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Development and testing of an automated sprinkler irrigation system for vegetable farming

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Abstract
Automated sprinkler irrigation was designed to enhance optimal performance of an irrigation system. It was designed in a plot of 0.225ha from a reservoir to field or crops in Imo state polytechnic Umuagwo, Nigeria during the dry seasons. A pumping mechanism was used to deliver the needed amount of water to the soil. The system was developed to reduce the usage level of water and irrigate with the actual water requirement on crops with soil-moisture sensor, temperature sensor and water availability sensor. In addition, this automated system gives the sensor information. The results obtained showed that the soil in the study area was sandy loam, moisture content of 10.5%, bulk density of 1.53g/cm^3, particle density of 2.62g/cm^3, porosity of 41.05%.The result of particle size distribution reveals that Uniformity coefficient (CU) = 1.92, Coefficient of gradation (CC) =0.81, 16% clay, 22% silt and 62% sand. Results from the design showed that irrigation frequency of 6 days, net depth of 4.69cm, gross depth of 6.7cm, irrigation interval of 11days and irrigation period of 3 hrs. Total number of sprinkler head used was 12 sprinkler heads, a total discharge (q) of 0.73 litres/ sec/ sprinkler and discharge capacity of pump (Q) was 1.27 litres/sec. Proximate analysis and mineral composition of okra were determined using the standard methods of association of official Analytical Chemistry.

Keywords: Automation, irrigation, moisture sensor, temperature sensor.

1. Introduction

Most Nigerians including rural and urban dwellers have no access to adequate water and quality food. Today, our society is seriously facing water problems to meet future food demands from a rising global population whilst minimizing any environmental impact. Thus, it is very important to raise agricultural production (yield) in tandem with advances in water and nutrient efficiency (Kumar et al., 2016; Monaghan et al., 2013). When natural resources are no longer sufficient to meet a crop's water needs, irrigation is the artificial method used (Idama and Ekruyota, 2021). Irrigation raises water content in the soil's root layer, hence increasing soil fertility, while also lowering the surface temperature and increasing humidity. In dry locations and during periods of below-average rainfall, it also aids in the growth of crops, maintenance of landscapes and the re-vegetation of disturbed soils.

Several methods of irrigation are used today depending on water availability, the type of irrigated crop and the financial investment the farmer is willing to make. To solve the issues on hunger, starvation and criminality caused by food insecurity, the deployment of autonomous agricultural systems that will help increase food production has become essential (Idama and Ekruyota, 2021). Nigeria, Africa's most populous country has a population of over 200 million people. The country is still primarily on agricultural advancement, with over 70% of the population engaged in subsistence agriculture (World Bank, 2014). The need for automation in irrigation arose because in most developing countries, agricultural lands are located very far from the farmers' houses and as such the manually operated irrigation systems are often located farther from the cities and towns, this increased cost to the farmer since he will have to transport himself to the farmland during the irrigation period or employ labour to ensure the effective control of the irrigation system, thus the automated system of irrigation will help the farmer to irrigate his farm with ease even in his absence.

Irrigation is managed by man and as a dynamic being with various engagements may not always be available to irrigate and control the system due to his dynamic nature. This may cause water deficiency to the plant. Water deficiency can be detrimental to the plant before visible wilting occurs. In order to ensure human society survives, water is very crucial (Manju, and Sagar, 2017). Farmers can apply the proper amount of water at the right time using automated irrigation, regardless of the availability of labor to switch valves on and off.

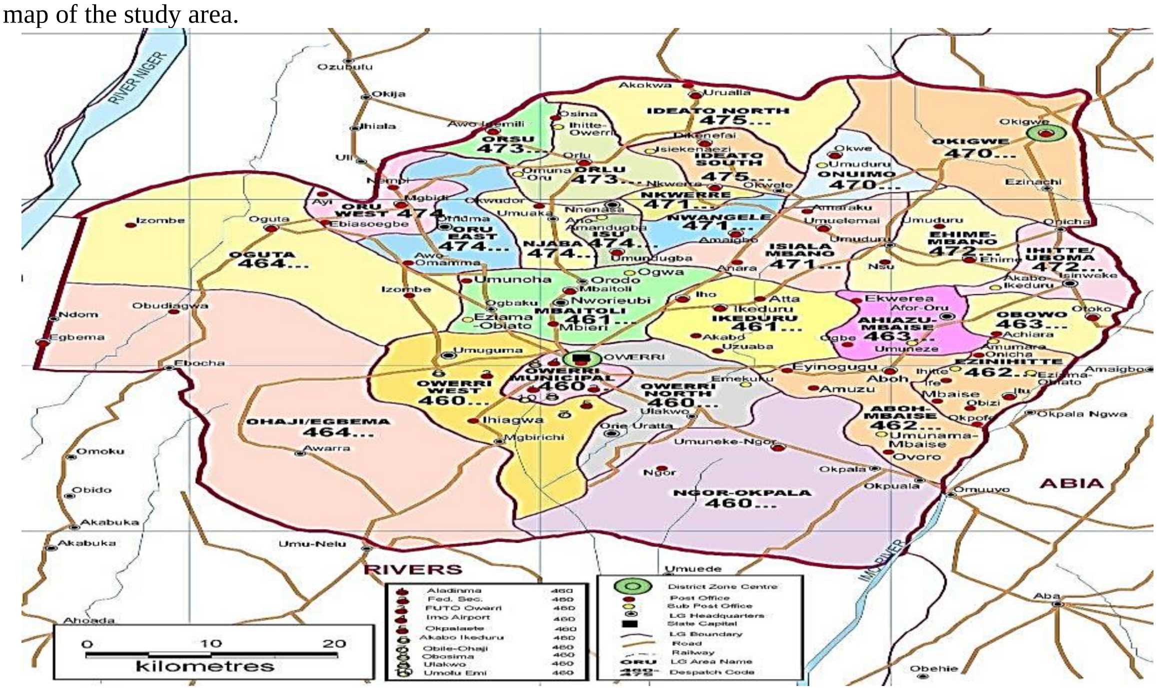
Various sensors such as tensiometer, relative humidity sensors, rain sensors, temperature sensor control irrigation scheduling. Preliminary findings show that using advanced mobile phones as water system sensors could result in a useful farming tool (Alberta et al 2018; Vermesan and Friess, 2015). Wireless sensor networks are now widely used in the food and agricultural industries. A wireless modem based on the Global System for Mobile Communication (GSM) and General Packet Radio Service (GPRS) (SIM900A) play a significant role in communicating the temperature, humidity, and soil moisture content sensor value to a remote area in today's world.

In this automated system, soil moisture content is automatically measured every few seconds using moisture sensors. If the soil moisture is insufficient to meet the land's agricultural crop's water needs, the system sends a wireless message to the valves in the irrigation pipelines, causing the power supply to the valves to stop. This study aims at the design of automated sprinkler irrigation for vegetable farming that would use water efficiently to avoid water wastage and optimize the use of water in the process.The novelty approach of this system lies in the ability to measure the moisture content of the soil using automated sprinkler irrigation system designed to enhance optimal performance of an irrigation system on a plot of 0.225 hectares in Imo state polytechnic Umuagwo, during the dry seasons.

2.0 Material and methods

2.1 Study Area

The research was conducted at Imo State Polytechnic Umuagwo-Ohaji, Imo State Nigeria. It is located 26km from Owerri on the Port Harcourt road. The area lies on Latitude 5°18'12.60"N and Longitude 6°56'26.39''E. Below is the map of the study area.



(Source: Ikpeama et al, 2017)

Figure 1: Map of Imo State

2.1 Materials

Arduino Board: is an open source platform that can be used to create electronic projects. Arduino is a programmable circuit board that may be used to create programs for specific tasks. It contains fourteen digital pins, 6 analogue pins, a 16 MHz crystal oscillator, a USB port, a power source jack, and a reset button.

Figure 2: Arduino board

Relay: A relay is an electrically operated switch that automatically operates a switch using a magnet. When a circuit needs to be regulated by a separate low-power signal or when multiple circuits need to be controlled by a single signal, relays are utilized.

Soil Moisture Sensor: The soil moisture sensor detects the moisture in the soil. When the soil probe is plunged into the soil, the module output is HIGH, as indicated by the RED led on the computer chip, indicating that the soil moisture is low. The below shows how this sensor analyzes the soil's dielectric constant using transmission line techniques.

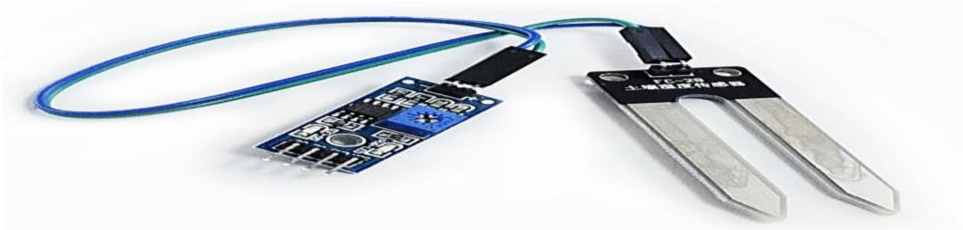


Figure 3: Soil moisture sensor

DHT11 sensor: The DHT11 sensor measures the temperature and humidity of the plant's root zone. This sensor has a protective shell on top of it that can endure any weather condition. This sensor is placed near the plants' root zones and monitors both temperature and humidity at the same time. The measured data is sent to an Arduino board's analog pins, which cover the digital output and display both values on the LCD.

SIM900A Module: Using AT instructions, the SIM900A module sends data from the microcontroller unit to the mobile phone. The receiver and transmitter pins of this module are linked to the Arduino board's transmitter and receiver pins, as well as the ground and VCC pins of both the Arduino and SIM900A modules as shown in Figure 4.

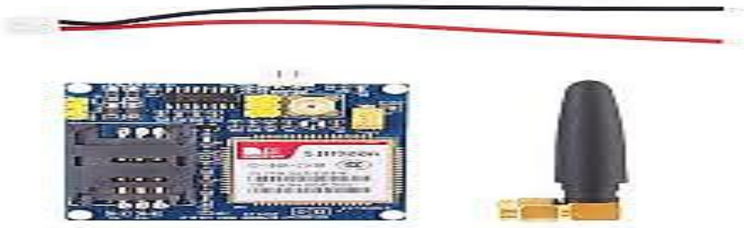


Figure 4: SIM900A Module

Transistor: The 2N2222 is a typical NPN bipolar semiconductor device; bipolar junction transistors (BJTs) are utilized for low-power amplifying and switching applications. It's made for low-to-medium current, low amplifying current, medium voltage, low power, and moderate-to-high speeds. It was first developed as part of the TO-18 metal.

Figure 5: Transistor

Resistor: It is an electrical device that uses resistance as a circuit component and can be a passive two-terminal electrical part. Resistors are type of electrical component that is used to reduce current flow, change signal levels, divide voltages, bias active components and terminate transmission lines among other functions.

Figure 6: Resistor

Pipe: PVC irrigation pipes are the most commonly utilized. The diameter of the pipes chosen for land irrigation is determined by the water source's availability and the area of the field to be watered.

2.2 Soil Sampling

Soil samples were collected from the site and used to analyze different soil physio-chemical parameters such as soil pH, Particle size distribution, soil texture, bulk density, particle density, porosity, moisture content, soil temperature, soil electronic conductivity, soil organic content, soil Nitrogen, soil Phosphorus, soil Potassium before the design.

2.2.1 Soil pH was used to determine the pH level of the soil using pH meter model Hana model H1991300 (ALPHA; 1998)

2.2.2 Particle Size Distribution: This test is required for the proper classification of soil, particularly coarse soil, because it represents the relative parts of distinct particle locations (Ali et al., 2013). It is possible to detect whether the soil is mostly composed of gravel, sand, silt, or clay sizes, as well as which of these size ranges is most likely to affect the soil's engineering, physical and chemical properties.

Soil sample from the plots were collected with auger and oven dried with electric oven (set at 1050C) and sieved with a set of sieve. Sand was poured in the topmost sieve with a mechanical shaker for about 10 minutes. The weight passing through each sieve were calculated from equation 1

$$\% \, passing = \frac{Weight \; of \; each \; seive}{Total \; weight} \times 100 \qquad 1$$

Graph of percentage passing (%) against sieve size (mm) was plotted to determine the uniformity coefficient and coefficient of gradation.

2.2.3 Soil Texture: The soil textural triangle shown in Fig 9below was used to classify soil based on the relative amount of sand, silt and clay as a percentage. Soil with higher proportion of sand retains less nutrients and water compared to clay soils.

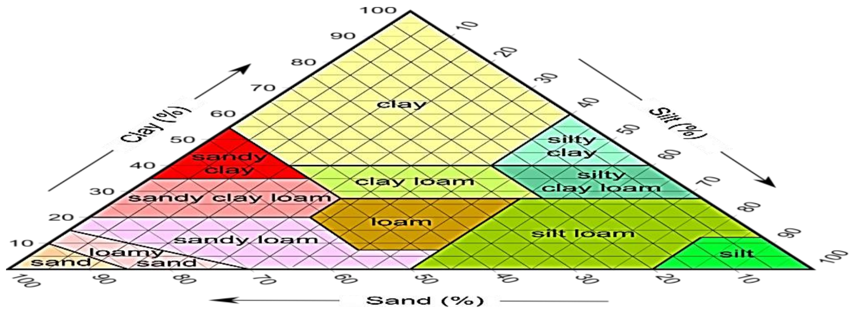


Figure7: Soil Textural Triangle

2.2.4 Bulk Density (BD): The bulk densities of different soils were calculated as the ratio of the dried mass of soil to its total volume (Han et al., 2016, walter et al., 2016) using equation 2.

$$Bulkdensity\rho\left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right) = \frac{Weight\ of\ dry\ soil\ (g)}{Total\ soil\ volume\ (cm^3)} \qquad 2$$

2.2.5 Particle Density (PD): The Particle density of the soil samples were determined using the formula in equation 3 to provide information about the potential release of carbon from the soil into the atmosphere as the organic matter decomposes over time.

$$Particle\ density\ = \frac{Weight\ of\ dry\ soil\ (g)}{Volume\ of\ sand\ particle\ (cm^3)} \qquad 3$$

2.2.6 Porosity: Porosity of the soil samples were determined using the formula in equation 4

$$Porosity\ \%\ = (\frac{1-BD}{PD}\ )\ X\ 100 \qquad 4$$

Where BD = bulk density (g/cm^3)
PD = particle density (g/cm^3)

2.2.7 Soil Temperature: Daily soil temperature was determined from the plot during the growing period, this was done using soil thermometer.

2.2.8 Moisture Content (MC): Daily moisture content of the soil was determined from the four blocks during the growing period, this was done using soil moisture meter. The moisture content was calculated from the following formula.

$$\%\ Moisture = \frac{(W_1 - W_2)}{W_1} \times 100 \qquad 5$$

Where
W_1 = weight of wet sample + crucible
W_2 = weight of oven dried sample + crucible.

Consumptive Use of Crop (CU): Consumptive use (CU) was computed as the product of crop factor and potential evapotranspiration. This is expressed mathematically in equation 6

$$CU = KET_p \qquad 6$$

Where K = Crop factor
ET_P = Potential Evapotranspiration
The above equation was used to determine monthly consumptive use for the growing crop.

2.3 Design of the sprinkler system

Design was done with no significant wind effect, spacing along the mainlines (sm) as 65% and spacing along lateral lines (sl) as 50%. Also sprinkler with operating pressure of 250kpa and wetted diameter of 25m was considered.

Table 1: Design of the sprinkler system

Wind speed (km/hr)	**Spacing along the main line (S_m) diameter**	**Spacing along the lateral line (S_l) Diameter**
No wind	65%	50%
0-6.5	60%	50%
6.5-13	50%	40%
>	30%	30%

Source: (Adopted from Hurd 1969)

For medium pressure system from table 2, selecting a sprinkler with operating pressure of 250Kpa and wetted diameter of 25.00m, therefore obtaining Sprinkler spacing with no wind effect will be;

Operating pressure = 250Kpa

Diameter of coverage = 25.00m

Wind effect = Non

Spacing of lateral along the main (S_m) = 65% of the wetted diameter

Spacing of sprinkler along the lateral (S_l) =50% of the wetted diameter

Therefore;

$S_m = \frac{65}{100} \times 25 \quad = \quad 16.25m$

$S_l = \frac{50}{100} \times 25 \quad = 12.5\text{m}$

Therefore to determine the number of laterals to be used in the field, since the longest side of the field is 50m = $\frac{50}{16.25} = 3\ laterals$

Number of sprinkler headper laterals line will be the width of the field, which is 45m

$$= \frac{45}{12.5} = 3.6 \quad = 4\ laterals$$

Therefore total number of Sprinkler head = 3 x 4 = 12 Sprinkler heads

The required discharge of an individual Sprinkler

$$q = \frac{S_l \times S_m \times I}{360} \qquad 7$$

Where,

q = Required discharge of individual sprinkler, l/sec
S_1 = Spacing of sprinklers along laterals, m
S_m = Spacing of laterals along the main, m
I= Optimum application rate, cm/hr.

S_1 = 12.5m

S_m = 16.25m

I = 1.3cm/hr

$$q = \frac{16.25 \times 12.5 \times 1.3}{360} = 0.73\ litres/\sec/\ sprinkler$$

Total discharge q = 0.73 X 12 = 8.76 litres/sec.

The maximum net depth to be appliedper irrigation can be calculated using equation of net depth $d_{net} = (FC - PWP) \times RZD \times P$
Where:
d_{net} = readily available moisture or net depth of water application per irrigation for the selected crop (mm).
FC = Soil moisture at field capacity (mm/m)
PWP = Soil moisture at the permanent wilting point (mm/m)
RzD = The depth of soil that roots exploit effectively (m)
P = The allowable portion of available moisture permitted for depletion by the crop before the next irrigation.
Area of the field = 50m x 45m = 2250m^2 = 0.225ha
Soil type = Sandy loam
Rooting Zone depth of Okra (P) = 50% = 0.5m

The depth of soil that the roots exploits effectively (RzD) = 0.7

Soil infiltration rate = 3.6cm/hr

$$d_{net} = (FC - PWP) \times RZP \times P$$

Okra d_{net} = 13.4 x 0.7 x 0.5 = 4.69cm

Therefore volume of water to be applied

$$\frac{0.225 \times 10000 \times 4.69}{1000} = 10.55m^3$$

$$Irrigationfrequency(IF) = \frac{d_{net}}{W_U} \quad 8$$

Where
IF = Irrigation frequency (days)
d_{net} = net depth of water application (mm)
W_u = peak daily water use (mm/day)
So the peak demand for the selected vegetable crops was 7.65mm/day or 0.77cm/day.

$$IF = \frac{4.69cm}{0.77cm/day} = 6\ days$$

$$Grossdepth = \frac{Netdepth}{Fieldefficiency}\frac{4.69}{0.70} = 6.7cm$$

6.7 cm of water is needed to take care of losses delivery from the conveyance material.

$$Irrigationinterval(IR) = \frac{GIR}{CU} = \frac{6.7cm}{0.59} = 11\ days$$

$$Irrigationperiod = \frac{GIR}{Applicationrate} = \frac{6.2}{2.5cm/hr} = 3hrs$$

Capacity of the Sprinkler system

$$Q = \frac{2780\ (A \times D)}{F \times H \times E} \quad 9$$

Where
Q = Discharge capacity of pump (l/s)
A = Area to be irrigated = 2250m^3 = 0.225ha

D = Gross depth of water application (mm) = 4.69cm

F = No of days allowed for the completion of one irrigation (irrigation interval) (days) = 11 days

H = No. of actual operating hour per day = 3

E = Water application efficiency =75%

$$Q = \frac{2780\ (0.225 \times 4.69)}{11 \times 3 \times 70} = 1.27 litres/sec$$

2.4 Mechanism of the Automated System

The automated irrigation system automatically measures the moisture level in the soil using a moisture meter for monitoring the moisture content of the soil, an Arduino micro controller, temperature and humidity sensors. Fig.8 below shows the flowchart of the System algorithm showing the various steps involved in the operation of the System. When the System is turned ON, it scans for available Wi-Fi networks and connects to an already configured Wi-Fi network. If the Wi-Fi network is ready, the system establishes connection with the channel on the Wireless link and sends the moisture content, ambient temperature and flow rate data to the Micro-controller and SMS. If the Wi-Fi network is not ready, the system repeats the cycle of connecting to the configured Wi-Fi network and this cycle will continue until configured Wi-Fi network is ready.

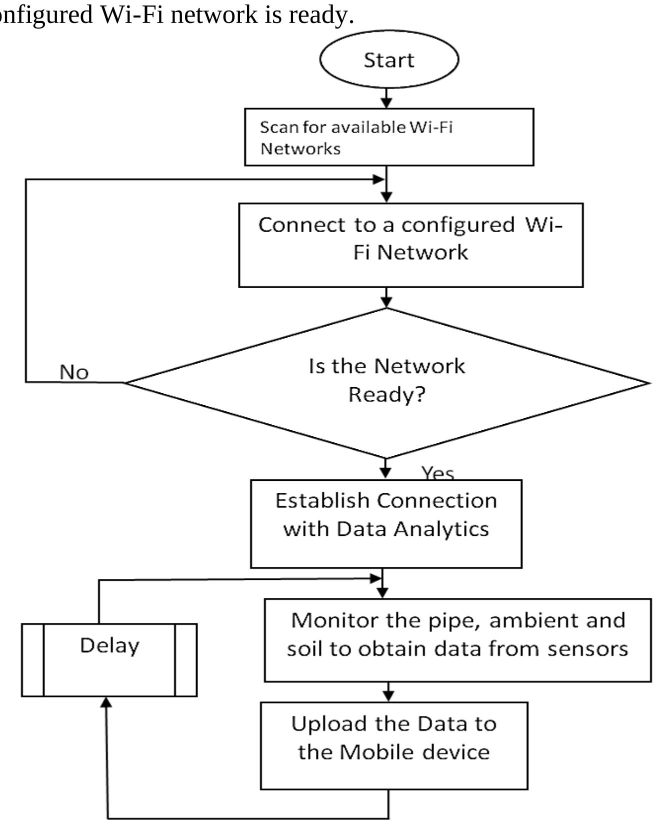


Figure 8: Flowchart of the System Algorithm

It can be seen from table 4, the result obtained from the experiment on the field and the mechanism of the automated system as seen in figure 10 of the flowchart reveals that a GSM modem can be used to send the condition of the farm to the farmer through SMS. Therefore, without going to the field, a farmer can get the information about crop condition.

2.5 Proximate Analysis and Viscosity of Okra

Proximate and mineral Composition of Okra were determined using the standard methods of association of official Analytical Chemistry. These were done to estimate the relative amounts of protein, lipid, water, ash and carbohydrates in any sample on various tillage depth, irrigation rate and fertilizer application. The results of the composition of proximate on Okra on various tillage depth, Irrigation rate and Fertilizer application are shown in table 3.

3.0 Results and Discussions

3.1 Proximate analysis: The result of proximate analysis of Okra from the plots are presented in table 3 while result of soil analysis are shown in table 4 below.

Table 3: Proximate Analysis and Viscosity of Okra

Tractor/Tillage Depth (cm)	Irrigation Rate (ml/s)	Fertilizer Application Kg/ha	% Moisture Content	% Ash Content	% Fat Content	% Protein Content	% Fibre Content	% Carbohydrate	Viscosity (Centipulse)
0		0kg/ha	92.24	0.68	0.54	1.73	2.40	2.41	41
	150	150kg/ha	91.38	0.58	0.48	2.03	2.10	3.42	78
		200kg/ha	91.46	0.59	0.54	2.16	2.11	3.12	84
		0kg/ha	91.50	0.59	0.43	2.18	2.18	3.12	79
	250	150kg/ha	90.18	0.59	0.58	2.48	2.24	3.50	120
		200kg/ha	90.80	0.58	0.48	2.48	2.20	3.45	135
10	150	0kg/ha	91.89	0.65	0.42	1.73	2.53	2.61	57
		150kg/ha	90.96	0.59	0.43	2.23	2.30	3.48	79
		200kg/ha	90.98	0.76	0.49	2.44	2.23	3.09	88
	250	0kg/ha	91.05	0.56	0.55	2.38	2.27	3.19	120
		150kg/ha	90.75	0.69	0.51	2.38	2.02	3.65	84
		200kg/ha	91.33	0.61	0.46	2.01	2.10	3.49	78
20	150	0kg/ha	91.83	0.55	0.43	1.80	2.66	2.71	43
		150kg/ha	90.36	0.58	0.48	2.53	2.20	3.69	140
		200kg/ha	90.78	0.66	0.51	2.34	2.02	3.69	84
	250	0kg/ha	90.58	0.68	0.53	2.45	2.57	3.18	57
		150kg/ha	91.06	0.59	0.43	2.23	2.30	3.38	79
		200kg/ha	90.78	0.66	0.48	2.65	2.33	3.10	88
30	150	0kg/ha	91.63	0.65	0.45	1.75	2.53	2.89	68
		150kg/ha	90.09	0.59	0.58	2.48	2.24	3.79	110
		200kg/ha	90.69	0.78	0.61	2.41	2.13	3.36	90
	250	0kg/ha	92.02	0.51	0.43	2.13	2.14	2.77	79
		150kg/ha	90.90	0.55	0.58	2.58	2.14	3.25	120
		200kg/ha	91.10	0.54	0.51	2.48	2.22	3.17	150

Results shows that Okra pod contains moisture content 90.02-92.24%, Ash content 0.51-0.78%, Fat content 0.43-0.61%, protein content 1.73-2.58%, Fibre content 2.02-2.66% and Carbohydrates range of 2.41-3.79%. Highest viscosity of 150 was recorded on tillage depth of 30cm with 250ml/s of Irrigation rate and 200kg/ha of Fertilizer application, followed by 140 viscosity recorded on 20cm depth of tillage with 150ml/s of irrigation rate and 150kg/ha of fertilizer. Finally the least in terms of Viscosity of Okra was recorded at 41 on Zero tillage with 150ml/s of Irrigation rate and 0kg/ha of fertilizer application.

Table 4: Results of irrigation parameters

S/No	Parameters	Results
1	**Soil analysis**	
	Soil type	Sandy loam
	Average moisture content	10.5%
	Average bulk density	1.53g/cm^3
	Average particle density	2.62g/cm^3
	Average porosity	41.05%
	Optimum Infiltration rate	
	Field Capacity	1.35cm/hr
	Particle size distribution	13.4%
		Uniformity coefficient (CU) = 1.92
		Coefficient of gradation (CC) =0.81
		16% clay, 22% silt and 62% sand
		Therefore soil analysis is uniformly graded
2	Consumptive use (CU)	4.25mm/day
3	Evapotranspiration (ET_P)	4.9mm/day
4	Available soil water	10.55
5	Irrigation frequency	6 days
6	Net depth of irrigation	4.69cm
7	Gross depth of irrigation	6.7cm
8	Irrigation interval	11 days
9	Irrigation period	3 hrs
10	Spacing of lateral along the main (S_m)	1612.5
	Spacing of sprinkler along the lateral (S_l)	12.5m
11	Number of laterals	3 Laterals
	Number of sprinkler head per laterals	4 laterals
	Total number of Sprinkler head	12 Sprinkler heads
12	Total discharge (q)	0.73 litres/sec/sprinkler
13	Discharge capacity of pump (Q)	$1.27 litres/sec$

Results of irrigation parameters in table 4 showed that spacing of lateral along the main (S_m) was 16.25m while spacing of sprinkler along the lateral (S_l) was 12.5m. The required discharge of the sprinkler (Q) was 8.76litres/seconds and capacity of the sprinkler system was 1.27 litres/sec. The system had a net depth of 4.69cm, gross depth of 6.7cm, Irrigation interval (IR) of 11 days and Irrigation period of 3hrs. The highest bulk density was at 1.59g/cm^3 obtained at zero tillage depth, while the least was 30cm tillage depth with1.48g/cm^3. Particle density had the highest at Zero tillage with 2.65g/cm^3 while the least was at 30cm tillage depth with 2.58g/cm^3. The highest porosity was at zero tillage with 42.6% while the least was 30cm tillage with 40.1%. Particle size distribution showed that sample A had 1.8 uniformity coefficients (UC), 0.77 coefficient of gradation (CC) with 16% clay, 24% silt and 60% sand. Sample B had 1.89 UC, 0.81 of CC with 15% clay, 23% silt and 62%. Sample C had 1.97 of UC, 0.80 of CC with 17% clay, 20% silt and 63% and sample D had 2.0 of UC, 0.86 of CC with 17% clay, 22% silt and 61%. The highest Okra yield 101.57g on tillage depth of 20cm , 250ml/s of Irrigation rate and 150kg/ha of Fertilizer application, followed by 97.35g at 30cm tillage depth with 150ml/s of Irrigation rate and 150kg/ha of Fertilizer application, while the least was 56.62g on Zero tillage with 150ml/s of Irrigation rate and 0kg/ha fertilizer application.

4.0. Conclusion

The quantity of water required for the plant growth and the evaporating waters was estimated to be 4.25mm/day. The results showed that the developed automated sprinkler irrigation helped to monitor the soil moisture, reduced wastage of water and irrigates automatically. The study shows that it is possible to design an automated sprinkler irrigation system in the study area located at department of Agricultural and Bioenvironmental Engineering Experimental farm, Imo state Polytechnic Umuagwo.

5.0 Recommendation

Further research on automated irrigation system is hereby recommended for an enhanced operation.

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