Growth and Yield of Eggplant (*Solanum melongena*) under Solar-powered Smart and Manual Drip Irrigation Systems in Mokwa, Nigeria.

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Abstract

Two drip systems (manual and intelligent) were designed and installed, and garden eggs irrigated under each of them. For the intelligent system, sensors connected to Arduino Micro Controller were used to accomplish the task of irrigation scheduling, while in the manual, human being monitor the behavior of the plants, and irrigate based on the design scheduled. Preliminary soil test revealed that soil of the area is sandy loam with a pH of 6.80.Systems efficiencies were determined as88.40 and 89.3% respectively for manual and intelligent. The eggplant under the intelligent system responds and yield better (7 fruits per stand at a time, with an average weight of 6g per fruit).Total volume of water used throughout the growth period by each eggplant from the intelligent and manual systems was approximately 47 and 70 liters respectively. The irrigation water use efficiency (IWUE) determined for the intelligent and manual plots were respectively 89% and 44.3%. In all, the intelligent system saves more water than the manual, the intelligent system is therefore encouraged.

Keywords: Arduino, Drip Irrigation, Micro-controller, Irrigation Scheduling, Irrigation water use.

1. Introduction

Irrigation is as old as civilization, and has been described as the first modification made to the structure of the earth by man. It has gone beyond only applying water to crops, but applying good quality water, of the right quantity at the right time, with little or no human effort (Jibril, 2024).In Nigeria, irrigation practices can be traced back to 700 AD., but became more pronounced after the drought of 1970 to 1975. At this moment, the need for irrigated crop cultivation grew. A study was then carried out in early 1970s, 1972 precisely, to examine the water resources and irrigation development potential in the country. The outcome of the study led to the institution of three models public irrigation schemes; namely the Bakolori scheme, the Chad Basin scheme, and Kano River irrigation scheme (Adelodun and Choi, 2018).

According to Jibril (2005), artificial water application system has undergone several changes as a result of factors such as availability of water, soil and crop types, and most importantly, Irrigation Water Use Efficiency(IWUE). It was stressed that application of water to crops could be achieved either by just pouring water on the surface where crops are growing (Surface system), applying water beneath the surface or ridge for the plant roots to tap (Sub-surface), pumping water through network of pipes and delivering to the farmland in a rain-like form (Sprinkler System), and, pumping water through pipes and delivering to the farm at each plant base (Drip/Trickle system).

In the past, monitoring of soil moisture in agriculture is done manually, but in this era of precision agriculture, it has been replaced by more efficient techniques with the help of sensors through IoT (Placidi *et al.,* 2020). Precision agricultureinvolves remotely watching, assessing, and utilization of information or data by inter-connectivity of machines to accomplish some designated farming activities (Barapatre and Patel, 2019). Automated irrigation system is a valuable tool for accurate soil moisture control in highly specialized farms, thus, leading to high irrigation water use efficiency (IWUE) (Jibril *et al.,* 2023).

Factors such as initial installation costs, fragile nature, unavailability of materials, lack of technical officers, and low efficiency have been the major hindrances to quick acceptance of sensor-based irrigation monitoring. This research therefore aimed at comparing the performance of garden egg under a manual and an intelligent drip irrigation system.

2. Materials and Method

2.1 Description of the Study Area

Mokwa Local Government Area in Niger State is located on Latitude 9° 17’ 41.35” N and Longitude 5° 03’ 14.83” E. It has a total land area of approximately 4,338km^2 (1,675 sq mi) and an estimated human population of 244, 937 (NPC, 2006), whom are predominantly Nupe speaking people. The long southern border of the local government area is formed by the Niger River from Lake Jebba in the west beyond the confluence of the Kaduna River in the east (Figure 1).

It is an agrarian domain, occupying a strategic land area with maximum potential for all year round crop cultivation and rearing of animals. It falls under the Southern Guinea Savanna (i.e. comprising short grasses and scattered trees) of the tropical climate vegetation belt of Nigeria, having two (2) distinct seasons (rainy and dry seasons). The rainfall commences in the months of April-May and terminates in October-November, with an average annual rainfall amount of 1229mm. The Average maximum and minimum monthly temperatures of the area are 34 and 27 ^{O}C respectively, with an average daily sunshine hours is 7.0.

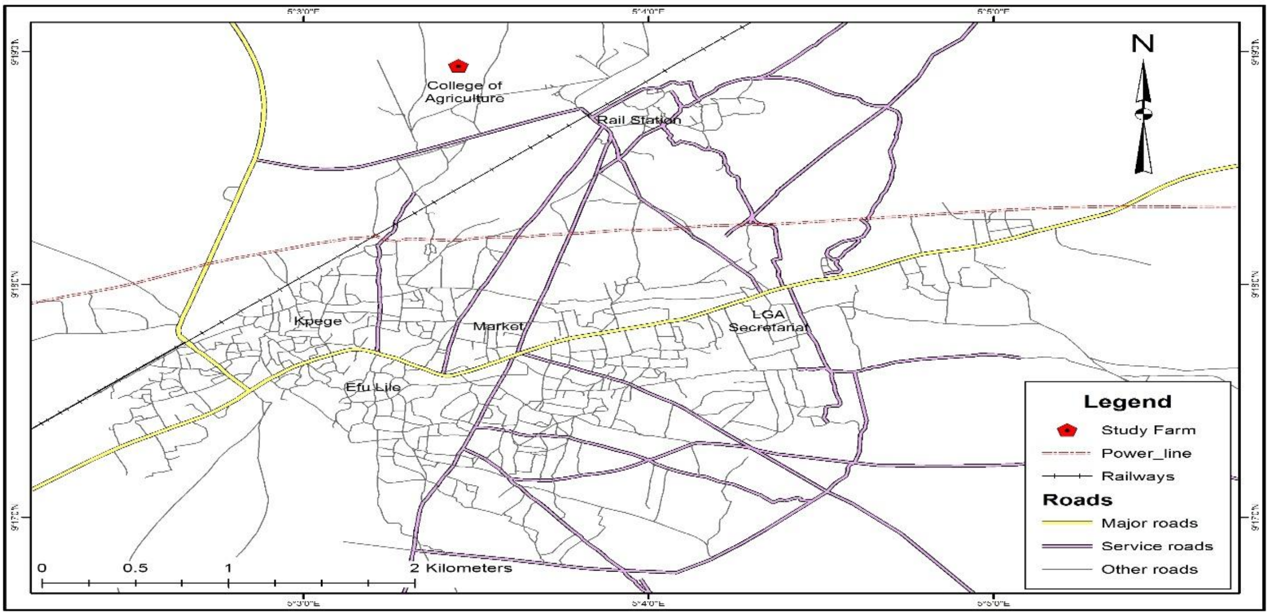

Figure 1: Location of the study area

2.2 Experimental Procedure

Based on the design, the experiment consists of four (4) plots, having three (3) sub-plots in each, and each sub-plot measured 2m by 5m with all having 1m part ways within plots and border. Soil samples were collected on the field from each plot using soil auger in two (2) different points, placed in polythene bags and labelled appropriately. The soil textural class was determinedby the method of particle separation by suspension(Palada *et al.,* 2011).

2.3 Irrigation Scheduling

Knowing when to and how much water to apply is a major task in efficient irrigation design. This has to do with determining the effective root zone depth, plants water requirement with regards to type of soil and, their water holding capacity.

3.3.1 Time of irrigation

This is the time taken for the soil voids (within plants root zone depth) at different point of the experimental site to be filled with water after irrigation. This was determined using the equation presented by (Khalifa, 2012) as:

$$T_i = \frac{V_w}{Q_e} \qquad (1)$$

where; T_i is time of irrigation in hours, V_w is volume of water applied in liters, and Q_e is emitter discharge in liters per hour.

3.3.2 Volume of water for irrigation

Considering the tomato plots:

- Length of ridge = 5m, width of ridge = 0.4m, area of ridge = 2.0m^2.

Amount of water required (effective wetted area per ridge) for each plot is determined (Edoga and Edoga, 2006):

$$A_w = A_r \times L_r \times G_d \qquad (2)$$

where, A_w is amount of water needed in plot (l), A_r is the area of a ridge in a plot (m^2), L_r is the total number of ridge in a plot is 6, G_d is the gross irrigation depth is 0.011866m. The same was determined for the eggplant plot, also considering its number and size. Amount of water per irrigation for each plot was determined as:

$$Aw_r = A_r \times G_d \quad (3)$$

where, Aw_r is amount of water needed for irrigation per ridge, A_r is the area of a ridge = 2m^2, G_d is the gross irrigation depth = 0.01186m. The amount of water needed to wet a single ridge to a required gross irrigation depth was determined in litres and result noted. On every ridge, a total of 20 plant stands were transplanted, therefore approximate amount of water each stand will receive was determined and documented.

3.3.3 Irrigation interval

This simply described how frequent will the irrigation be, that is at what interval of hours or days will the next irrigation take place. Knowing the depth of water applied in the soil root zone, the irrigation interval or frequency was determined as (Hunter, 2017; Richard *et al.,* 2006; Michael and Ojha, 2006):

$$I = \frac{d}{ET_c} \quad (4)$$

where; d is depth of application or readily available water (RAWC) in the effective root zone, ET_c is the crop water requirement of the specific plant under study; and I is the irrigation interval or irrigation frequency.

2.4 System establishment

The entire system was established/constructed in three (3) phase in accordance with the Menco Global Agro Limited Dripkit installation guide:

1. Installation of water source (reservoir tanks)
2. Laying of pipes and emitters
3. Commissioning.

2.5 Land clearing and ridging

Land clearing and ridging was done manually using local farming tools such as hoes, rakes and cutlasses. A total number of two ridges of 10 m length was constructed on each sub-plot, having 1 m path-way between sub-plots. The first two (2) plots were irrigated by the intelligent drip system, while the other two (2) were irrigated with manual drip system.

2.6 Seedbed preparations, rising of seedlings and transplanting

Seedbeds were prepared using local hand tools and wet with enough water for three (3) days consecutively. The height, length and width of seedbeds prepared was 30cm by 500cm by 100cm. Seeds of eggplants were obtained from local irrigation farmers. A shade was provided to conserve moisture and to reduce the effect of intense sunlight until they were three (3) weeks. Transplanting of seedlings on the ridges was done using cutlass and hand trowel. Plant stand was one (1) per hole at 30cm by 40cm intra and inter spacing during transplanting.

2.7 System hardware arrangement

Installations of the automatic system absolutely obeyed the ground rules of the Institute of Electrical and Electronic Engineers (IEEE). As the sunlight falls on the solar panel, it liberates the electrons within the material which then produce a DC current (energy), regulated by the charge controller before storage in the energy banks (batteries). Moisture sensorswere connected to the Arduino Micro Controller boards (MCB), installed in the root zone at a depth and width as specified by the wetted perimeter experiment. The temperature and humidity sensors were also connected to the Arduino board so as to read the appropriate environmental parameters and respond in-line with the program. The Arduino Micro Controller boards obtain their energy (5 volts) from the battery bank. The relaytakes its energy directly from the battery banks and take care of the solenoid valve which opens to the field. The Arduino Micro Controller board has an inlet and outlet pins for receiving information and giving out result after processing. All hardwarewas connected to the MCB by specific colour of wire for easy identification, and placed in a safety wooden pack for protection.

2.8 System software arrangement (algorithm) and Flow Chart

The algorithm is as thus:

1. Open valves to start irrigation
2. Is the soil moisture content less than the required (< 30 %)?
3. Is the environmental temperature at a range to avoid excessive evapotranspiration (≤ 25 ^{O}C)?
4. If all conditions above are satisfactory, then irrigate
5. If soil void is filled with moisture (= 60 %), then stop irrigation.

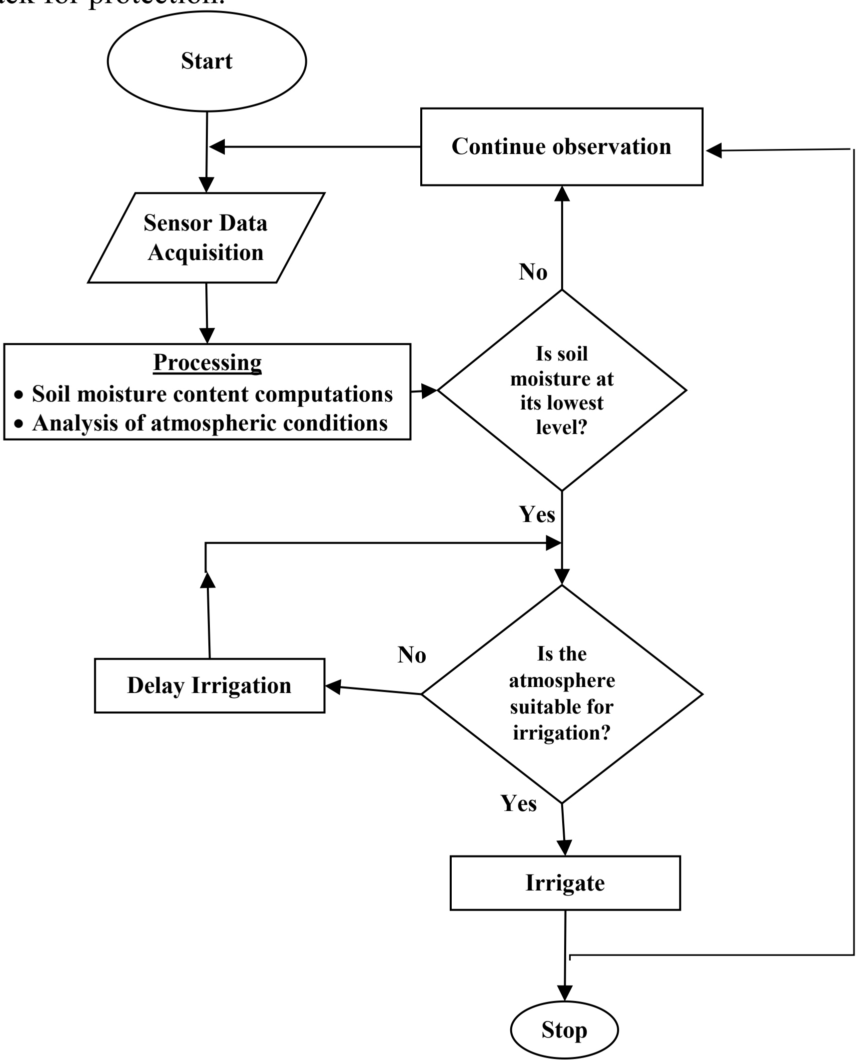

Fig. 2: Flow Chart of the System Command

2.9 Data Collection and Analysis

The yield of garden egg was determined as thus: From each plot, five (5) healthiest plants were randomly chosen to measure plant height, stem diameter, number of leaf per plant, leaf area, flowering time, number of fruits per plant and fruit weight per plant in accordance with (Mirdad, 2011). Weighing balance, ruler and venire callipers were the major instruments used for measurements. Measurements made throughout the plants growing periods were noted and recorded.

At the end of the experiment, data obtained were subjected to simple statistical analysis. Irrigation efficiency and yield of crops obtained at the automated section of the experiment were compared with those obtained from the manual section. The irrigation water use efficiency (IWUE) expressed in kg/m^3 is determined (Machibya *et al.,*2004).

$$AWUE\, {}^{P}/_{U} \qquad (5)$$

W here; P is crop production (total dry matter or the marketable yield) in kilogram (Kg)and U is the volume of water applied in litres (L or m^3).

3. Result and Discussion

3.1 Irrigation Scheduling

Result presented here are the depth of water applied in (liters), readily available water in the soil root zone, time of application in (hours) and irrigation frequency in (days). From the design, length and width of ridge considered are 5000mm and 400mm respectively. This gave a net irrigation depth of 10.08mm and gross irrigation depth of 11.86mm. Each plot is having six (6) ridge with a total of forty (40) plant stands. Total volume of water in liters required to give a plot an effective wetting pattern was determined as 142.32 liters, translating to3.56litres per plant stand on every irrigation period. The time of irrigation, otherwise known as irrigation duration was determined to be approximately one and a half hour (that is, 90 minutes), which is in conformity with the wetted perimeter test.The irrigation frequency determined was 3days. In all, since transpiration rate determined is not uniform, it signifies non-uniformity of water consumption by crop at different growing stages. This outcome is in line with the previous findings (Dewidar*et al.,*2015).

3.2 Growth under manual and intelligent drip system

Figures 3 and 4represents the average plant height and stem diameter of eggplants on both the manual and intelligent plots. From Figure 3, it could be seen that till the 6th week after transplant, there was no appreciable increase in the average plant heights. Visible increase in average plant heights occurred immediately after the 6th week of transplant. By the end of the 8thweek, rapid growth and development was observed as well as flowering. The rapid growth occurred in plants on both plots (manual and smart), even though those growing on the smart plot showed better responses. However, there was no fruiting because of insect and disease infestation, thus, making the flowers to dry off due to nectar sucking by insects. This necessitates the use of chemical (insecticides) in order to control the insects. On the other hand, there is no significant or visible differences between the plant stems from the two plots as could be seen from Figure 4. It was a uniform trend from transplanting till the late growing stage. This indicates that the plants can also do very well even with deficit water as supplied by the intelligent system.

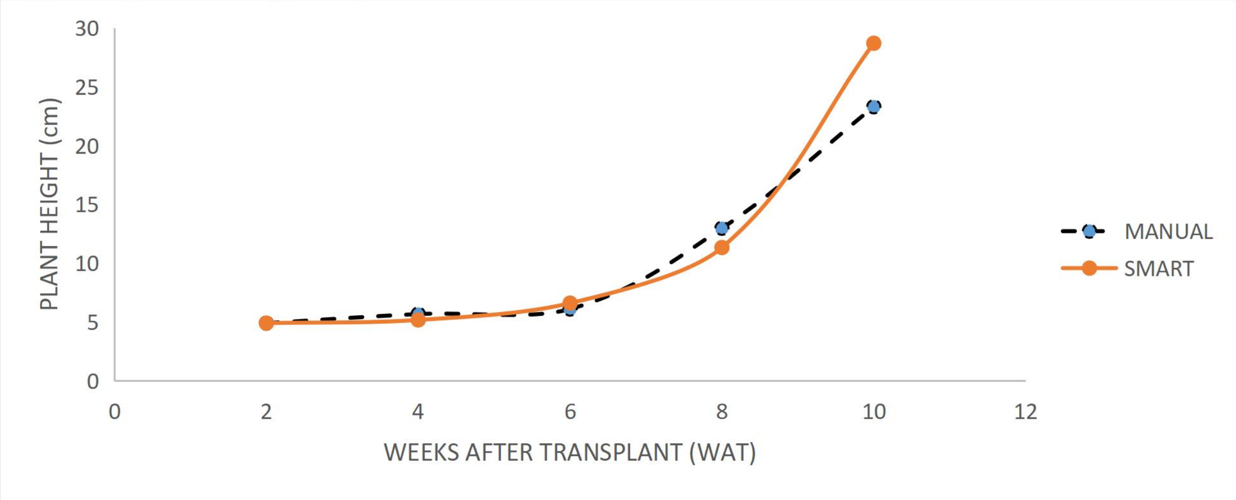

Figure 3: Height of eggplants against weeks after transplant

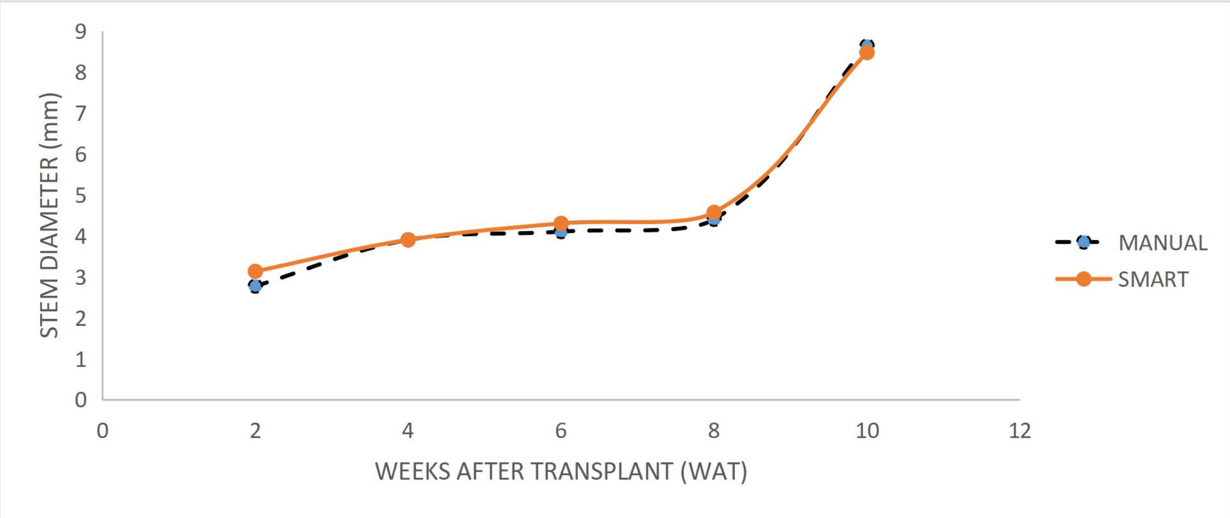

Figure 4: Stem diameter of eggplants against weeks after transplant

Figures 5 and 6are plots of leaf count and leaf area of eggplant against time, grown on both plots (manual and smart). Considering Figure 5, it could be seen that at 2 weeks of transplant, there were the same number of leaves by every eggplants growing on both plots. There was however gentle deviation immediately after 2 weeks of transplant till the beginning of the late growing stage (8^{th} week) when flowering commences. Wide gap in the number of leaves began after the 8^{th} week, and that continues till the 10^{th} week, with those growing on the smart plot having more leaves than those on the manual plot. Also, there was no significant differences between the average leaf area of eggplants growing on both plots in the first 6 weeks of establishment. But there is of course increase in leaf area of plants on both plots as clearly explained by Figure 6. The increase continued until the plants late growing stage, with those on the intelligent plot slightly having wider leaves than those on the manual plot.

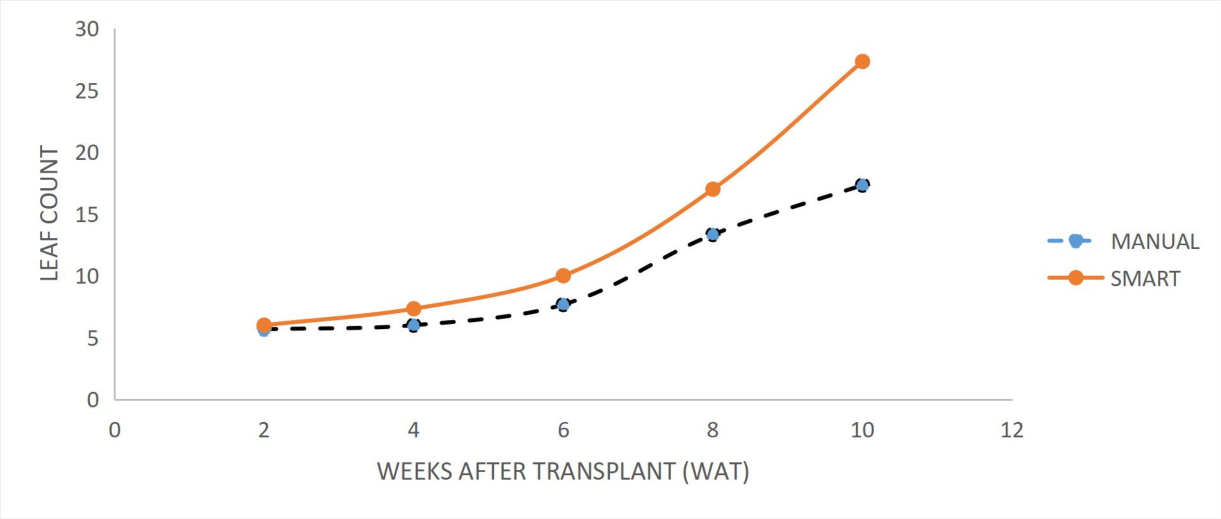

Figure 5: Leaf count of eggplants against weeks after transplant

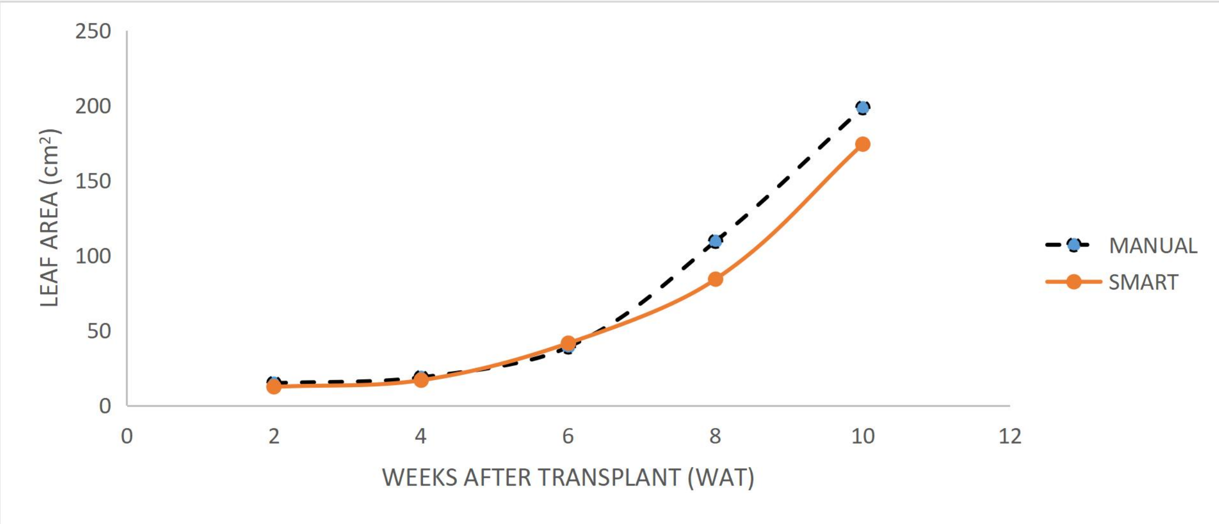

Figure 6: Leaf area of eggplants against weeks after transplant

3.3 Crop yield and irrigation water use efficiency

The eggplant starts flowering at 6 weeks after transplant (63 days after sowing) and fruiting commences at the 9th week after spraying with insecticides due to flower abortion. The eggplant under the intelligent system responds and yield better, producing 7 fruits per stand at a time, thus having 2 more than the yield from the manual section (5 fruits per stand at a time). Average weight, length and diameter of eggplants from intelligent and manual plots were 6.0 g and 6.2 g; 1.35 cm and 1.63 cm; 0.21 cm and 0.17 cm respectively. The irrigation water use efficiency (IWUE) as presented in Table 1 from the intelligent and manual plots were obtained as 89% and 44.3% respectively.

Table 1: Crop yield irrigation water use efficiency (IWUE)

Water application	Garden Egg			
	Plant stand	Volume of water (L)	Yield per plot (kg)	IWUE (%)
Intelligent	40	1,128	1.008	89.0
Manual	40	1,680	0.744	44.3

Also, considering volume of water consumed by plants from both plots, results showed that the highest volume of water was consumed during the mid-growth stage, while the least was recorded during development stages as indicated by the trend lines (Figures 7and 8). This outcome is in line with the submission in FAO Irrigation and Drainage Paper No. 56.

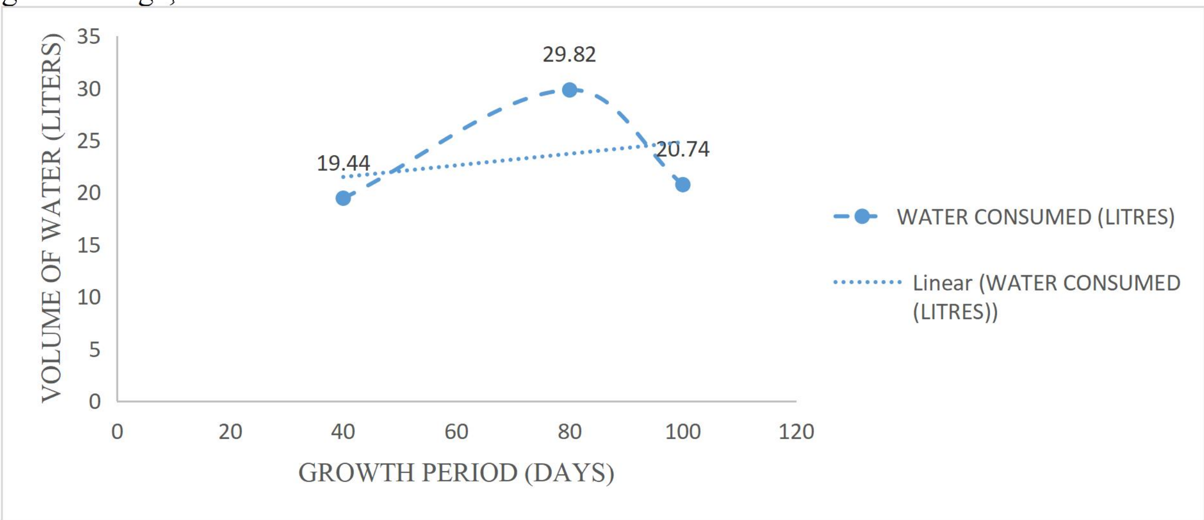

Figure 7: Water consumed at stages of growth by garden egg on the manual plot

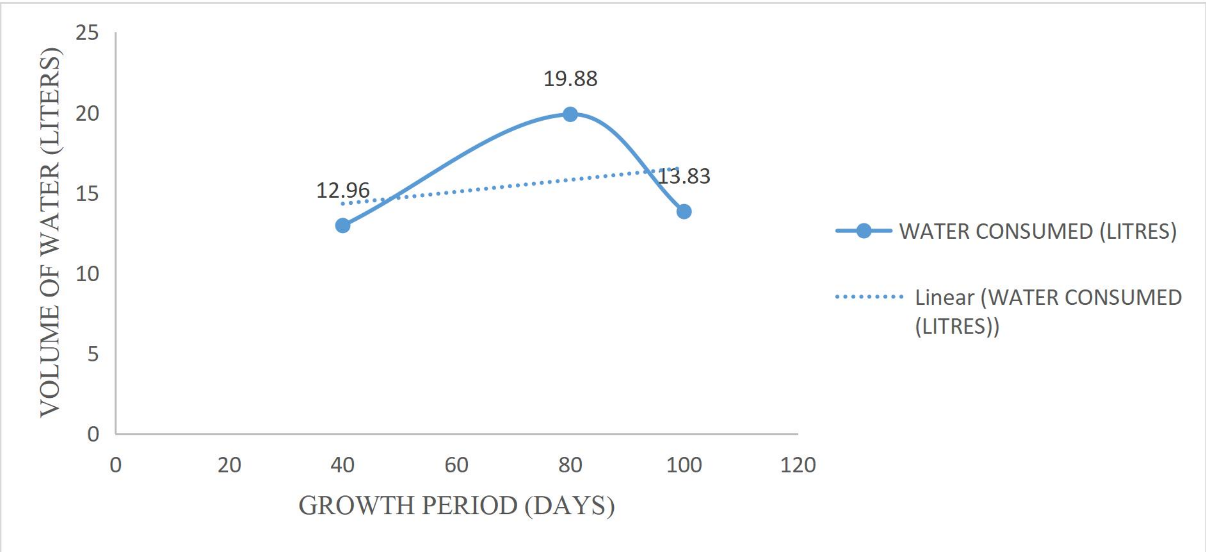

Figure 8: Water consumed at stages of growth by garden egg on the intelligent plot

4. Conclusion and Recommendations

The research concentrated ondeveloping a solar-powered intelligent and manual drip irrigation system for garden egg (*solanum melongena*) cultivation, and compare their performance. The two systems were designed and established. Arduino Micro-Controllers were the mean drivers used for the automation. The systems efficiencies were also determined in accordance with established literatures. Soil moisture sensor placement depth and width around the effective rooting depth was established for that particular soil type.

Two drip systems (manual and intelligent) were designed and installed, andplants irrigated under each of them (i.e. manual and intelligent system). For the intelligent system, sensors connected to Arduino Micro Controller were used to accomplish the task of irrigation scheduling, while in the manual, human being monitor the behavior of the plants, and irrigate as at when necessary.Key system performance such as system efficiencies, crop yield, approximate quantity of water used throughout crops growing periods as well as irrigation water use efficiency (IWUE) were also determined for both systems. In all, the intelligent system saves more water than the manual, this is because soil moisture placement depth and timing of the irrigation was properly done. More so, the yield of eggplant grown under the intelligent system was more than the ones under the manual system.

5.2 Recommendations

From results obtained, it is recommended that:

- In designing an intelligent irrigation system, knowledge of plant rooting depth and wetted perimeter should be a priority.
- A single soil moisture sensor is efficient and recommended as proved by this research.
- Adoption of the intelligent system be encouraged, because apart from its initial installation cost, it saves time, energy and water used. It is also cheap to maintain and user friendly.

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