

DEVELOPMENT OF AN AUTOMATED DRIP IRRIGATION SYSTEM BASED ON SOIL MOISTURE MONITORING FOR CROP PRODUCTION ON SILT LOAM SOIL IN GIREI, ADAMAWA STATE, NIGERIA

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ABSTRACT

Automatic drip irrigation is an artificial method of supplying water to the roots of the plant with minimal human intervention which employs the use of different technologies in its design, development and implementation. The purpose of the study was to design and develop an automatic drip irrigation system based on soil moisture monitoring on silt loam soil. The existing moisture content of the soil at four locations designated as treatment A, B, C and D were used as sampling points at an incremental depth of 100 mm to a depth of 300 mm were determined. PIC microcontroller was used to automate the process of drip irrigation by receiving moisture content signals from the soil moisture content sensor and compared the value with the set point from the knob. The result showed that mean soil moisture content of 12.73% was obtained for the entire sampling points and depth of sampling in the study area. There was no significance difference among the mean soil moisture content at depth of sampling at 5% level of significance. Also, it was observed that as the discharge increase, the moisture level rises in the soil and at that moment, the valve was closed which had correlation coefficients (r^2) value of 0.99 and 0.87, respectively. Thus, the mathematical relationship between soil moisture content and pump discharge can be relied upon to predict the behavior of the automatic drip irrigation system. The performance evaluation showed that the set-up is very reliable. The efficiency of the setup was found to be 99.4%, thus requiring minimal human intervention. It is recommended that the communication between sensor and control unit could be of a wireless type either Bluetooth or WiFi so that one can use smart phones to control the system instead of having to be physically around the set up to make changes.

Key word: Development, Automated, Drip, Irrigation, Soil, Moisture, Monitoring, Girei

1 INTRODUCTION

Water is a resource that all living species need. It is therefore very precious and has to be used with moderation to be preserved for the generations to come. Agriculture is an industry that uses a lot of water. Most of the time, this resource is not used efficiently and substantial amounts of water is wasted, thus drip irrigation which is an artificial method of supplying water to the roots of the plant could be used as it trickles water onto the soil at low rates of 2-20 liters/hour. Drip irrigation prevents soil erosion, saves water and can be used to supply fertilizer [1]. However, to handle drip system, there is the need of human intervention. If the person responsible is not available to switch the system ON or OFF, it may lead to starvation or overwatered plants which make the soil water logged that may impair crop growth and aerobic activities [2]. Someone have to be on ground to start or shutdown the system. Since humans have the tendency to forget, sleep off, get exhausted etc., the human traits tend to affect the efficiency and

effectiveness of manual drip irrigation system and it also involves waste of energy and time. Thus, there is need for automation of the entire system. The system should be capable of analyzing the situation and based on that make some intelligent decisions [3]. An automated drip irrigation system does the operation of the system without requiring manual involvement of persons. This automazation with the help of electronic appliances, sensors, computer, timers, sensors and other mechanical devices can be achieved. Automatic drip irrigation systems can be programmed to discharge more precise amounts of water in a targeted area, which promotes water conservation. Thus, there was the need to design and develop an automatic drip irrigation system based on monitoring of soil moisture that can conserve and utilize the available water for crop production.

2 LITERATURE REVIEW

2.1 Drip irrigation

Drip irrigation is the most energy and water efficient of all the irrigation systems. Water savings of up to 50% compared to sprinkler irrigation are common [4]. Ideally, water is applied in the proper amount to the root ball of the plant, minimizing water leaching from the root zone and minimizing evaporation of water since the water isn't sprayed into the air [4, 5, 6, 7]. The water can be emitted at uniform distances along a pipe or a tube with an emitter that directs water to a certain section of the soil. The drip hose can be placed above ground or buried in the ground, which is called sub-surface drip irrigation [8]. Sub-surface irrigation has the advantage of nearly zero evaporation, but it is difficult to diagnose if an emitter becomes plugged or damaged. Drip irrigation operates at low pressures, 10 to 20 psi at the emitter. The system pressure will need to be higher to overcome pressure loss in filters, valves, backflow preventers, pressure regulator and tubing [9]. Drip method helps in achieving saving in irrigation water, increased water-use efficiency (since soil evaporation, surface runoff, and deep percolation are greatly reduced or eliminated), decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer-use efficiency [10, 11, 12]. In addition, the risk of aquifer contamination is decreased since the movement of fertilizers and other chemical compounds by deep percolation is reduced. Reductions in weed germination and weed growth often occur in drier regions [13]. However, if emitter discharge exceeds soil infiltration, a soil overpressure develops around emitter outlet, enhancing surfacing and causing undesirable wet spots in the field. Timely and consistent maintenance and repairs are a requirement. Leaks caused by rodents can be more difficult to locate and repair, particularly for deeper drip irrigation systems [8].

2.2 Automated Irrigation System

An automated irrigation system does the work quite efficiently and with a positive impact on the place where it is installed. Once it is installed in the agricultural field, the water distribution to crops and nurseries becomes easy and doesn't require any human support to perform the operations permanently. If installed and programmed properly, automatic irrigation systems can even save money and help in water conservation. Automatic irrigation systems can be programmed to discharge more precise amounts of water in a targeted area, which promotes water conservation. A pre-set amount of water can be applied in the field segments by using automatic volume-controlled metering valves where a pre-determined quantity of water is programmed to be sprinkled across an area of land for a set interval of time [14].

2.3 Automated Drip Irrigation Systems

Automatic irrigation controllers employed in drip methods are purely volume-based systems, where a predetermined quantity of water is supplied to various portions of the farmland with the help of automatic volume-controlled metering valves. The quantity of water these systems supply is always the same whether power supply is available or not. Volume based systems basically involve the connection of volume meters to generate pulses after discharging a specific amount of water and the controller measures these pulses in order to regulate the supply [15]. Drip irrigation can also be achieved automatically by a spreadsheet model that provides both water budgeting and forecasting for a vast area of land divided into plots. Such an operation ensures that the whole farmland is watered every day based on current demand by

measuring the size of each plot, as well as programming the amount of water required to irrigate every plot during an extended simulation and the prioritization of plots to be irrigated based on raw deficit and net revenue [16, 17].

2.4 Components of Automatic Irrigation Systems

2.4.1 Microcontroller

A microcontroller is a highly integrated chip which performs controlling functions. A microcontroller, or embedded controller, is similar to a microprocessor as used in a personal computer, but with a great deal of additional functionality combined onto the same monolithic semiconductor substrate [18, 19].

2.4.2 Sensors

This is an Electrical resistance sensor which is made up of two electrodes. A current is passed across the electrodes through the soil and the resistance to the current in the soil determines the soil moisture [20]. If the soil has more water, resistance to flow of current will be low and thus more current will pass through. On the other hand, when the soil moisture is low the sensor module outputs a high level of resistance. This sensor has both digital and analogue outputs. Digital output is simple to use but is not as accurate as the analogue output. The soil moisture sensor is often sensing devices embedded within some sort of insulation which measure the water content in soil [21].

2.4.3 Liquid crystal display

Liquid Crystal Display (LCD) screen is an electronic display module. An LCD has a wide range of applications in electronics. The most basic and commonly used LCD in circuits is the 16x2 display. LCDs are commonly preferred in display because they are cheap, easy to programme and can display a wide range of characters and animations. A 16x2 LCD have two display lines each capable of displaying 16 characters. This LCD has Command and Data registers. The command registers stores command instructions given to the LCD while the Data register stores the data to be displayed by the LCD [22].

2.4.4 Water pump

The water pump is the process of artificially supplying water artificially for a particular task. It can be electronically controlled by interfacing it to a microcontroller. It can be triggered ON/OFF by sending signals as required [16].

2.4.5 Solenoid valve

Solenoid valve is an electromechanically operated valve controlled by an electric current through a solenoid. It basically works as an actuator for the system. A solenoid valve consists of two main sections which are the solenoid and the valve. The solenoid converts electrical energy into mechanical energy which, in turn, opens or closes the valve mechanically. Solenoid valve depends on the pressure between input and output as the pressure at the input must always be greater than the pressure at the output for it to work [23].

2.4.6 Transistor

A 2N2222 may be a common NPN bipolar semiconductor device; bipolar junction transistors (BJT) used for general purpose low-power amplifying or switch applications. It is designed for low to medium current, low amplifying current, low power, medium voltage, and might operate at moderately high speeds. It had been originally created within the TO-18 metal [24].

2.4.7 Resistor

A resistor is an electrical device which may be a passive two-terminal electrical part that implements resistance as a circuit component. In electronic circuits, resistors unit of measurement accustomed reduce current flow, alter signal levels, divide voltages, bias active components, and terminate transmission lines are among its uses [24].

3 MATERIALS AND METHODS

3.1 Materials

Microcontroller, Solenoid Valve, Soil Moisture Sensor Module, Resistors, Capacitors, Relay, LED, Battery, Reservoir, Pump, Soil Auger, Ruler, Soil Moisture meter.

3.2 Design Methods

3.2.1 System description

The automatic drip irrigation system consisted of seven units designed to continuously sense the moisture level of the soil. The system responds appropriately by watering the soil with the exact required amount of water and then shuts down the water supply when the required level of soil moisture is achieved. The reference level of soil moisture content was made to be adjustable for the three most common soil textures (sandy, loamy and clayey soils) Also the amount of irrigation, i.e. the volume of water delivered to the soil, was adjustable by the system operator (mild, nominal and high levels).

3.2.2 Design considerations

The design considerations include installation costs, water saving, human intervention, reliability, power consumption, and maintenance. Critical considerations include installation costs since costs generally determine the feasibility and viability of the project. The water saving is equally an important aspect since there is a demand to minimize water loss and to maximize the efficiency of water used, power consumption and availability of parts.

3.2.3 Hardware design

The hardware design entails the design of each building block and interconnecting them thereafter to form the block diagram of the system as shown in Figure 1.

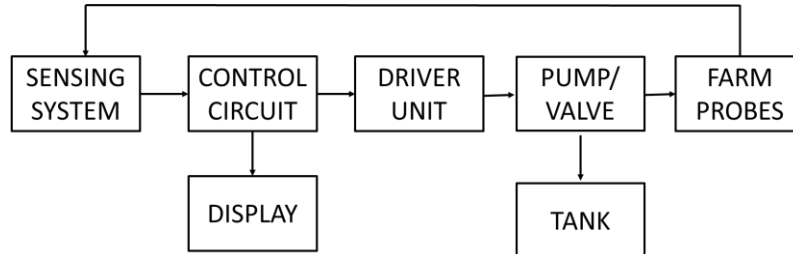


Figure 1. Functional Block Diagram of the Automatic Drip Irrigation System

The moisture sensors were designed using probes made from corrosion-resistant material which can be stuck into soil sample. Voltage levels corresponding to the wet and dry states of the soil sample was computed by measuring the resistance between the moisture detector probes and matching them to output voltages of a comparator circuit. A submersible low-noise micro water pump was used to deliver the water to the base of the plants. The volume of water required for irrigation per time was computed by considering the capacity of the water pump and the water channels. The required irrigation time was determined by considering the response time of the water pump and the water volume required per irrigation instance. A timing circuit was also designed to use the required irrigation time to control the duration of each irrigation instances. Circuit construction was implemented on a Vero board.

3.2.4 Water pump and power supply circuit

This unit consisted of a DC water pump and power supply circuit which has Voltage of 12V DC at 5A and power of 60watts. It was used as the main load of the system, and the power supply signal current is controlled by the microcontroller and an amplified by the transistor TIP41 as shown in Figure 2. The pump was able to supply up to 250 cm³ of water in about 10 seconds.

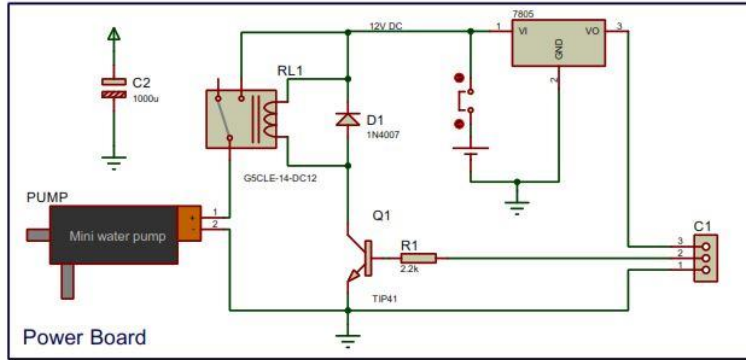


Figure 2. Power Circuit

3.2.5 The sensing circuit

The sensor designed is made up of two conducting metal probes placed in a block of varnished wood. The distance of separation of the probes is 4cm. The probes have conducting wires attached to them at the end above the block as shown in Figure 3.

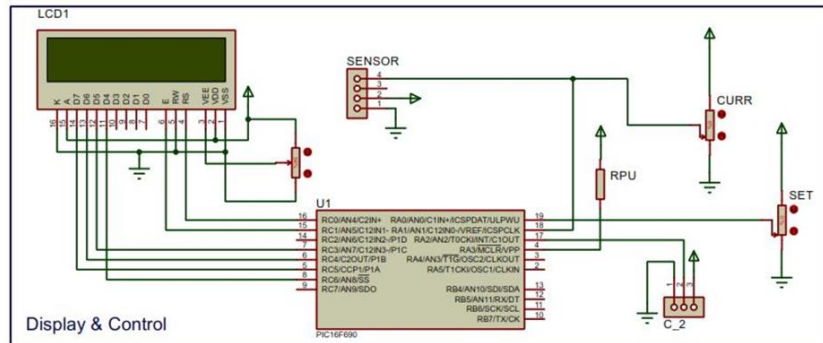


Figure 3. Sensing, control and display circuit

3.2.6 The control circuit

One of the most important components of an automatic irrigation system is the irrigation controller also called a timer or clock. A timer was used as the brain of the control circuit due to its operational characteristics in the monostable mode. The timer was used to produce voltage to energize the relay coil, consequently activating the pump motor circuit for some seconds, which is the time needed for irrigation. A normally-open relay was used as the actuator to implement the triggering of the pump-motor circuit. A free-wheeling diode was connected across the relay coil to allow for current dissipation due to stored energy when the relay coil becomes de-energized. A 16 × 2 alphanumeric liquid crystal display (LCD) module was used as display unit. The module was connected to port B of the microcontroller. The circuit diagram for the control circuit is as shown in Figure 3.

3.2.7 Software design

The software design started with testing soil moisture sensor by writing a control program in C language to enable the sensor detects the moisture content of the soil. The sensor then sends the signal to the microcontroller which sends out a display on LCD and instructs the driver unit to turn on or off the pump depending on whether detected soil moisture content exceeded the threshold value. The overall system flowchart is as shown in Figure 4.

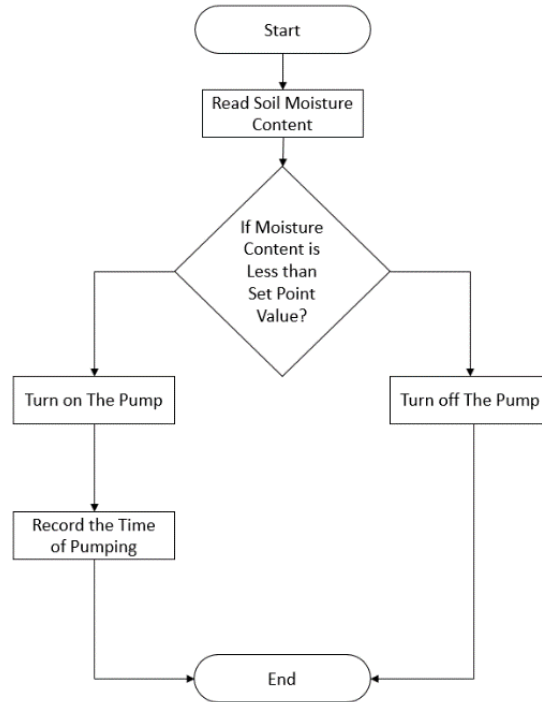


Figure 4. System Flowchart

3.2.8 Construction procedure

The construction started with the production of the circuit PCB layout. This was achieved using Proteus ARES software. The layout was printed on a glossy paper and transferred to a plane copper board. This was achieved by placing the printed layout on the copper board, while using an electric iron to transfer the layout by heating. After the heating process, the board was soaked in water to remove the glossy paper leaving the track of the layout on the board. The board was then placed inside a solution of ferric chloride with warm water to remove the copper or etch the part of the board that was uncovered with the track layout. After etching, holes were drilled to allow components terminal to pass through using hand drilling machine in the lab. The second step in the construction procedure was to place the components for soldering. The components terminals were soldered to the PCB board for proper connection of the functional circuit.

3.2.9 Packaging and system design layout

On completion of the work, the circuitry was enclosed in a case to provide support and prevent damage. Due to the nature of components used in the construction, a plastic casing was used for packaging because it is strong, durable and can withstand mild external stresses. It also serves as a heat sink to the bridge rectifier and an aesthetic was also applied to make it look beautiful. The system design and principle of operation was achieved by the connection of the various components available for the project. The layout and connection is as shown below in Figure 5.

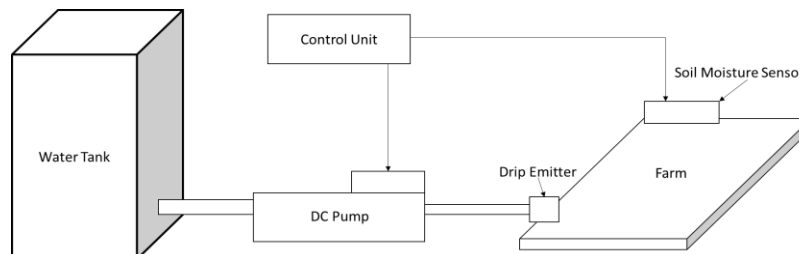


Figure 5. System principle of operation

3.2.10 System principle of operation

The working principle of operation of the automatic drip irrigation system by sensing the moisture of the soil involves the following; the soil moisture sensor is inserted in the soil near the roots of the plant. The soil moisture sensor measures the conductivity of the soil. Wet soil will be more conductive than dry soil. The soil moisture sensor module has a comparator in it. The voltage from the prongs and the predefined voltage are compared and the output of the comparator is high only when the soil condition is dry. This output from the soil moisture sensor is given to the analogue input pin of the microcontroller. The microcontroller continuously monitors the analogue input pin. When the moisture in the soil is above the threshold, the microcontroller displays and the motor is off. When the output from the soil moisture sensor is high i.e. the moisture of the soil is less, the microcontroller will trigger and displays on the LCD. When the transistor is turned on, the relay coil gets energized and turns on the motor. The LED is also turned on and acts as an indicator. When the moisture of the soil reaches the threshold value, the output of the soil moisture sensor is low and the motor is turned off, this continued until the required amount of water is obtained.

4 RESULTS AND DISCUSSION

4.1 Soil Moisture Content

Table 1 shows the soil moisture at different sampling points and depths in the study area. The result indicate that moisture content varies in all the depths and points of sampling. It was observed that mean moisture content increases with depth of sampling from 11.45% at 10 cm to 13.83% at 30 cm depth. Also, the Table revealed that the lowest mean moisture content of 7.30 % was obtained at sampling point B followed by sample point A which had mean moisture content of 12.60%, while the highest mean value of moisture content of 16.67% was recorded at sample point D. Mean soil moisture content of 12.73% was obtained for the entire sampling points and depth of sampling for the study area. Statistically, using analysis of variance as presented in Table 2, it was observed that there was no significance difference among the mean soil moisture content at depth of sampling at 5% level of significance while the difference between the mean soil moisture content among the soil sampling points were highly significant at 5% level of significance which is in line with [25].

Table 1. Soil Moisture Content (%) at Different Points and Depth

Depth of Sampling (cm)	A	B	Sample Points C	D	Mean
10	10	7.8	12	16	11.45
20	12.8	7.8	14	17	12.9
30	15	6.3	17	17	13.83
Mean	12.6	7.3	14.33	16.67	12.73

Table 2. ANOVA Table for Soil Moisture Content at sampling Points and Depths

Source of Variation	Df	SS	MS	F	F crit
Replication	3	0.014271	0.004757	17.951	4.757063**
Treatment	2	0.001147	0.000573	2.162	5.143253*
Error	6	0.001593	0.000265		
Total	11	0.01701			

*= significance **= highly significance

4.2 Performance Evaluation of the Automatic Drip Irrigation System

After proper design and construction of the automatic drip irrigation system, it was important to evaluate the performance of the drip irrigation system. Table 3 shows the result of the performance evaluation of the automatic drip irrigation system. The table indicates that soil moisture content increases with increase in volume of water applied, while the discharge decreases with increase in volume of water in the study area which is in line with [25].

Table 3. Field Performance Evaluation of the Developed Automatic Drip Irrigation System

Moisture Content (%)	Volume (l)	Time (s)	Discharge (l/s)
18	0.70	2.49	3.55
22	0.75	2.60	3.47
24	0.76	2.28	3.00
26	0.76	2.14	2.81

4.3 Effect of Soil Moisture Content on Flow Rate of DC Pump

In order to properly visualize effect of moisture content on the system flow rate of the DC pump, a plot of the relationship of the flow rates and moisture content was carried out as shown in Figure 6. Figure 1 reveals that as the volume of water increases, the moisture content decreases which indicates that the valve tend to close to allow the flow of water from the reservoir to be reduce. This indicates a negative linear relationship between volume and soil moisture content. In addition, it was observed that as the discharge increase, the moisture level rises in the soil and at that moment, the valve was closed. These showed linear relationships with correlation coefficients (r^2) value of 0.99 and 0.87, respectively. Thus, this mathematical relationship between soil moisture content and pump discharge can be relied upon to predict the behavior of the automatic drip irrigation system which is in line with [18].

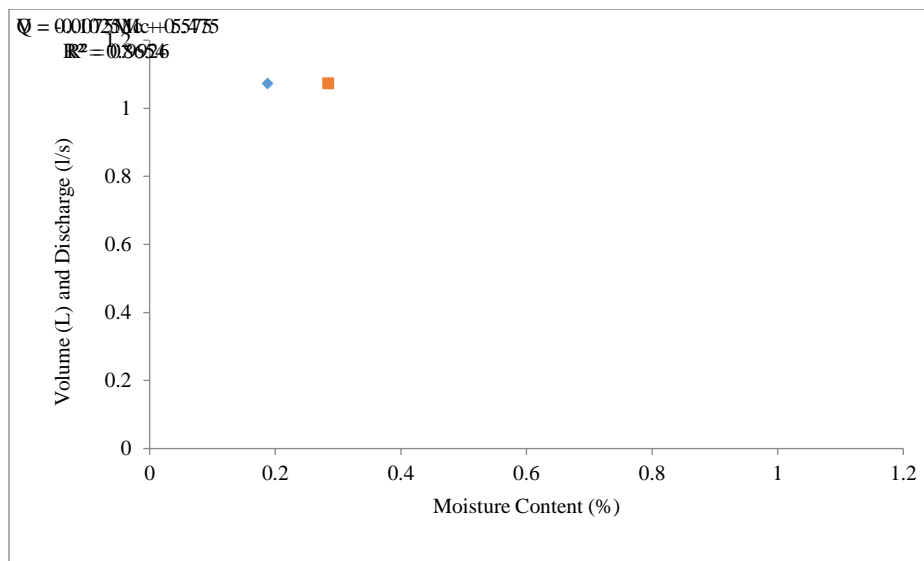


Figure 1. Relation of the Moisture Content, Volume and Discharge

4.4 Efficiency of the System

The efficiency of the system was the ratio of the output (soil moisture meter reading) to that of the input (set point moisture content) of the system which had a value of 99.35%. This shows that the system has a higher performance which is in line with [26]. Statistically using student’s t-test, it was observed that there was no significant difference between the set point moisture content and the experimental soil moisture content at a 5% level of significance.

Table 4. Efficiency of System

Set Moisture Content (%)	Soil Moisture Meter Reading (%)	Efficiency (%)
18.00	17.80	98.89
20.00	19.90	99.50
22.00	21.90	99.55
24.00	23.90	99.58
26.00	25.80	99.23
Mean		99.35

5 CONCLUSIONS

In this study, an automatic drip irrigation system was designed and developed for monitoring soil moisture content of farm lands in Girei Local Government Area of Adamawa State. Mean soil moisture content of 12.73% was obtained for the entire sampling points and depth of sampling in the study area. There was no significance difference among the mean soil moisture content at depth of sampling while the difference between the mean soil moisture content among the soil sampling points were highly significant. Negative linear relationship between volume and soil moisture content was observed. Linear relationships with correlation coefficients (r^2) value of 0.99 and 0.87, respectively, were recorded which can be relied upon to predict the behavior of the automatic drip irrigation system. The automatic drip irrigation system was found to be reliable as its performance does not change with time. The mean efficiency of the automatic drip irrigation system was found to 99.35% which indicates that the set-up is highly efficient and requires minimal human intervention.

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