Water saving with a PLC based adaptive irrigation system

SHAHIDIAN, S.[1] , SERRALHEIRO, R.P.[1], TEIXEIRA, J.L.[3], SANTOS, F.L.[1], OLIVEIRA, M.R.G.[2], COSTA, J.L.[5], TOUREIRO, C.[1], HAIE, N.[4], MACHADO, R.M.[2]
[1, 3]Department of Rural Engineering
[2]Plant Production Department
[4]Department of Civil Engineering
[1, 2]University of Évora
[3]Instituto Superior de Agronomia
[4]Universidade do Minho
[5]Câmara Municipal de Évora
Address [1]Largo dos Colegiais, 7000 Évora
PORTUGAL
shakib@uevora.pt

Abstract: - Irrigation is presently the main user of world´s fresh water. Most of it goes to irrigating small plots where it is not feasible to implement full-scale Evapotranspiration based irrigation controllers. The dramatic development of Programmable Logic Controllers, PLCs, and their rather affordable price has made it possible to use them as stand-alone irrigation controllers. In this paper a PLC is used to adapt the daily irrigation amount to actual ETc, using a Hargreaves-Samani type equation. Once the ETc is calculated, then the PLC manages the irrigation according to the specifications given by the farmer. First year results indicate an 8% saving in irrigation water.

Key-Words: - PLC, irrigation, automation, Hargreaves, irrigation controller, Evapotranspiration.

1 Introduction

Municipalities waste thousands of cubic meters of purified water to maintain the parks and green areas in cities and towns. They rely on controllers with a fixed schedule to operate the irrigation systems. These controllers are usually programmed for very hot and dry conditions, and waste a lot of water on cooler or clouded days. Farmers with drip systems also use fixed schedule irrigation programmers and thus waste large amounts of water in cooler days.

The purpose of this work is to develop autonomous irrigation systems that use simple climate criteria to adapt daily irrigation amounts to plant needs. Criteria such as temperature, total radiation and total wind can be measured directly by PLCs which then adapt the irrigation schedule to the observed conditions, saving great amounts of water.

Thus, this work intends to develop a cost-effective, reliable and easily deployable irrigation controller that is adaptive to daily climate conditions, without the need for expensive sensors and costly weather-stations.

2 Present day irrigation controllers

Water is becoming one of the most precious natural resources. Meeting future water needs requires aggressive conservation measures. This requires irrigation systems that apply water to the landscape based on the water requirements of the plants. Many irrigation controllers have been developed for automatically controlling application of water to landscapes. Known irrigation controllers range from simple programmers that control watering times based upon fixed schedules, to sophisticated devices that vary the watering schedules according to climatic conditions.

With respect to the simpler types of irrigation controllers, farmers, Municipalities and comercial owners of green areas typically set a watering schedule that involves specific run-times and days, and the controller executes the same schedule regardless of the season or weather conditions. From time to time a technician may manually adjust the watering schedule, but such adjustments are usually only made a few times during the year, and are based upon the technicians perceptions rather than actual watering needs. One change is often made in the late Spring when a portion of the plants become brown due to a lack of water. Another change is often made in the late Fall when the homeowner assumes that the vegetation does not require as much watering. These changes to the watering schedule are typically insufficient to achieve efficient watering.

More sophisticated irrigation controllers measure evapotranspiration rate to establish the amount of water to be applied to the crops. Evapotranspiration is the water lost by direct evaporation from the soil and plant and by transpiration from the plant surface. Potential evapotranspiration (ETo) can be calculated from meteorological data collected on-site, or from a nearby location. The standard methodology consists in calculating ETo through FAO Penman-Monteith method, using data from weather stations [1]. It is a method with strong likelihood of correctly predicting ETo in a wide range of locations and climates and has provision for application in data-short situations [2]. The Penman-Monteith method can be expressed as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where:

ET_o – reference evapotranspiration [mm day^{-1}],
R_n – net radiation at crop surface [MJ m^{-2} day^{-1}],
G – soil heat flux density [MJ m^{-2} day^{-1}],
T – air temperature at 2 m height [ºC],
u_2 – wind speed at 2 m height [m s^{-1}],
e_s – saturation vapor pressure [kPa],
e_a – actual vapor pressure [kPa],
e_s-e_a – saturation vapor pressure deficit [kPa],
Δ – slope vapor pressure curve [kPa ºC^{-1}],
γ – psychrometric constant [kPa ºC^{-1}],

The great disadvantage of this type of systems is the cost involved in acquiring and processing the information necessary for calculating the ETc which limits their use to large irrigated areas [3]. This has encouraged the search for a robust and practical method that can be based on a reduced number of weather parameters for computing potential evapotranspiration (ETo), and the creation of a series of different methods such as the Blaney-Criddle, the modified Jensen-Haise, the FAO Blaney-Criddle, the FAO Radiation and the Priestley-Taylor method [4] [5] [6] [7].

Teixeira et al. [8] studied six different methodologies for estimation ETo, and concluded that the results obtained by the Hargreaves-Samani method, based only on temperatures, are similar to the other 5 methods, and since it was the only one that did not need calibration, it could be used for estimating ETo without any additional sensors.

The Hargreaves-Samani method can be expressed as:

$$ET_o = \alpha(T + 17.78)(T_{\max} - T_{\min})^{0.5} R_a$$

where:

T_{max} – maximum air temperature [ºC],
T_{min} – minimum air temperature [ºC].
R_a – extraterrestrial radiation [MJ m-2 day-1],
α - calibration constant which is 0.0023 for the study area.

PLCs are “Programmable Logic Controllers” that are being used extensively in manufacturing processes. They have a processor, some form of keyboard and screen, have input ports and the capacity to command a number of electric devices through relays. Originally expensive and limited in capacity, PLCs have evolved tremendously in recent years, and today squeeze innumerous functions into a box the size of a mobile phone.

The aim of this research is to develop an economical PLC based system that automatically adapts the application depths to actual weather conditions, using simple criteria, and then executes the irrigation accordingly. This system can be mass produced and adopted by farmers, municipalities and companies in any country where irrigation is needed during some part of the year.

3 The adaptive PLC irrigation controller

An Industrologic IC51 controller was selected due to its particular characteristics, including the fact that it has 8 relays, so it can simultaneously control eight independent irrigations sectors. It is based on a Atmel AT89C51 processor and can be configured with up to eight 12 bit A/D inputs which are essential for reading air temperature values.

The programming language is Tiny Machine Basic written specifically for the hardware on the IC5. Given the limited memory of the controller, (8K EEPROM) Tiny Machine Basic was used as the only valid programming tool.

A 1k thermister with a 1% accuracy was used to determine the temperature. It was connected in half duplex to the analog I/O port. The thermister was placed in a ventilated and shaded box, adjacent to the field, so that the readings were not influenced by sunshine or by the crop transpiration which usually decreases air temperature.

An unanswered question was the height at which the thermister should be placed since it is known that temperature changes with height above the plant canopy. In order to answer this question a series of thermisters were placed at different heights between 0.5m and 2.5m, and the temperature variations were measured. Fig. 1 shows the difference in temperature at different heights over a 24 hour period. The data show that temperature reading is maximum at 2.5 m height, and minimum at 0.5m. These results indicate that the t_{max}-t_{min} component of the equation increases with height. To estimate the effective influence of height on ETo, this parameter was calculated for the different heights studied, and the results are presented in Fig. 2. It was thus decided to carry out readings at a height of 1.5 m, in order to obtain a more precise and realistic measurement of the air temperature.

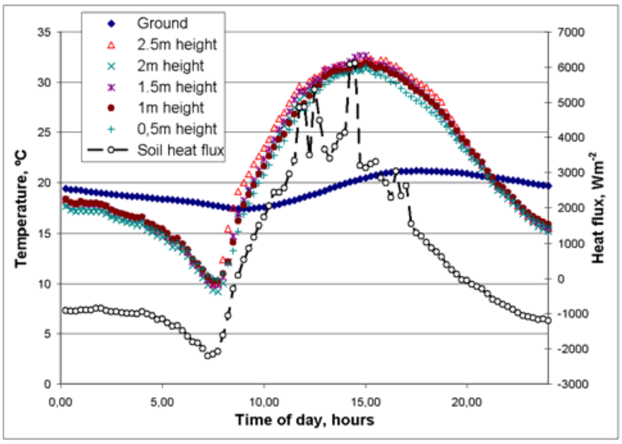

Fig.1. Evolution of ground and air temperature at different heights. Heat flux from the soil was also measured, and it clearly indicates a positive flux of heat to the soil during the daylight hours.

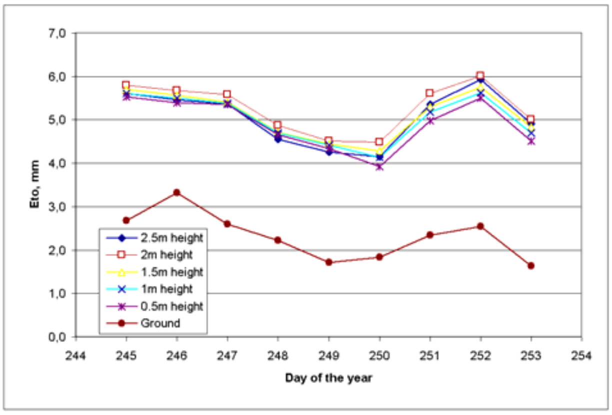

Fig.2 ETo calculated from temperatures measured at different heights.

The PLc was programmed to carry out hourly readings, and at the end of every 24h period, calculate the average, maximum and minimum temperature. With this information it calculated the ETo using the Hargreaves equation. The main challenge of working with the IC51 is that it uses only 8bit numbers, thus larger numbers had to be avoided. Also Tiny Machine Basic does not have many mathematical functions, so, for example, the square root function had to be carried out resorting to a square root table nested in the program.

4 Results

A 2000m^2 field located in Évora, Portugal, was prepared and planted with corn. It was divided into three repetitions with two treatments: Standard irrigation using commercial irrigation controller, and the PLC-controller developed in this work, using calculated daily ETo. The standard irrigation controller was set to irrigate according to the peak irrigation needs for the average year, that is 5.36 mm day^{-1}.
Corn was planted on the 10th of May, and it was irrigated accordingly until harvest. Daily temperatures, as well as daily water applications were registered. Fig.3 shows the daily water application according to the two treatments during a 45 day period at the end of the season. It is possible to observe that the controller was able to adjust the irrigation amount to the decrease in crop needs, while the standard controller continued to apply the pre-programmed depth of water. The average amount of water applied by the PLC-controller was 4.98 mm day^{-1}, while the standard controller applied 5.36 mm day^{-1}.
The results indicate that the program responded well to changes in temperature and was able to correctly adapt the water application to the ETo in the field. Actual water saving from the use of the PLC was only 8% in this trial, although it resulted in some increase in total corn yield, when compared to the standard irrigation controller. The yield increase was not statistically significant.

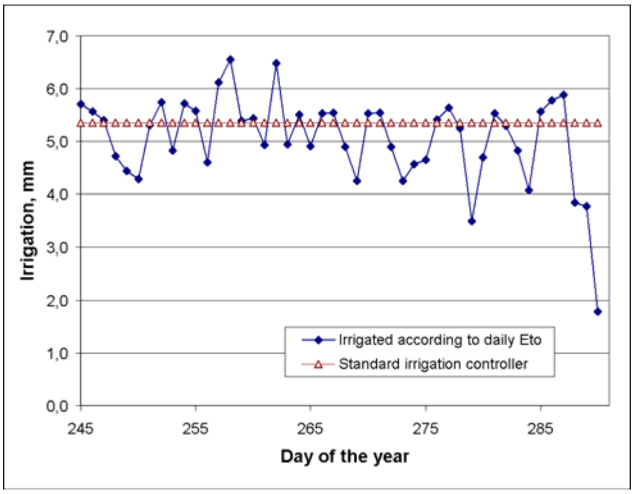

Fig.3 Daily irrigation depth in each trial.

5 Conclusion

A rather inexpensive PLC was used to make hourly measurements of air temperature at a height of 1.5m. These temperatures were registered and used by the PLC to calculate daily Evapotranspiration from a corn-field. The program then used this information to apply the exact depth of water needed by the crops to ensure maximum production.

The first year results were very satisfactory indicating an 8% water saving, along with some increase in crop yield, when compared to irrigation with a fixed water depth using a standard irrigation controller.

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