Drip irrigation using a PLC based adaptive irrigation system

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Abstract: - Most of the water used by man goes to irrigation. A major part of this water is used to irrigate small plots where it is not feasible to implement full-scale Evapotranspiration based irrigation controllers. During the growth season crop water needs do not remain constant and varies depending on the canopy, growth stage and climate conditions such as temperature, wind, relative humidity and solar radiation. Thus, it is necessary to find an economic irrigation controller that can adapt the daily water application to the plant needs. 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. This equation only requires temperature values to calculate Evapotranspiration. Once the ETc is calculated, then the PLC manages the irrigation according to the characteristics of the field, the irrigation equipment and the growth stage of the crop. First year results are very encouraging and indicate a 12% saving in irrigation water. It was also found that heat flux form the soil can influence canopy temperature.

Key-Words: - PLC, irrigation, automation, Hargreaves, irrigation controller, Evapotranspiration, heat flux, crop coefficient.

1 Introduction

Water is becoming a precious resource. Municipalities use 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 to satisfy the peak water need, and end up wasting a lot of water on cooler or clouded days. Farmers with drip and sprinkler systems also use fixed schedule irrigation programmers and thus end up wasting large amounts of water in cooler days and at the beginning of the growing season when the crop water needs are minimum.

The purpose of this work is to develop autonomous irrigation systems that use a single climate criterion to adapt daily irrigation depths 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, leading to a reasonable saving in the amount of irrigation water.

Thus, this work intends to develop a cost-effective irrigation controller that is adaptive to daily climate conditions, without the need for expensive sensors and costly weather-stations. It must also be reliable and easily deployable in order to work under harsh outdoor conditions without the need for supervision or regular monitoring.

2 Present day irrigation controllers

Water is gradually 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 actual water requirements of the plants. Many types of irrigation controllers have been developed for automatically controlling application of water to landscapes. Known irrigation controllers range from simple programmers that control application depth based upon fixed schedules, to sophisticated devices that vary the watering depth according to climatic data obtained from expensive weather stations.

With respect to the simpler types of irrigation controllers, farmers, Municipalities and commercial 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.

The more sophisticated irrigation controllers calculate daily evapotranspiration to establish the exact 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 weather station. The standard methodology consists in calculating *ETo* through the FAO Penman-Monteith method, using data from a series of sensors (thermometer, anemometer, pyranometer and RH sensor) [1].

This methodology is generally considered to be the most reliable because it is based on physical principles and considers a large number of climatic factors, which affect reference evapotranspiration. 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:

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

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 irrigation systems based on Penman-Monteith equation is the cost involved in acquiring and processing the information necessary for calculating the *ETo* 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, and the creation of a series of different methods such as the Hargreaves-Samani, the modified Jensen-Haise, the FAO Blaney-Criddle, the FAO Radiation and the Priestley-Taylor method [4] [5] [6] [7] that rely on one or two climate parameters.

Briefly, these methods can be expressed as:

The Priestley-Taylor method

The Priestley-Taylor method (Priestley-Taylor 1972; De Bruin, 1983) is a simplified form of the Penman-Monteith equation, that only needs radiation and temperature to calculate *ETo*. This simplification is based on the fact that *ETo* is more dependant on radiation that on relative humidity and wind. The Priestly-Taylor method can be expressed as:

$$ET_o = \alpha \frac{\Delta(R_n - G)}{\Delta + \gamma} + \beta \tag{2}$$

where α and β are calibration factors. This model was calibrated for Switzerland and values of 0.98 and 0.94 were obtained for α and β, respectively.

The Makkink method

The Makkink [11] method can be seen as a simplified form of the Priestley-Taylor method. The equation can be expressed as:

$$Et_o = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_s}{2{,}45} + \beta \tag{3}$$

Where α is usually 0.61, and β - 0.012.

The Turc method

This method also uses only two parameters and was specially designed for the humid climate of western

Europe (France). The methodology is based on average daily radiation and temperature values. It can be expressed as:

$$ET_p = \alpha\left(\left(23{,}9001R_s\right) + 50\right)\left(\frac{T}{T+15}\right) \quad (4)$$

Where α is 0,01333 and *Rs* is expressed in MJ m^{-2} day^{-1}.

The Jensen and Haise method
This is a similar method that was derived for the drier parts of the United States [12]:

$$ET_0 = \alpha\frac{T\,R_s}{2{,}450} + \beta \quad (5)$$

Where α is 0.025 and β is 0.08.

The Hargreaves-Samani method can be expressed as [13]:

$$ET_o = \alpha\left(T + 17.78\right)\left(T_{\max} - T_{\min}\right)^{0.5} R_a \quad (6)$$

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.

The values of the extraterrestrial radiation can be found in tables and used without the need for actual field measurement, since these values are given in function of location and month of the year. For the conditions of this trial (latitude=39ºNorth), these values are presented in Table 1:

Table 1. Average monthly values of Ra for southern Portugal [13]

Month	May	June	July	Ago	Set
Ra	16.4	17.2	16.7	15.3	12.8

Teixeira et al. [14] 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 radiation measurement, it could be used for estimating *ETo* without any additional sensors. It has been shown that since the Hargreaves-Samani method uses a single parameter, it has a larger spatial variability, [15] and thus it needs to be calibrated regionally [16]. Thus the calibration parameter (0.0023) assumes different values depending on the location. In a previous work, the authors calibrated the model for the local conditions of this trial [17].

Other authors calibrated the Hargreaves-Samani equation, and changed its original coefficient (0.0023) to 0.0026 [16]. In a seperate work, comparing the results of daily ETo estimated by the Hargreaves-Samani method and the adjusted Thornthwaite method and daily ETo measured by weighing lysimeter, it was found that the accuracy of the Hargreaves-Samani method is higher than that obtained by the Thornthwaite method.

The reliable assumption that temperature is an indicator of the evaporative power of the atmosphere is the basis of temperature-based methods such as the Hargreaves-Samani [18]. These temperature-based methods are useful when data on other meteorological parameters are unavailable, although some authors [19] [20] consider that the estimates produced are generally less reliable than those, which take other climatic factors into account, although they have always obtained R^2 values of more than 0.92. It has been observed that the Hargreaves-Samani method is the most sensitive to temperature change while its relative sensitivity varies with location and time of year [19].

It is also known that the water loss from a crop is related to the incident solar energy, and thus it is possible to develop a simple model that relates solar radiation to evapotranspiration. By relating the measured net global radiation to the estimated reference evapotranspiration, [18] developed a simple model using 30 years of observed data, and obtained a high correlation (0.97) between the net global radiation and evapotranspiration. This simple model can be used to calculate evapotranspiration in areas with only the measured net global radiation rather than using a very complex Penman-Monteith model.

The soil heat flux, *G,* is the energy that is transferred to and from the soil. *G* is positive when the soil is warming (usually during the day) and negative when the soil is cooling. The usual units of heat flux are Wm^{-2}. The value of *G* is usually small compared to the total radiation received.

Initially, when a crop starts to grow, its water needs are relatively small and increase along the growth season. Thus it is necessary to calculate the actual crop evapotranpiration, *ETc*, as opposed to the general reference evapotranspiration, *ETo*. According to the FAO56 methodology [21] [22], the *ETc* is calculated by multiplying the reference evapotranspiration by a crop coefficient, *Kc*.

$$Et_c = K_c\, ET_o$$

The same methodology presents values of *Kc* for different crops at various growth stages. For corn, these values and the length of the growth stages are presented in Fig.1 [2].

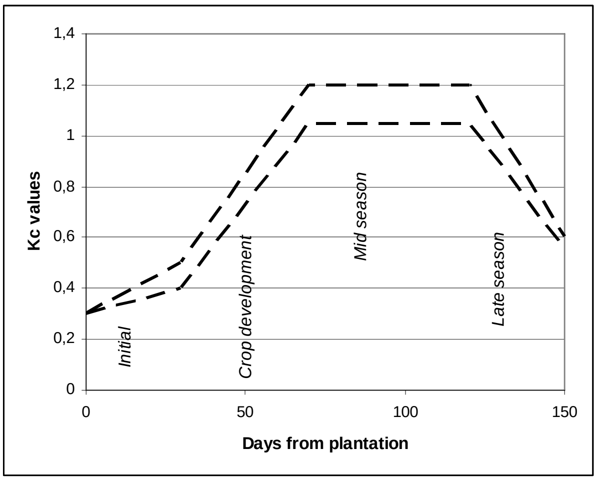

Fig. 1 Duration of corn´s different growth stages, and the associated values of *Kc*, according to the FAO56 methodology. The length of the growth stage will depend on climate and variety.

PLCs are “Programmable Logic Controllers” that are being used extensively in manufacturing processes. They have a processor, some form of keyboard and screen, have analog/digital 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. Thus, due to the advances in electronic engineering in the last decades, it is possible to deploy inexpensive computing and control equipment in individual fields, and fully automate the water application [23].

As already mentioned the aim of this research is to develop an economical PLC based irrigation controller that automatically adapts the application depths to actual weather conditions, using simple climate criteria, and then carries out the irrigation accordingly. This system should be cheap and reliable in order to be mass produced and adopted by farmers, municipalities and companies in any country where irrigation is needed during some part of the year.

3 Material and Methodology

3.1 The PLC and controller

Various industrial PLCs were studied, including the Siemens MicroMaster, Ibercomp uPLC IV and the Bipom MM-51. After careful consideration the Industrologic IC51 controller was selected due to its particular characteristics, including the fact that it has 8 output relays, allowing it to 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 (Fig.2). Its low cost and modularity (possibility of being used with or without a touchpad and a LCD) was also taken into consideration, as a plus factor.

The programming language used by the Industrologic PLCs is Tiny Machine Basic written specifically for the hardware on the IC51. Given the limited memory of the controller, (8K EEPROM) Tiny Machine Basic was used as the only valid programming tool. This is better than the LOGO!soft software used by Siemens, although not as dynamic and capable as the Bascom Basic used by the other PLCs.

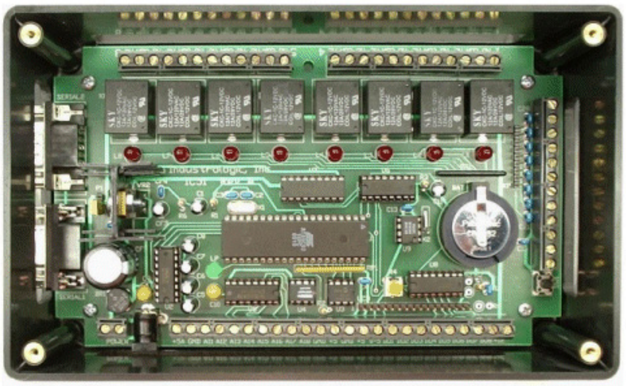

Fig. 2 the Industrologic IC51 controller. It is based on an Amtel processor, and is easily programmed via the RS232 interface (left). The eight relays are soldered on the main board and are easily accessible (top). It has a real time clock and back-up battery (right) which facilitates the irrigation programming.

A 1k thermister with a 1% accuracy was used to measure the air temperature. It was connected in half duplex to an analog I/O port, using a 1k resistance. 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.

The irrigation system was managed by a solenoid valve connected to one of the relays on the IC51. This arrangement allowed the controller to command the irrigation events without the need for supervision. The system was powered by a 12 V solar panel feeding a 12V, 7A backup battery via a charge regulator. This solar system was also used to power the electric valves used for irrigation.

3.2 Irrigation Program

The PLC was programmed to carry out hourly temperature readings, and at the end of every 24h period, calculate the average, maximum and minimum temperatures. With this information it calculates the ETo using the Hargreaves-Samani 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. The program flow chart is presented in Table 2.

Table 2 Flow chart of the irrigation management program

```
Read day of the year and crop growth stage

Read thermister voltage
Calculate temperature
Manage time of the day and number of measurements still needed
Wait until next temperature measurement
Calculate average, maximum and minimum temperatures

If it is irrigation time
  Calculate ETo
  Establish Kc according to the date
  Calculate ETc
  Carry out irrigation in different sectors.

Continue making hourly temperature measurements
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3.3 Temperature measurement

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 along a pole at 0.5m increments between 0.5m and 2.5m height, and the temperature variations were measured over the three month growth period. Fig. 3 shows the difference in temperature at different heights over a 24 hour period. The data show that, during the day, temperature reading is maximum at 2.5 m height, and minimum at 0.5m.

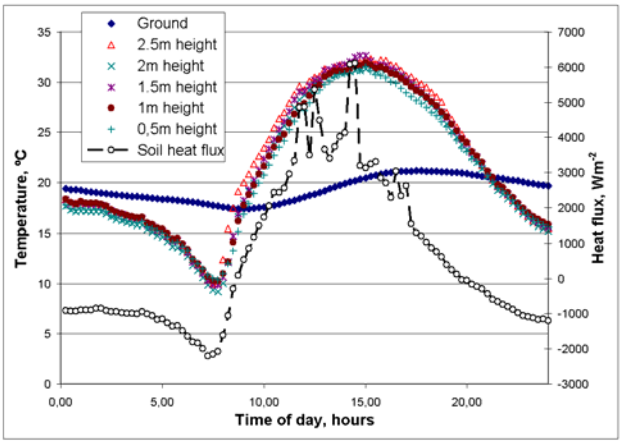

Fig. 3 Evolution of ground and air temperature at different heights. Heat flux from the soil was also measured. It is possible to observe that the daily variation in the soil temperature is relatively small.

These results indicate that the t_{max}-t_{min} component of the Hargreaves-Samani equation increases with height, and thus it calculates higher values of *ETo*. To estimate the effective influence of sensor height on *ETo*, this parameter was calculated for the different heights studied, and the results are presented in Fig. 4. It was thus decided to use the readings at a height of 1.5 m, in order to have an average value, and thus obtain a more precise and realistic measurement of the air temperature.

These results indicate that *ETo* calculated using the ground temperature can be very misleading, since the relatively small amplitude of temperatures at the ground level lead the Hargreaves-Samani equation to under-estimate the *ETo* values.

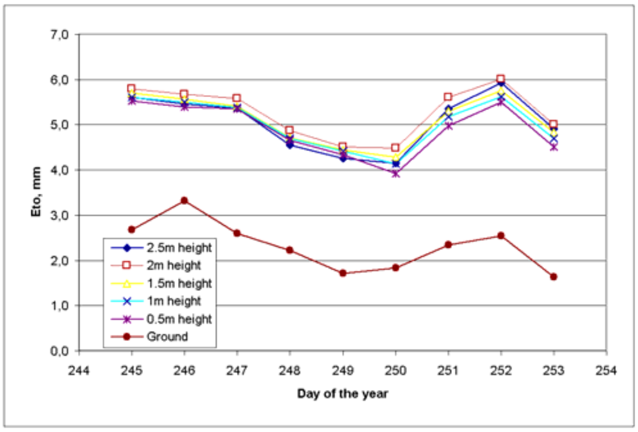

Fig.4 ETo calculated over a 10 day period using temperatures measured at different heights.

Data also demonstrate the influence of heat flux to and from the soil, *G*, in balancing the temperature of the air. According to the data presented in Fig.s 3 and 5, soil absorbed heat during the day, having reached a maximum absorption rate of 6000 Wm^{-2} at around 14:00. After that, heat absorption decreased gradually and then at around 18:00, the soil no longer absorbed heat from the air, and actually returned some of the heat back to the atmosphere. The maximum heat flux from the soil to air was at around 7:00, just before sunrise, and reached values of up to 3700 Wm^{-2}. The average heat flux during the season was 2.8 Wm^{-2}.

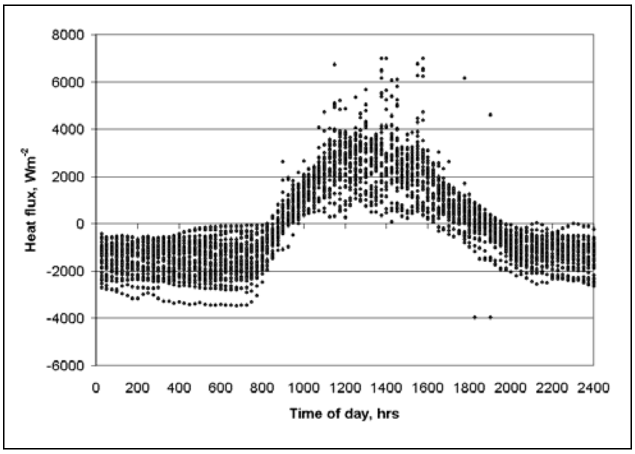

Fig. 5 Hourly heat flux to and from the soil. Positive values indicate heat transfer to the soil.

It is also interesting to study the relation between heat flux from the soil and the temperature gradient between the air and the soil, Δt. In order to carry out this study the hourly heat flux to air from the soil were plotted against the air-ground temperature gradient.

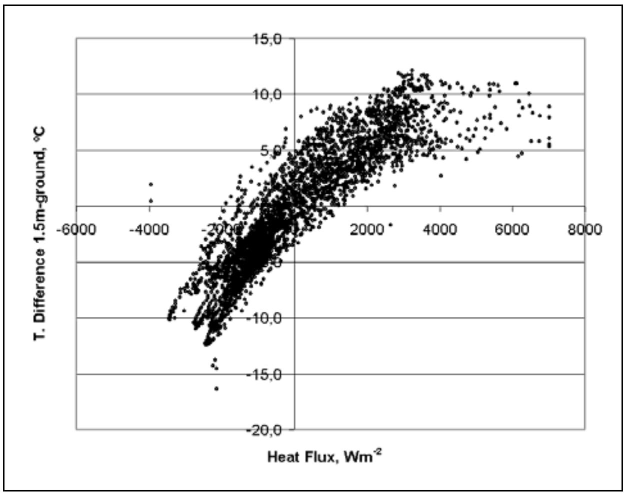

Fig. 6 Relation between the air-ground temperature gradient and the heat flux to and from the soil.

The results (Fig. 6) indicate that the air-ground temperature gradient had values of approximately -10 to 10ºC in the period. An analysis of the air-ground temperature gradient verses the heat flux (Fig.6) reveals that the heat flux was proportional to the temperature gradient, and thus it might be assumed that it is driven at least partially by the temperature gradient, since the soil is mostly protected from direct solar radiation.

3.4 Experimental layout

A 2000m^2 field located in Évora, Portugal, was prepared and planted with corn. Évora has a Mediterranean climate, with a dry summer (June-September) and a rainy winter. The plot has sandy loam soil with low fertility. The field was divided into six blocks, representing three repetitions with two treatments:

Treatment A: Standard irrigation using commercial irrigation controller with a fixed irrigation depth set at the beginning of the growth season,

Treatment B: the adaptive PLC-controller developed in this work, with daily *ETo* calculation, and incorporation of Crop Coefficents, *Kc*.

The standard irrigation controller was set to irrigate according to the peak irrigation needs for the average year calculated specifically for the location of the trial, which is 5.36 mm day^{-1}.

Corn was planted in lines distanced 75 cm, on the 20th of May (day 141), using various varieties of hybrid corn (Fig. 7). The spacing between the plants was 12cm.

Fig. 7 general view of the trial field on 20 July, showing the corn lines. Water supply lines are visible in the forefront of the image, carrying water to each individual block.

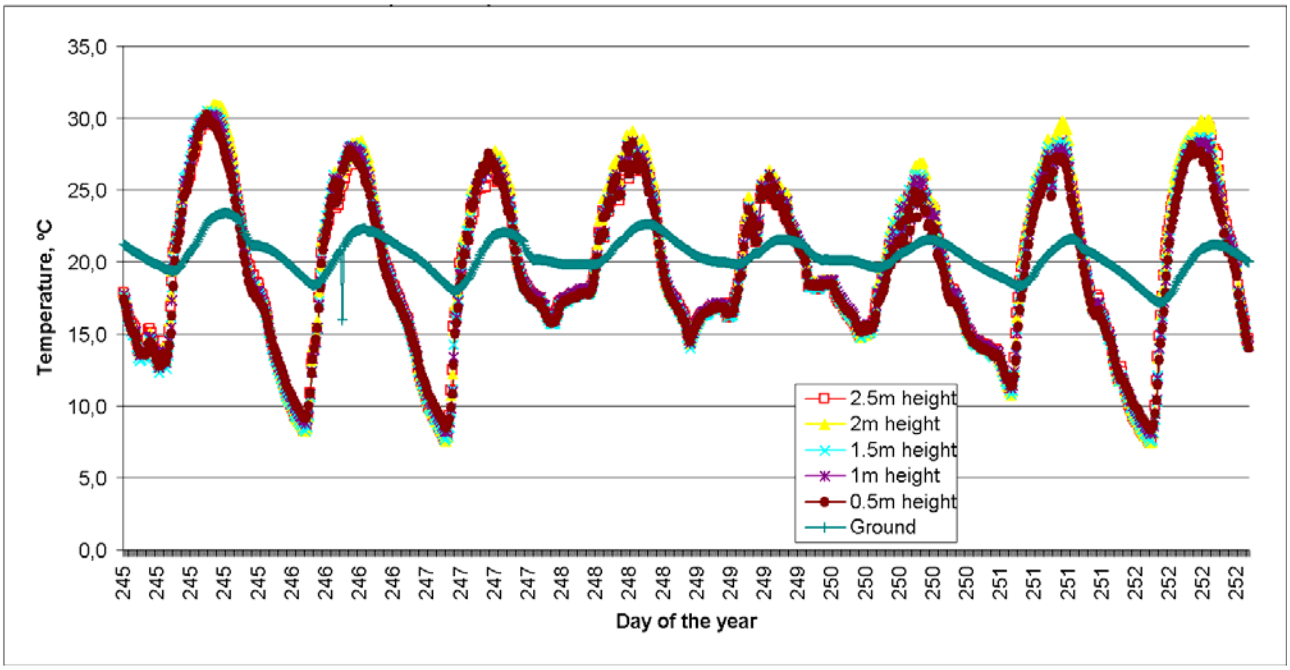

Fig. 8 Evolution of hourly temperatures during an eight day period in early September

Tape drip lines were placed between every other row of corn. The drippers were spaced 20cm, and had a flow rate of 1ls^{-1}. Water was pumped from a nearby well, and filtered before passing on to the drip lines. The average pressure in the line was kept at around 1.2kg m^{-2}.

The irrigations were carried out every other day at 16:00 hrs according to the two treatments mentioned above until harvest. Hourly temperatures, as well as daily water applications were monitored and registered.

4 Results

The hourly temperatures were registered using a CR10 datalogger and thermisters located at different heights (0.5, 1, 1.5, 2 and 2.5m). A sample of hourly temperatures registered during days 245 and 252 are presented in Fig. 8. Daily temperature variations ranged between 11ºC and 23ºC. It can be observed that there is a significant variation in the daily temperature pattern, and that even during a relatively short period in a calm summer, there can be significant variations in the daily temperature fluctuations.

It can also be observed that daily temperature variation is least at 0.5m height, which is possibly related to the favorable heat flux to and from the soil. The results indicate that during the day, at 2m height the temperatures were generally higher than at 0.5 m, with temperature differences of up to 2.2ºC, while at night time, the temperature gradient was inverted and the temperature difference was up to -1.6ºC (Fig. 9). In average, the leaves located at 0.5m were 0.1ºC warmer than those located at 2m height. The sensors located at the top of the canopy (1.5, 2 and 2.5m) registered the maximum daily temperature amplitude.

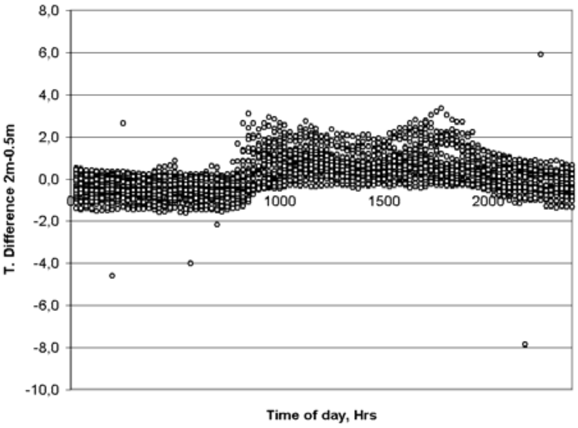

Fig. 9 Hourly variation of the temperature gradient between the top part of the canopy (2m height) and its lower part (0.5m height).

Fig.10 shows the daily *ETo* calculated for a45 day period at the end of the season. It is possible to observe that the controller was able to adjust the *ETo* to variations in the daily temperatures, while the standard controller continued to apply the pre-programmed depth of water.

Equally important as the daily calculation of *ETo*, is the use of Crop Coefficient, *Kc* values to adjust the calculated reference evapotranspiration to the actual crop needs based on its growth stage. The gradual increase in the value of *Kc* follows the growth of the crop and the increase in its biomass, while it is ensured that sufficient water is applied during the flowering stage, in which the *Kc* values for corn reach 1.2. Once the grain is formed, the *Kc* value decreases gradually leading to significant water saving the end of the season.

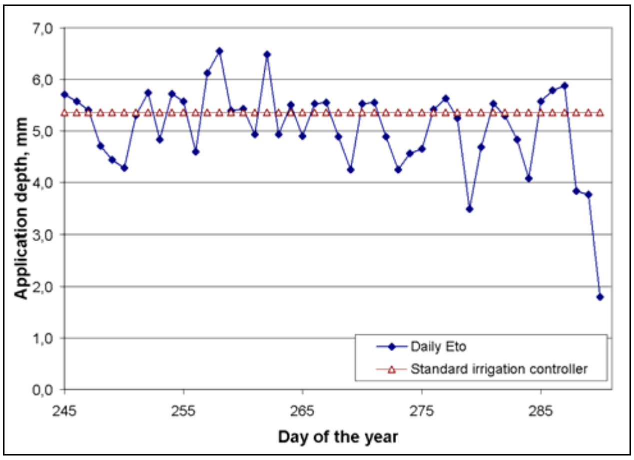

Fig.10 Daily *ETo* calculated by the Adaptive controller as compared to the fixed *ETo* used by the standard controller during the last 45 days of the trials.

Fig. 11 shows the actual water application during the last 45 days of the season by both treatments, as well as the daily *Kc* values. Once the flowering was over and the grains were formed, the adaptive controller used decreasing *Kc* values in order to respond to decreasing water needs of the corn, resulting in a significant and gradual decrease in the water application.

The average amount of water applied by the adaptive controller was 4.79 mm day^{-1}, while the standard controller applied 5.36 mm day^{-1} over the whole season.

These results indicate that the program responded well to changes in temperature and was able to correctly adapt the water application to the *ETo* and the *ETc* in the field.

Actual water saving obtained through the use of the adaptive controller was about 12% 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.

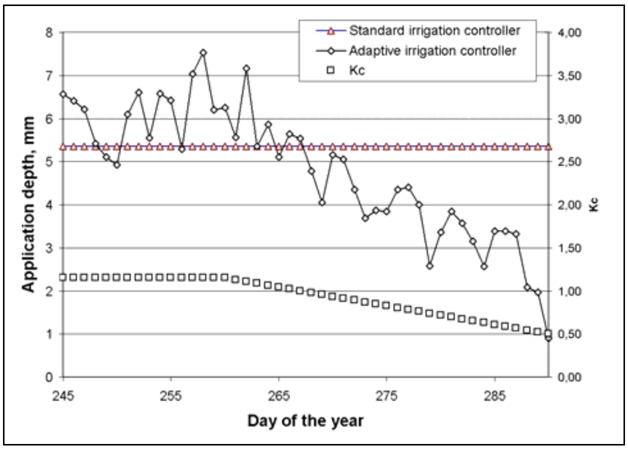

Fig.11 Daily *ETc* calculated by the Adaptive controller based on *ETo* and *Kc* values, as compared to the fixed *ETo* values used by the standard controller.

5 Conclusion

In this work an adaptive irrigation controller was developed and tested in a 2000m^2 corn field. A rather inexpensive PLC was used as the heart of the system making hourly measurements of air temperature at a height of 1.5m. These temperatures were registered and used by the PLC to calculate daily reference Evapotranspiration from a corn-field. These values were then converted to *ETc*, using the methodology and *Kc* values originally proposed by FAO56.

The program then used this information to calculate the exact depth of water needed daily by the crop to ensure maximum production. The irrigations were carried out using a drip system, with drippers spaced at 0.2m and a flow rate of 1ls^{-1}.

The first year results were satisfactory indicating a 12% water saving, along with some increase in crop yield, when compared to irrigation with a fixed water depth using a standard irrigation controller.

It was observed that in the particular case of corn, the use of Crop Coefficient values is very important, as it leads to significant water saving at the beginning and end of the growth season.

It was also found that the heat flux from the soil influenced the temperature gradient in the canopy. The soil served as a heat sink during the day, helping to keep the lower part of the canopy slightly cooler. The temperature difference between the upper layer and the lower layer of the canopy reached 2.2ºC in some cases. At night the soil released heat, helping to increase the temperature of the same lower part of the canopy. This heating effect was responsible for temperature differences of 1.6ºC between the upper and lower part of the canopy.

There are still two major challenges to the wide-spread use of this type of automatic controllers by the average farmer. One is the need to adjust the Crop Coefficient (Kc) values to the growth stage of the crop. Although this can be done based on general information relating to the crop variety, it is preferable if a methodology could be devised for the controller to at least be able to detect flowering and adjust the Kc automatically.

Another major remaining challenge is the need to detect rainfall. Although in the Mediterranean climate no rain is expected during the corn growing season, the system need to be able to detect rain in case of public gardens, where the grass stays all year round, and make the necessary changes in the irrigation schedule.

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References:

[1] Baptista, J.M, Almeida M.C., Silva A.C.M., Ribeiro R., Fernando R.M., Serafim A., Alves I., Cameira M.R. (2001) *Programa Nacional para o uso eficiente da água*, LNEC

[2] Allen, R.G.; Pereira, L.S.; Raes, D. and Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirement. *FAO Irrigation and Drainage Paper*. 56, FAO, Rome

[3] Jensen, M. E. and Haise H.R. (1963) Estimating evapotranspiration from solar radiation. *Journal of Irrigation and Drainage Division, Proc. Amer. Soc. Civil Eng*. 89:15–41.

[4] Priestley, C. H. B. and Taylor R.J. (1972) On the assessment of the surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review* 100: 81–92

[5] Igbadun, H., H. Mahoo, A. Tarimo and B. Salim (2006) Performance of Two Temperature-Based Reference Evapotranspiration Models in the Mkoji Sub-Catchment in Tanzania Agricultural Engineering International: *the CIGR Ejournal.* Manuscript LW 05 008. Vol. VIII. March

[6] La Loggia, F., Pennisi, M. and Sardo, V. (1997) Hargreaves-Samani method and evapotranspiration pan in the estimation of reference evapotranspiration. Acta Hort. (ISHS) 449:113-118

[7] Wu I., (1997) A Simple Evapotranspiration Model for Hawaii: The Hargreaves Model, CTAHR Fact Sheet, Engineer's Notebook no. 106

[8] Priestley, C.H.B., Taylor R.J., (1972) On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review,* 100(2): 81-92.

[9] De Bruin H.A.R. (1983) a model for the Priestley-Taylor parameter. *J. Clim. Appl. Meteorol.* 22,pp.572-578

[10] Xu C., Singh V.P. (2002) Cross Comparision of Empirical Equations for Calculating Potential Evapotranspiraton with Data from Switzerland, Water Resources Management, Volume 16, Number 3, pp.197-219.

[11] Makkink GF. (1957) Testing the Penman formula by means of lysimeters. *Journal of the Institution of Water Engineers* 11: 277±288

[12] Jensen, M.E., Haise, H.R., (1963), Estimating evapotranspiration from solar radiation. *J. Irrig. Drainage Div. ASCE*, 89: 15-41.

[13] Samani Z. (2000) Estimating Solar Radiation and Evapotranspiration using minimum climatological data. *J. Irrig. and Drain. Engrg.* Volume 126, Issue 4, pp. 265-267 (July/August)

[14] Teixiera, J, Shahidian, S., Rolim, J., (2008) Regional analysis and calibration for the South of Portugal of a simple evapotranspiration model for use in an autonomous landscape irrigation controller, *WSEAS Transactions on Environment and Development*, Issue 8, Volume 4, August.

[15] Gavilán P., Estévez J., Berengena J. 2008 Comparison of Standardized Reference Evapotranspiration Equations in Southern Spain J. *Irrig. and Drain. Engrg.* Volume 134, Issue 1, pp. 1-12 (January/February)

[16] Sepaskhah, A.R., Razzaghi F., (2009) Evaluation of the adjusted Thornthwaite and Hargreaves- Samani methods for estimation of daily evapotranspiration in a semi-arid region of Iran, *Archives of Agronomy and Soil Science,*55:1, 51 – 66.

[17] Shahidian S., Serralheiro R.P., Teixeira J.L, Santos F.L., Oliveira M.R.G., Costa J.L., Toureiro C., Haie N. 2007 Desenvolvimento de um controlador de rega autónomo, automático e adaptivo- Estudo comparativo de cinco métodos para o cálculo da ETo. *IV Congresso Nacional y I Congresso Ibérico de Agroengenhieria*.

[18] Lee T.S., Najim M., Aminul M.H. 2004,Estimating evapotranspiration of irrigated rice at the West Coast of the Peninsular of Malaysia, *Journal of Applied Irrigation Science*, Vol. 39. No 1/2004, pp.103 – 117

[19] McKenney, M. S. and N. J. Rosenberg, 1993: Sensitivity of some potential evapotranspiration estimation methods to climate change. - *Agricultural and Forest Meteorology* 64, 81-110.

[20] Jablouna M., Sahli A., 2007 Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data: Application to Tunisia *Agricultural Water Management* Volume 95, Issue 6, June 2008, Pages 707-715

[21] Allen, R., Pereira, L.S., Raes D., Smith M., 1998 Crop evapotranspiration- Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper*, 56, Rome.

[22] Hajare H.V., Raman N.S., Dharkar E.J. (2008) New Technique for Evaluation of Crop Water Requirement. *WSEAS Transactions on Environment and Development*, Issue 5, Volume 4, May pp.436-446

[23] Souza M., Pereira S.L., Fontana C.F., and Dias E.M., (2008) Integrated Management and Optimization of the Sanitation Cycle Using Intelligent Automation Systems and Communication Networks, *WSEAS Transactions on Systems and Control,* Issue 4, Volume 3, April.