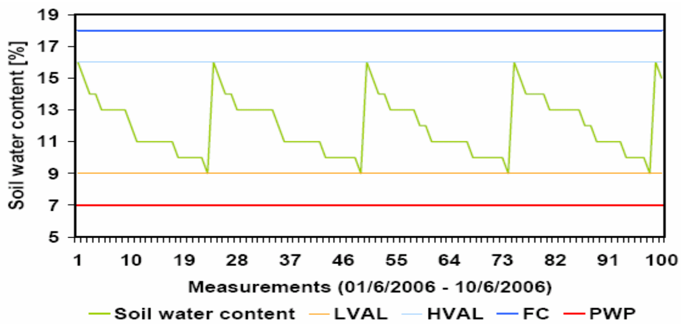

Figure 6 - The soil water change at soil type B in depth 20 cm and its regulation by control system.

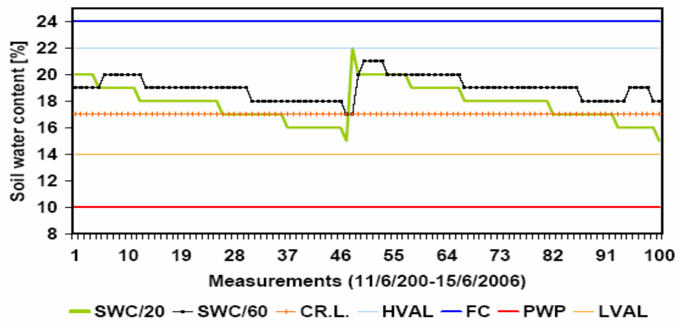

Figure 7 - The soil water changes at soil type A in depth 20 cm and 60 cm and their regulation by the control system.

4 Conclusions

This paper presents a feedback irrigation control system in real time. From the experimental validation of the control system, it is obvious that it is possible to create optimum conditions for the plant growth, despite the changes of wind velocity, temperature and relative humidity of the environment. The measurements and the regulation of soil water were done automatically. The normal growth of plants confirms that there are not dry periods in the root zone during the summer hot days in Larissa (Greece), while the water consumption was limited. The major water consumption was observed during the months of July and August.

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