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Research Article

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Microcontroller Soil Texture based Automatic Irrigation Management System

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Abstract Water they said is life and has no enemy, but this valuable natural resource in limited in nature and faces a lot of pressure from fast increase in world population and global warming or climate change. Agricultural irrigation plays important role in making this precious natural resource becomes limited and need for it to be protected has come. One of the primary goals of every automatic irrigation systems available in the market today is to preserve water. But many fail in that aspect because they did not take into consideration the soil texture of the field they are to irrigate, thereby wasting the water that they are to conserve in the first place. Our proposed automatic irrigation system with aid of control theory takes into account the soil texture of the field to be irrigated and determine the appropriate amount of water required by the soil. The automatic irrigation system consists of Arduino UNO microcontroller as the main controller and lots of sensors and actuators. The system contains three moisture sensors for the three soil texture types under consideration in the research (Sandy, Loamy, Clay). The results indicated that fields that contain the same plant should be irrigated with virtually the same amount of water irrespective of soil texture. It shows that the only difference between sandy, loamy and clay soil texture considered in this research was the frequency of water application, since their water holding and drainage capacities not the same. Sandy soil drained faster and was irrigated twice a week compare to loamy and clay soil which was irrigated once per week because their water holding capacity is higher than sandy soil. The system successfully prevented water wastage and leaching since field was irrigated according the soil texture water holding capacity and plant needs.

Keywords Automation, Irrigation, Soil, Texture, Automatic, Sensors, Depletion, Actuators

1. Introduction

A huge percentage of Nigeria income is generated from crude old, and the world speeding up its fight against climate change. UK in particular announced its plans to ban the sale of new gas and diesel cars by 2035 [1], if the whole world is to follow the same foot step in banning machineries that makes use of fuel and diesel, Nigeria will run out of business sooner than expected. The need for alternative revenue generating is need and agriculture is the best option. Irrigated agriculture plays an essential role in crop production in countries like Nigeria where there is no rain fall all year round [2].

According this author [3], fresh water available for farmers for irrigating their crops will always be limited as the result of great demand from other sectors like industries, homes, and tourism. To combat this great challenge that faces the whole world, he [3] said that more water efficient automatic irrigation system is needed. One of the primary goals of every automatic irrigation systems available in the market today is to efficiently preserve available fresh water. In this framework, many of these automatic systems failed because they did not take into consideration soil texture of the farm to be irrigated. Our proposed automatic irrigation with aid of control theory will play a vital role in decreasing fresh water wastage by taking into consideration soil texture of the farm to be irrigated.

In [4], the author states that when to irrigate the farm and how much water to apply can be tasking for farmers, taking into account uneven rain events throughout the year and different soil types. He said the right amount needs to be applied to get maximum yield as too little water could stress the crop while too much could cause the crop to be underdeveloped by washing soil nutrients available for the crop or leaching.

1.1. Research Objectives

The main objective of this research is to ascertain the required of water for different soil texture using automatic irrigation system. In order to get the precise water consumed by different soil texture type, the experiment was carried in a controlled farm field that has three subplots as shown in figure 3. Amaranthus Hybridus, commonly called Green Gmaranth was used as plant sample because of its ability to grow year round under different condition and was evenly planted in the three subplots.

2. Literature Review

Multiple sensor automatic irrigation system was proposed by [2], where multiple sensors and actuators were used in irrigating the farm. The system where controlled by central microcontroller which collects data from the moisture sensor, magnetic water-level sensor, temperature sensor, and light-dependent resistor and determining if there is need for irrigation. The system sends information to the farmer through Global System for Mobile (GSM) communications when there is need for irrigation. The system is capable of saving water since different crops have different level of water consumption at different stages of their growth. Unfortunately, in this work if the sensors were not well placed in the field, information about the true state of the farm will not be sent to the microcontroller. This will lead to loss of water if the sensors are placed on dry location or loss of crop if the sensors are placed in wet location that is far from the crops.

Agricultural Internet of Things (IoT) was designed by [5], where real time farm data collection and irrigation automation was made possible. The system collects information like, water level, soil moisture, soil fertilizer, crop height, real scene photos of the field. The terminal monitoring equipment in the farm forwards the gathered information through the GPRS gateway to the cloud server where they can be analyzed. The system have upper and lower water level threshold that helps to determine when to open or close the solenoid valve in the rice field for irrigation to take place. The system successfully automated the irrigation system which led to low power consumption of the system and also reliable and collected information was useful in data analysis. On the other hand, the system is highly dependent on GPRS which can fail any time and cost huge loss to farmer since rice farm does not require any form of water drought.

Author [6] designed a web based electronically controlled automatic irrigation system with Arduino and soil humidity sensor. The humidity sensors placed on the farm sends regularly the soil humidity to the Arduino microcontroller. The received humidity value is compared with the set reference value on the microcontroller, the electric pump is started if the value is low and stops if it reaches saturation point. The system also has the ability to be controlled through the web. The auto carried out the testing in controlled laboratory and got a satisfactory result by reducing cost of energy because it use photovoltaic (PV) array. The system is not totally effective because enough sun light is needed to charge the PV array for pumping water, and lack of sun light will make the system ineffective.

3. Materials and Methods

In order to implement this automatic irrigation system based on soil texture, the following soil characteristics will be taken into consideration for prepare irrigation management.

Field Capacity (FC) - Field Capacity (θ_{FC}) is the upper limit around the root zone, which is the water content that can be held by the soil against gravity after being saturated and drained as shown in figure 1 [7]. This state is attained after one day of rain or irrigation for sandy soil textures while for heavy textured soil that contain more silt and clay it can be attained in three days [8].

Permanent Wilting Point (PWP) – The lower limit around the root zone is called Permanent Waiting Point (θ_{WP}), which is the minimum soil moisture that every plant needs in order not to wither [7]. Anything below wilting point, the plant cannot obtain enough water to maintain its normal growth and will never recover according to this author [8]. This is as a result of plant transpiration and direct evaporation which decreases the soil moisture level to a point below θ_{WP} sometimes near dryness [9].

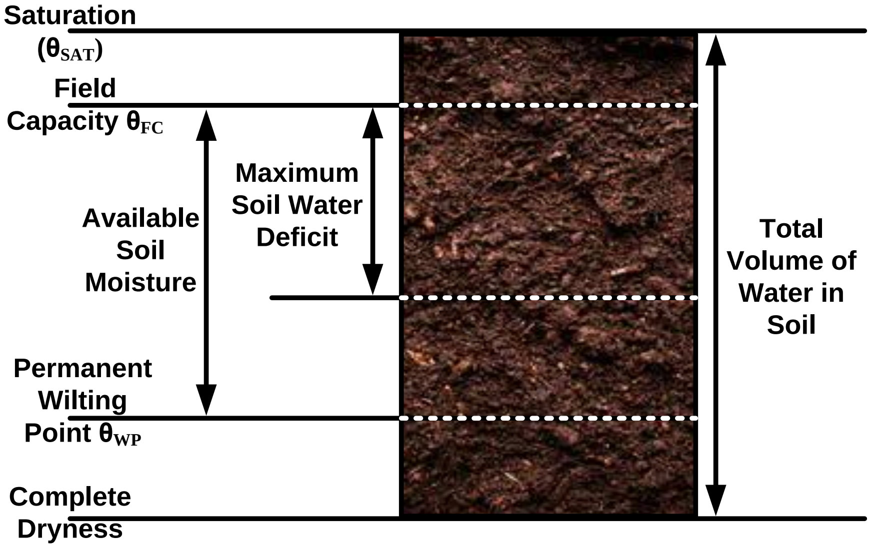

Figure 1: Soil moisture terminologies [10]

Available Water Capacity (AWC) - This is the maximum amount of soil water that can be absorbed by plant root [11]. Available water capacity is commonly the difference between the upper limit field capacity (θ_{FC}) and lower limit permanent waiting point (θ_{WP}) as show in equation (3.1) [12].

$$\theta_{AC} = \theta_{FC} - \theta_{WP} \qquad (3.1)$$

Average available water capacities are displayed in table 1.

θ_{AC} is also the soil water content that lie above θ_{WP} and below θ_{FC} as represented in equation (3.2).

$$\theta_{PW} < \theta_{AC} < \theta_{FC} \qquad (3.2)$$

Available water capacity of the soil is measured in terms of inches of water inch of soil depth and its general values are provided in table 1.

Soil-Water Content (SWC) - This is the quantity of water held in the soil at any particular point in time which can also be expressed as volumetric or gravimetric water content.

Volumetric water content (θ_v) is the volume of liquid water per volume of soil and is defined mathematically as [13]:

$$\theta_v = \frac{v_{water}}{v_{soil}} = \frac{v_{wet} - v_{dry}}{v_{dry}} \qquad (3.3)$$

Where:

v_{water} is the volume of water in the soil sample
v_{soil} is volume of soil in the soil sample
v_{wet} is the volume of the soil when it is wet
v_{dry} in the volume of the soil when it is dry.

Gravimetric water content (θ_g) is the mass of water per mass of dry soil also defined mathematically as [14].

$$\theta_g = \frac{m_{water}}{m_{soil}} \qquad (3.4)$$

Where:

m_{water} is the mass of water in the soil sample
m_{soil} is the mass of soil in the sample.

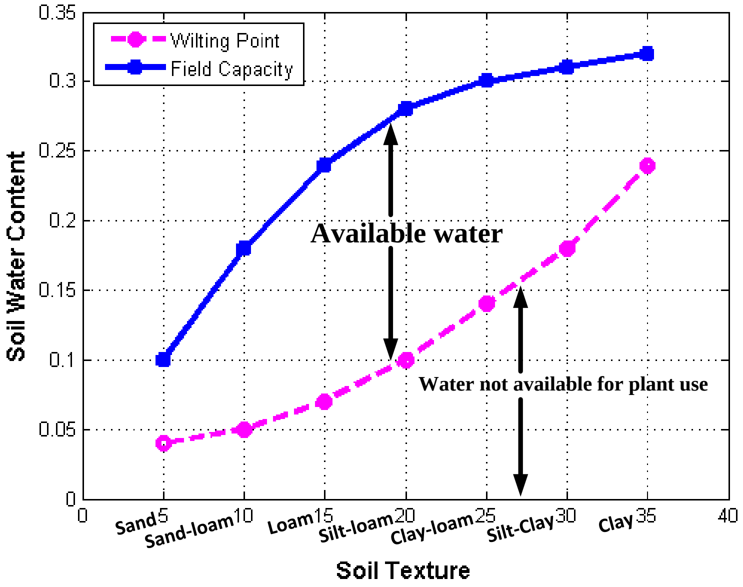

Figure 2: Water content at field capacity and at wilting point for various soil textures

Common soil textural field capacities and the permanent wilting points are represented in figure 2. The region between field capacity and permanent wilting points is called available water capacity and with increase in clay content of the soil texture leading to increase in available water capacity while too much sand deceases the available water capacity.

Table 1: Plant water availability for different soil textures

Soil Texture	**Field Capacity (inches)**	**Wilting Point (inches)**	**Available water Capacity**		
			Low	**High**	**Average**
			inches of water / inches of soil		
Sand	0.1	0.04	0.06	0.08	0.07
Sand-loam	0.18	0.05	0.11	0.13	0.12
Loam	0.24	0.07	0.16	0.18	0.17
Silt-loam	0.28	0.1	0.17	0.19	0.18
Clay-loam	0.3	0.14	0.15	0.17	0.16
Silt-Clay	0.31	0.18	0.12	0.14	0.13
Clay	0.32	0.18	0.13	0.15	0.14

Table 1 is field capacity (inches) and permanent wilting point (inches) for different soil texture and their corresponding available water capacity.

Soil Water-holding Capacity

When talking about soil water holding capacity, one cannot ignore soil texture since it is the major factor that determines the water holding capacity of such soil. The texture of the soil according to [4] is the relative amounts of sand, silt and clay particles in the soil. Determining the water holding capacity of the soil will help our automatic irrigation system schedule irrigation of the farm optimally. Table 1 can be used to estimate the available soil water in a field based on different soil texture.

Table 1 can be used to estimate the available soil water in a field based on different soil texture.

As a good irrigation scheduling practice, author [4] suggested in a field that consists of more than two different soil texture that one with the lowest available amount of soil water should be used for irrigation scheduling. On dominants, [4] said that available soil water of soil texture that dominates (in terms of coverage) the field should be used for irrigation scheduling instead of less dominant soil texture.

Water Pump Capacity

The water pumping capacity of the irrigation system will help to determine water application rate of the system. The pumping capacity is the units of gallons per minute (gpm) per irrigated acre. Using table 2 as example, a water pump with pumping capacity of 100gpm will be able to deliver 2gpm/acrce pumping capacity [4]. While water application rate can be calculated using the flow rate on the area as shown in equation **(3.5)**.

$$AR = \frac{q/A}{452.57} \qquad (3.5)$$

Where:

AR = Water application rate (in/hr)

q= Flow rate (gpm)

A= Area being irrigated (acres)

This calculator assumes no evaporation or wind drift losses.

Table 2: Water pump capacities for different irrigation area (acres)

Pumping	**Irrigation Area (acres)**				
Rate (*gpm*)	**50**	**100**	**150**	**200**	**250**
100	2.00	1.00	0.67	0.50	0.40
200	4.00	2.00	1.33	1.00	0.80
400	8.00	4.00	2.67	2.00	1.60
600	12.00	6.00	4.00	3.00	2.40
800	16.00	8.00	5.33	4.00	3.20
850	17.00	8.50	5.67	4.25	3.40
900	18.00	9.00	6.00	4.50	3.60
950	19.00	9.50	6.33	4.75	3.80
1000	20.00	10.00	6.67	5.00	4.00

3.1. Proposed irrigation system

The experiments were carried out in a land with three subplots: clay, loamy and clay soil each having one third of total land space used in the experiment as shown in figure 3. Each subplot were given two separate treatments, first to test the system automatically irrigating the field with enough water when the MAD reaches 50% or less and secondly the system irrigate the field seven days in a week. Each treatment were conducted and monitored for four weeks.

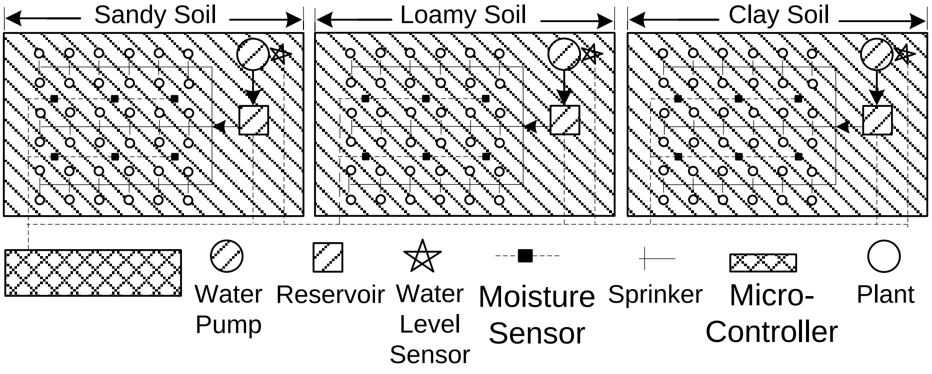

Figure 3: Diagram of the experimental area with subplots in the farm

3.2. Block diagram of proposed methodology

The proposed automatic irrigation system based on soil texture which consists of ATmega2560 microcontroller, three moisture sensor, water level sensor and water pump, one for each soil texture under consideration in this research is shown in figure 4.

The system is grouped into three subroutines, with each containing sensors and actuator for collecting data and actuation of loamy, sandy or clay soil. The work of the microcontroller is to control the entire operation of the system, receiving data from individual sensors on the system and determining which corresponding actuator to activate based on the data been processed.

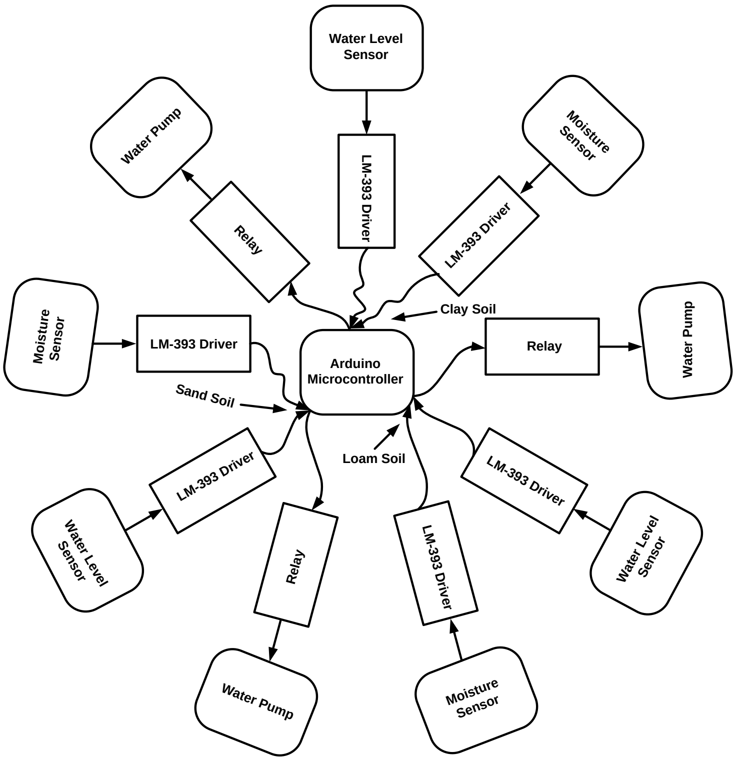

Figure 4: Proposed system hardware block diagram

3.3. Working principle of the proposed system

The flow control of our proposed automatic irrigation system is depicted in figure 5.

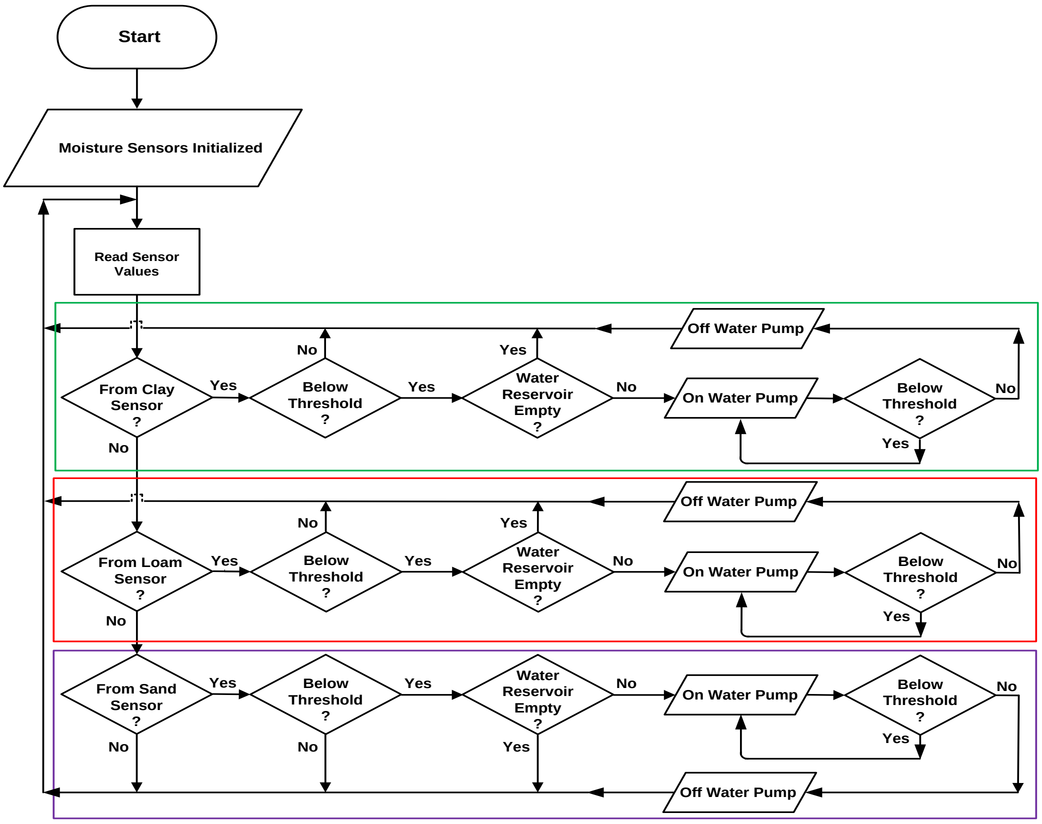

Figure 5: System flow diagram

After system initialization, the microcontroller receives an interrupt signal from the moisture and determines which of the three moisture sensors (Clay, Loam, sand sensors) sends the signal.

Upon determining the moisture sensor that sends the signal, the microcontroller checks if the signal value is below the set system threshold (MAD 50%) for that particular soil moisture sensor. If the moisture sensor value is low, with the help of water level sensor the system checks if enough water is available in the reservoir. If both cases are true, that is low threshold value and enough water in the reservoir that system starts irrigating the field. Otherwise the system returns to its initial stage.

During the irrigation, the system continue checking when the moisture level of the soil reaches field capacity and it turns off the irrigation and returns to its initial stage of checking when the moisture level drops below the set threshold.

4. Results and Discussion

The plant used in this test has the same rooting depth of 10 inches across all three different soil textures (sandy, loamy and clay). Also 1.0 inch of water per week is required to wet 10 inches of the rooting depth.

4.1. Automatic Irrigation Test

In this first test, the field is required to be irrigated with enough water for plant normal growth for a total of four weeks when the soil MAD reaches 50% automatically.

Table 3: Automatic irrigation treatment test worksheet

Soil Texture	AWC (inch/inch soil)	Root Dept (inches)	Plant Type	Required water (inches)	MAD (%)	Irrigation Freq.	Applied Water (Inches)				Total Water (inches)
					Per Week		Wk1	Wk2	Wk3	Wk4	
Sandy	0.06	10	Green	1.0	50	2	0.98	0.97	0.98	0.98	3.91
Loamy	0.15	10	Green	1.0	50	1	0.97	0.96	0.96	0.98	3.78
Clay	0.18	10	Green	1.0	50	1	0.96	0.96	0.95	0.95	3.82

First, the sandy soil with water holding capacity of 0.06 inch of water per inch of soil depth can only hold 0.50 inch of water at a time in theory. The result shows that the system did not apply 1 inch of water at a time rather a quantity a little shy of 0.50 inch twice in a week. Reason was that the soil texture under consideration cannot hold 1 inch of water at that root depth at a time.

The second loam soil, with water holding capacity of 0.15 inch but can hold 1.50 inch of water comfortably in rooting depth of 10 inches. The system only applied 0.96 inch in the first week and similar amount in the subsequent weeks which is a fraction off the required 1.0 inch of water at once per week against 1.50 inch of loamy soil water holding capacity at root depth 10 inches as show in table 3.

Lastly, the clay soil with the highest water holding capacity of 0.18 inch and can hold up to 1.80 inch in that amount of root depth. That system also did not apply that amount because it will also lead to leaching as result of excess 0.08 inch but only applied 0.96 inch which is close to water required per week.

The main difference in this first test was the frequency of irrigation; sandy soil was irrigated more frequently followed by loamy soil and then clay soil. The system gave the same amount of required water to the crop irrespective of the soil type but some were irrigated more frequently than others. The system was programmed not to allow the soil moisture contain of individual soil texture to go beyond Maximum Allowable Depletion (MAD) of 50%. Below the MAD, the system will automatically irrigate the field. The result shows that sandy soil attain this point very fast when compared to other soil texture loamy and clay leading to the field been irrigated twice per week and other two soil textures once per week.

4.2. Daily Irrigation Test

In this test, the plant is required to be irrigated with a total of 1 inch of water per week for its normal growth but on a daily basis.

Table 4: Daily irrigation treatment test worksheet result

Soil Texture	AWC (inch/inch soil)	Root Dept (inches)	Plant Type	Required water (inches) Per Week	MAD (%)	Irrigation Freq.	Applied Water (Inches)				Total Water (inches)
							Wk1	Wk2	Wk3	Wk4	
Sandy	0.06	2.0	Green	1.0	50	7	0.96	0.98	0.97	0.98	3.89
Loamy	0.15	0.80	Green	1.0	50	7	0.97	0.97	0.97	0.97	3.88
Clay	0.18	0.60	Green	1.0	50	7	0.96	0.97	0.97	0.96	3.86

In theory, it is expected that a minimum of 1/7 inch (0.14 inch) of water will be applied to the field irrespective of soil texture. The result in table 4 shows that the only difference in all three soil textures was the depth of soil wetted, because their water holding capacities are not the same. The system wetted approximately 2.0 inches of sandy soil, 0.80 inch of loamy soil and the clay soil was wetted with the least root depth of 0.60 inch. It also show that not all 0.14 inches of water was apply but a fraction of 0.02 inch was lost with the remainder reaching the soil. This is not effective since the plant needed its 10 inches root depth to be irrigated for normal growth but this leads to drought instead. This test clarify the popular false impression that plant should be water daily rather than when need arises.

5. Conclusion

This research paper presents an automatic irrigation system capable of minimizing water wastage in irrigation field by irrigating the field based on the soil texture. This research shows that different soil texture type can hold different amount of water and should not be irrigated with the same amount of water. It also shows that sandy soil drains quickly and should be irrigated more often compared to loamy and clay soil which have higher water holding capacity and drains slowly. Since the same type of plant Amaranthus Hybridus was used with the same root depth across all soil textures, the result shows that virtually the same amount of water was applied across all three soil textures for the period of eight weeks of monitoring. The only difference is the frequency of water application since their water holding and draining capacity of all three soils are not the same. The research did not take into consideration crop growth and yield because these attribute differs from soil texture to another which is not the interest of this research. The system successfully prevented water wastage and leaching and should be implemented in large scale for farms and domestic use.

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