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Soil moisture based automatic irrigation control system for a greenhouse

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ABSTRACT

Water stress continues to be a major factor that affects agricultural productivity in arid and semi-arid regions, which are characterized by high annual rainfall variability. Water-saving practices and sound water management strategies are urgently required to ensure the long-term viability of the agricultural industry in these regions. Automated irrigation systems provide greater control over the quantity of water applied which eventually improves water use efficiency. Thus, a new control strategy utilizing a control system made from mostly off-the-shelf electronic components was developed for controlling irrigation of a tomato crop in a greenhouse. The newly designed soil moisture-based automatic irrigation controller (SMAIC) managed water application using moisture sensors whereby data pertaining to soil moisture was used for the prediction of irrigation timing. SMAIC saved water by up to 74% compared to local farmer practice for greenhouse tomatoes. For all the treatments implemented, the yield was not significantly different. Irrigation water use efficiency (IWUE) was significantly higher in the SMAIC treatment.

Keywords: Automated irrigation Systems, PIC Microcontroller, Soil Moisture based sensors, Automated irrigation systems, Irrigation Water use

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1. INTRODUCTION

More than 90% of farmers in Sub-Saharan Africa rely on rain-fed agriculture for their livelihoods (FAO, IFAD, & WFP, 2015). However, most of these farmers occupy fragile to near fragile pieces of land in drought-prone areas where the major constraint to food production is the uncertainty of water availability, mainly due to high costs of production and competition for water between agriculture, industry, and domestic use, etc. The increase in frequency and severity of droughts, the shift in the onset of the rains, and increasing intensity of mid-season dry spells caused by climate change are set to add more pressure to agricultural production for these farmers in the future (IPCC, 2014; Zinyengere, Crespo, & Hachigonta, 2013; Knox *et al.*, 2012; Masanganise *et al.*, 2012; Schlenker & Lobell, 2010). Effectively managing risks to food security and making agricultural systems more resilient in the face of climate change requires sustainable irrigation methods that produce more yield (and of better quality) using less water (Munyaradzi *et al.*, 2013). As water supplies become scarce and, in some cases, polluted, there is a need to irrigate more efficiently in order to minimize water use. Efficient water management thus plays an important role in irrigated agricultural cropping systems (Boutraa *et al.*, 2011). Increasing water productivity or water use efficiency has been one of the main approaches to overcome the impacts of water shortage on agricultural production (Boutraa *et al.*, 2011; Jones, 1993). In irrigation systems, water use efficiency depicts the measurement of the effectiveness of delivered water to crops and the amount of wasted water through the same delivery system. Traditional water-saving irrigation management strategies send control actions to control valves for irrigation application within a specified interval mostly decided by the grower's experience. However, this approach saves water on the back of reduced yield (Zhao *et al.*, 2008).

Automated irrigation systems promise greater control over the amount of applied water which results in improved water use efficiency, especially for indoor crops (Boutraa *et al.*, 2011). Automatic irrigation methods also offer convenience and reduce human error. The development of efficient water-saving irrigation becomes the main method of mitigating the shortage of water, significant research and development of efficient greenhouse irrigation systems must be undertaken (Zhao *et al.*, 2008). Much research has been conducted to establish optimum schedules in drip-irrigated greenhouse crops (Jovicich *et al.*, 2003). These studies often involve varying the duration and/or frequency of irrigation, both based on pre-set time intervals. Automated irrigation scheduling systems require the use of soil, crop, or environmental sensors to determine the need for irrigation and then either a controller or a computer to control the irrigation sequence. This leads directly to the conceptualisation of a precision automated irrigation system as one that can:

1. Determine the timing, magnitude, and spatial pattern of applications for the next irrigation to the best chance of meeting the seasonal objective (i.e., maximisation of yield, water use efficiency, or profitability).
2. Be controlled to apply exactly (or as close as possible to) what is required.
3. Through simulation or direct measurement knows the magnitude and spatial pattern of the actual irrigation applications and the soil and crop responses to those applications; and
4. Utilize these responses to best plan the next irrigation.

There are mainly two types of controllers that are normally used to schedule irrigation. These can be open-loop or closed-loop controllers. Open-loop controllers are designed to take input and to compute the output for the system accordingly. They do not have feedback to determine whether the desired output is achieved or not. This often leads to over-watering which results in lower crop yields and wasted water. On the other hand, closed-loop or adaptive controllers, are based on pre-defined control concepts and use feedback from the controlled system in some manner (Bahat *et al.*, 2000). Adaptive irrigation control systems automatically and continuously readjust the controller to retain the desired performance of the system (e.g., Warwick, 1993), thus maximise both crop development and water use efficiency. In such a system, crop water status and amount of water to be supplemented can be assessed by measuring soil moisture and/or plant physical response to water (Ruixiu, Fisher, & Barnes, 2012; Taber & Henry, 2007). The use of plant indicators, while being the ideal method for irrigation scheduling, is still hampered by the relatively low knowledge of the dynamic nature of plant water status and by the lack of suitable indicators, relative to established scheduling methods based on climate and soil observations.

Automatic irrigation control systems that optimize water management by sensing soil moisture conditions and site-specific control of irrigation sprinklers or drip lines are potential solutions (Boutraa *et al.*, 2011). The performance of soil moisture sensor systems related to soil water content has been reported by among others (Marazky, Mohammad, & Al-Ghobari, 2011; McCready, Dukes, & Miller, 2009; Zotarelli *et al.*, 2009). Automatic soil moisture irrigation targets the maintenance of a desired soil water range in the root zone that is optimal for plant growth. The target soil moisture status is usually set in terms of soil tension or matric potential (expressed in kPa or cbar, 1 kPa =1 cbar), or volumetric moisture (expressed in percent of water volume in a volume of undisturbed soil). Once such a system is set up and verified, only weekly observations are required (McCready, Dukes, & Miller, 2009). A properly configured soil moisture-based automated irrigation system can save up to 60% of the water used in irrigation. For example, irrigation savings of 70% compared to typical farmer practices for the same yield was achieved by (Or, 2005) using switching tensiometers set at 15kPa on coarse soil.

A wide range of technologically advanced soil moisture sensors for efficient irrigation scheduling exists (Dukes & Scholberg, 2005). However, the costs of these sensors, combined with the controllers, are beyond the reach of ordinary farmers in most developing economies. As the necessity to optimize schedules for improved yields and water use becomes apparent, new monitoring and control methods that are more efficient will be required to closely match the application of irrigation to the greenhouse crop requirements (Shelford *et al.*, 2004). For these reasons, monitoring techniques and controllers that are affordable to low-income farmers need to be developed and implemented to determine site-specific irrigation volumes in order to maximise crop water use efficiencies and/or yield. These should also be applicable to open field farming for small and large-scale applications. The objectives of this research were to develop a new irrigation control system based on low-cost FC-28 dielectric soil moisture sensors and a PIC microcontroller and evaluate its performance against other scheduling approaches.

2. MATERIALS AND METHODS

2.1 Circuit Design and Programming

The circuit was developed with the PIC16F872 microcontroller as the core component of the controller. The PIC16F872 microcontroller (Microchip Technology, Inc., Chandler, Ariz.) is a 28-Pin, 8-Bit CMOS Flash Microcontroller with a 10-Bit analogue to digital converter (A/D). Fig.1 shows the circuit diagram of the designed soil moisture-based automatic irrigation controller, while Table 1 gives the list of components used in the design.

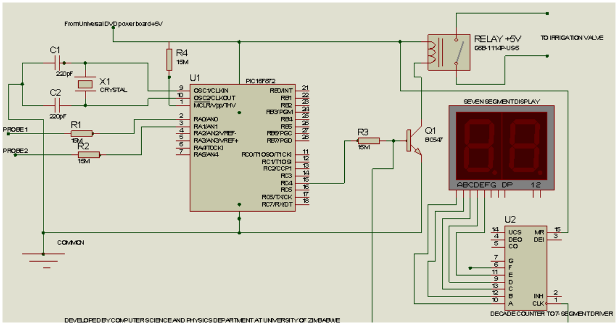

Figure 1: Soil moisture-based irrigation controller circuit diagram

Table 1: List of circuit components and sensors for the Irrigation Controller

Item	Quantity	Description
U1	1	PIC16F872 Microcontroller
RL1	1	5v dc relay
R1	1	resistor 10kΩ, 0.25w
R2	1	resistor 10kΩ, 0.25w
R3	1	resistor 10kΩ, 0.25w
R4	1	resistor 10kΩ, 0.25w
R5	8	resistors 390Ω, 0.25w
R6	2	resistors 100Ω, 0.50w
R7	1	resistors 2.2k, 0.25w
R8	4	resistors 470Ω, 0.50w
R9	3	resistors 1kΩ, 0.25w
C1	2	capacitors 0.022µF
LED	4	LEDs, 2 green & 2 red
X_1	1	4 MHz crystal
14	1	IN4006 diode
Q_1	1	BC547 NPN Transistor
U_2	2	4026 CMOS 7-segment drivers
	1	dual 7-segment display
Not shown	1	Universal DVD power board, 5V

The controller can be powered by either a 5-VDC battery which provides unregulated voltage or by the power from an AC source that will be rectified and regulated to give an output of the same 5-VDC needed to power the microcontroller and other components that operate on this same voltage. Other components that are not shown in the circuit diagram include the FC-28 dielectric soil moisture sensors which measured the soil moisture content of the soil. The total cost of materials, sensors and labour amounted to approximately US$65 compared to importing compatible complete units which would cost not less than US$200. The microcontroller was programmed using low-level assembly language and MPLAB Integrated Development Environment (IDE) was used to develop the code that was loaded into the PIC microcontroller. After successfully assembling the program, Real PIC Simulator 1.3 was used to simulate the program before downloading it to the microcontroller. Real PIC Simulator is the fastest software simulator targeting the Microchip baseline, and mid-range flash-based PIC microcontrollers like the one used in this design. To correct for faults, the program was simulated on screen. This also ensured that the program worked properly before downloading it into the microcontroller. Thus, circuits could be tested before manufacturing. WinPIC software was used for downloading the hex code into the microcontroller via a cheaply assembled laboratory programmer circuit.

2.2 How the Circuit Works

The automatic irrigation system was designed to continuously sense the moisture level through indirect use of water properties in the soil using moisture probes inserted into the soil at the plant root zone. The system responds appropriately by watering the soil with the exact required amount of water and then shuts down the water supply when the desired level of soil moisture is achieved. The soil moisture sensor measures soil conductivity at different depths as may be required. Dry soil is less conductive than wet soil and it is this attribute that was used to initiate and stop irrigation events during the experiment period. A voltage returned from the soil moisture probe was compared against a predefined voltage value (set threshold value for clay loam soil used in this experiment) with the comparator output being high only when the soil condition becomes dry. The microcontroller was programmed to acquire voltage signals (corresponding to soil moisture levels) from probe1 at input RA0/AN0 and from probe2 at input RA1/AN1. The two voltage values from the probes were averaged and compared against a threshold value as alluded to earlier. The comparison would give a decision on whether to trigger irrigation or not. If the voltage returned from the probes goes below a user set threshold (i.e., the moisture of the soil is less than the set value), then the controller through pin RB1, triggers irrigation via an energized DC relay, whose contacts allows a 24 VAC signal to power the irrigation solenoid valve that drives the drip lines for water application. If the average signal from the probes goes above the set value, the DC relay becomes de-energized and cuts off the 24-VAC signal that disables the irrigation solenoid valve, resulting in a no irrigation event. Operation of the DC relay was achieved via an NPN transistor whose base was directly connected to the microcontroller output at pin RB1.

2.3 Algorithm for the SMAIC

Step 1: Acquire input from sensor 1.
Step 2: Convert the analogue input to digital.
Step 3: Retrieve the digital value and store it in register 1.
Step 4: Acquire input from sensor 2.
Step 5: Convert the analogue input to digital.
Step 6: Retrieve the digital value and store it in register 2.
Step 7: Add the two registers, register 1 and register 2.
Step 8: Divide the sum of the two registers by 2.
Step 9: Compare the quotient against the threshold and decide whether to irrigate or not.
Step 10: Wait about two minutes and start all over again.

2.4 Probe Calibration and Installation

The FC-28 soil moisture sensor is shown in Fig. 2. It quantifies the resistivity between its electrodes in soil according to the water content in the soil.

Figure 2: The soil moisture sensor used in the research

The soil resistivity decreases with soil moisture increase and increases when the soil is dryer (Gaddam, Al-Hrooby, & Esmael, 2014; Susha *et al.*, 2005). Thus, when the soil is wet the output voltage decreases, and when dry the output voltage increases. The sensor has the following features:

1. Supply voltage: 3.3 V – 5 V
2. Output voltage: 0- 4.2 V
3. Current: 35 mA
4. Low power consumption

An experiment to calibrate the sensor was carried out at the Physics Department's Agrometeorology laboratory. The soil type was a shallow clay loam of the Kroonstad soil form (Ochric Planosol; FAO) with a high clay percentage (Soil Classification Working Group, 1991). The physical properties of the soil at the site were provided by the Department of Agriculture at the University of Zimbabwe. The experiment was conducted for 48 days, from the 10th April 2015 to the 28th May 2015. Four FC-28 soil moisture sensors were connected to the microcontroller analogue inputs to measure the soil moisture level. An SD shield containing a 4GB SD card was connected to the microcontroller together with a Real-Time Clock (RTC) for providing the real-time monitoring for data logging purposes. Thus, the whole setup constituted a data logging and control system for the soil moisture measurement. The microcontroller was programmed to measure and log soil moisture level into the SD card at one-minute intervals which were then averaged into daily averages and converted to generated voltages using the analogue to digital conversion (ADC).

A Theta probe (Delta-T Devices Ltd., Cambridge, UK) which was used as a standard in this study was connected to a CR23X datalogger (Model CR23X, Campbell Scientific Ltd., Logan, USA) which was programmed to collect data in 5s intervals and store one-minute averages which was averaged into daily averages. All the soil moisture sensors were installed inside a plastic container which was filled with red sandy clay soil with moisture content close to field capacity. The probes were installed in the container such that no air gaps were left as these would affect the sensor readings. The soil around the probe was not excessively compacted as this would affect our readings since the soil adjacent to the probe surface has the strongest influence on the probe reading. In this case, the probe reading is the measure of the volumetric water content.

Care was also taken to keep out attenuation on the probe's electromagnetic field by avoiding metal objects as this adversely affects output readings as well. Since an installation kit to install the probe was not available, a small flat bar was used to make pilot holes in the centre of each soil sample in a container.

The probe was then inserted into the hole making sure that the entire length of the probe was covered. Good contact between probe and soil was maintained by forcing the soil gently toward the probe using the same small flat bar.

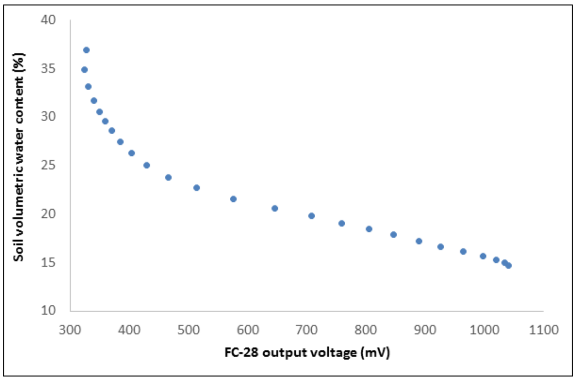

Figure 3: Relationship between the output voltage and the soil moisture for the FC-28 dielectric soil moisture sensor

The effects on downward water movement were minimised by installing the probe flat side perpendicular to the surface of the soil. The setup was left until soil moisture level depleted well below permanent wilting point in order to investigate the behaviour of the sensor over a large range of soil moisture levels. The graph presented in Fig. 3 was the calibration curve that relates the soil moisture with the output voltage of the sensor.

2.5 Controller Performance Test on Greenhouse tomato

To assess the functional performance of the soil moisture based automatic irrigation control system that had been developed, an experiment was conducted in real conditions in an experimental greenhouse situated in the Biological Sciences Department at the University of Zimbabwe in Harare (located at latitude 17.8° S, Longitude 31.1° E, elevation 1,480 m). The objective of the experiment was to implement the designed control system and evaluate its performance against other established scheduling methods.

A tomato crop (Lycopersiconesculentum Mill. Daniela variety), was established on 8 July 2015. Fertilizer was applied a day before transplanting the tomato seedlings which were cultured according to local grower practices. The seedlings were transplanted in 32 plastic containers under four different irrigation treatments in order to maintain a modest greenhouse experiment. Four irrigation treatments were applied with two replicates of each treatment (i.e., with four plastic containers for each set-up). The plastic containers were spaced at 0.5 m apart between rows and the plants separated 0.35 m apart (i.e., from container to container in a row). Each treatment and its replicate shared 8 plastic containers (four each). Water and nutrients were supplied through a single-line-source drip irrigation system (0.015 m internal diameter, 0.3 m emitter spacing, 0.8 litres/h per emitter, Toro Micro-Irrigation Co., El Cajon, CA.) producing a wetted radius of 150 mm. Fig. 4 shows the tomato crop layout that was used in the greenhouse.

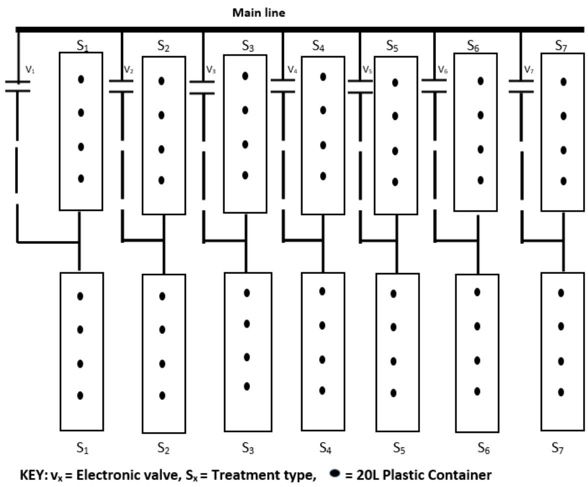

Figure 4: Greenhouse tomato crop layout

To allow the transplants enough time to get established, irrigation treatments were introduced 15 days after planting. Before this, all the treatments were irrigated under a similar schedule. The treatments consisted of the SMAIC, Tensiometer, On-Off Switching System, and Local grower as shown in Table 2.

Table 2: Irrigation treatments, soil moisture-based control, On/Off switch control, grower practice, and irrigation set-points were used for this research

Treatment	Sensor	Set Points (Threshold)
S1	New controller	405 mV (25 kPa)
S2	New controller	430 mV (15 kPa)
S3	Tensiometer	15 kPa
S4	Tensiometer	25 kPa
S5	Weather Data	ETc * 0.8
S6	Weather Data	ETc *1.00
S7	Grower practice	3mm/day

The newly designed controller allowed irrigation only when soil water content went below user set points. Threshold values for this treatment were 430 mV for S1, corresponding to the soil water status at 15 kPa and 405 mV for S2, corresponding to soil water status at 25 kPa as shown in Table 2. Tensiometer treatments were irrigated based on soil moisture measurements by tensiometers (A.M.I. Ltd, Israel) placed at a depth of 0.2m in between plants and at about 0.1 m from the drip line. Irrigation was applied when soil tension exceeded set threshold points of 15 kPa (for S3) and 25 kPa (for S4). Readings were taken at 7.30 am (local time) every morning and averaged from the two replications. On-Off Switch treatments (S5 and S6) were irrigated according to crop evapotranspiration (ET_c) that was calculated by the K_c-ET_0 method (Allen *et al.*, 1990; Doorenbos & Pruitt, 1977).

ET_0 (in mm day^{-1}) was calculated with a locally calibrated radiation method (Equations 1 and 2) that requires daily solar radiation outside the greenhouse (G_0, in mm day^{-1}) from real-time meteorological data taken from a nearby weather station located on the roof of the Physics Department and greenhouse transmissivity data (Ƭ, in %). The latter, which changes slightly during the cropping season, was determined monthly from solar radiation measurements carried out outside and inside the greenhouse.

For Julian days (JD) ≤ 220

$$ET_0 = (0.288 + 0.0019 \times JD)\, G_0 \times Ƭ \quad (1)$$

For Julian days (JD) > 220

$$ET_0 = (1.339 - 0.00288 \times JD)\, G_0 \times Ƭ \quad (2)$$

The radiation data was converted to equivalent evaporation (mm day^{-1}) from the relationship:

$$1 \text{ mm day}^{-1} = 2.45 \text{ MJ m}^{-2} \text{ day}^{-1}$$

ET_o was multiplied by the published crop coefficient (K_c) for tomato crops to obtain the crop evapotranspiration (ET_c). The K_c values used were 0.45 (from 8 to 22 July 2015), 0.75 (from 23 July to 31 August 2015), 1.15 (from 1 September to 30 October 2015), and 0.8 (from 31 October till harvest) (Brouwer & Heibloem, 1986). The local grower practice treatment scheduled irrigation for one hour each day throughout the crop growing period (i.e., on average 3.0 mm per day). Water used for each treatment was recorded using water meters (ABB Water Meters, Inc., Ocala, Fla.) connected to a low-cost event data logger (OM-CP EVENT 101A). Readings were taken every morning (7.30 am local time) from the counters in the water meters which were installed just after the filter and electronic valve in each set-up. The amount of water used for irrigation in the SMAIC was displayed by a seven-segment display and compared favourably with the water meter readings (Munyaradzi, et al., 2013). The irrigation water use efficiency was calculated for each treatment as:

$$IWUE = \frac{Tomatoyeild}{Totalirrigationwater} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Water Use

Irrigation water use per season during the experiment is as shown in Table 3.

Table 3: Tomato seasonal water use, yield, and irrigation water use efficiency (IWUE)

Treatment	Total irrigation per season (mm)	Yield tons/ha	IWUE kg/m^3
S1	142	38.1	27.3
S2	123	36.5	29.7
S3	158	32.4	20.5
S4	191	34.3	17.9
S5	306	32.7	10.7
S6	409	31.8	7.8
S7	480	28.9	6.0

The newly designed soil moisture-based automatic irrigation controller (SMAIC) treatments (S1- S2) at 430 mV and 405 mV threshold values respectively, used less water compared to other irrigation treatments employed in this research. Tensiometer treatments (S3- S4) also used less amounts of water compared to the On/Off switching treatments and the traditional practice irrigation treatment (S7). The SMAIC reduced water use substantially (70% to 74%), followed closely by the tensiometer system (60% to 67%), then the On/Off switching treatments at 15% to 36% respectively, all compared against the farmer practice irrigation treatment (S7). A change in soil moisture content threshold values for the clay loam soils, from 405 mV (25 kPa) to 430 mV (15 kPa) reduced irrigation by 7% (142 to 123 mm) for SMAIC whereas there was 21% (191 to 158 mm) irrigation reduction with tensiometer treatments. The substantial reduction in water use for SMAIC in the early stages of tomato growth was consistent with small plants' low demand for water.

3.2 Yield and IWUE

Table 3 indicates that high marketable yields were obtained from all the treatments S1 to S6 and that there was no significant difference in yield compared to farmer practice (S7). Average yields for tomatoes in Zimbabwe range from 5.7 tons/ha (the year 2002) to 8.3 tons/ha (the year 2007) for historical yield data for open field tomatoes as given by FAOSTAT (years 1961 – 2013). The yields for all the treatments (S1 to S7) were much higher compared to the average yields given by FAOSTAT. The wide difference could be explained by the fact that for the FAOSTAT average yields, data were not recorded but obtained by dividing the production data by the data on area harvested. The highest yields (36.5 tons/ha and 38.2 tons/ha) obtained for treatments S1 and S2 utilised significantly lower amounts of water as compared to treatment S6 (31.9 tons/ha yield value) and S7 (28.9 tons/ha yield value) irrigation schedules. More water than the crop optimal requirements would have been applied through the use of common farmer practice treatment (S7). The yield from the research was very high compared to the average yields for tomatoes from historical yield. This is comparable to other results from other countries (Peet, 2005). However, data from other countries (Ayas, 2015), show that yield can go as high as 91.0 tonnes/Ha.

The irrigation water use efficiency varied from 6 kg/m^3 (S7 with lowest IWUE value) to 29.7 kg/m^3 (S2 with the highest IWUE value) as shown in Table 3. The IWUE for On/Off switch ETc*100 treatment, 10.7 kg/m^3 (S5) and ETc*80 treatment, 7.8 kg/m^3 (S6) were not significantly different from farmer practice treatment, 6.0 kg/m^3 (S7) as compared to SMAIC and tensiometer treatments (S1, S2, S3 and S4 at 27 kg/m^3, 29.7 kg/m^3, 20.5 kg/m^3 and 17.9kg/m^3, respectively). Some of the pronounced differences in the irrigation water use efficiencies could have been because of fluctuations of temperatures in the greenhouse due to faulty equipment which needed regular repairs. However, water application using S5 and S6 treatments (i.e., 305 mm and 409 mm, respectively), saved a significant amount of water compared to the farmer-based treatment S7 (480 mm). Fig. 5 below shows a plot of irrigation amount for each treatment versus the period under irrigation.

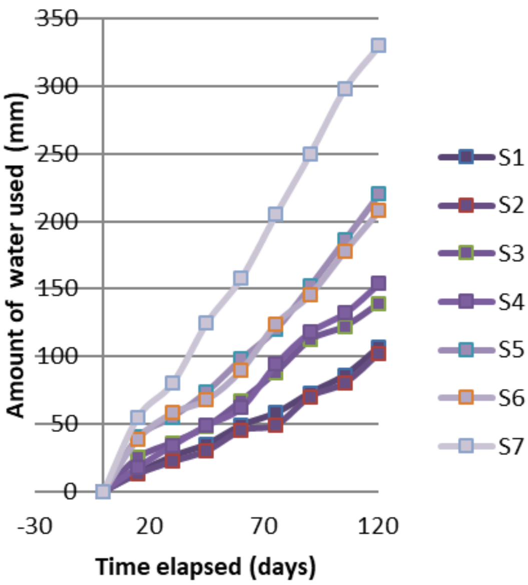

Figure 5. A plot of irrigation amount for each treatment versus the period under irrigation

The legend shows the different irrigation treatments labelled as follows; S1-S2 are the newly designed controller, S3-S4 the tensiometer treatments, S5-S6 On/Off switch-based while S7 is grower practice treatment.

4. CONCLUSION

A newly designed automatic irrigation controller was developed that uses signals from the soil to schedule irrigation. The controller was made from cheap off-shelf components found abundantly in local laboratory stores and electronic retail shops. The experimental results have confirmed the major advantages of soil moisture irrigation control over other methods of scheduling irrigation like evapotranspiration (ET) and local greenhouse farmer irrigation scheduling practice. This research demonstrated that by using the newly designed controller, significant water savings could be obtained (74%) compared to local farmer practice for greenhouse tomato in the area. SMAIC also utilized (56%) less water in comparison to the On/Off switching treatment for the clay loam soils used in this greenhouse set-up. The yield for all treatments was not significantly different. However, irrigation water use efficiency (IWUE) was significantly higher in the newly designed controller as shown in table 3 above.

The newly designed automatic irrigation controller (SMAIC) managed water application through capacitance soil moisture sensors which collected soil data and were connected to a microcontroller programmed to determine the irrigation amount and timing of scheduling requirements. Research in the field of automated irrigation systems has shown promising results in water savings, as reported by other researchers who found significant reductions in water use in pepper plants using soil water-based automatic irrigation systems in comparison to daily manually irrigated treatments. The research also managed to demonstrate the design and construction of a controller that is low cost, reliable and affordable by the low-income farmer. We conclude that the SMAIC is well suited for poor farmers in Africa and other developing countries in the world. It was constructed from cheap off-the-shelf components, which makes it affordable. Its effectiveness in saving water is also suited in sub-Saharan Africa where climate change-induced droughts have been persistent over the years.

Although we did not go on to field evaluate the control unit on any crop, further work is required to repeat this type of investigation. Future work should focus on the impact of this method against other available grower-based methods on yields and water use efficiencies for a Galina tomato crop at our University of Zimbabwe's Thornpark farm.

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