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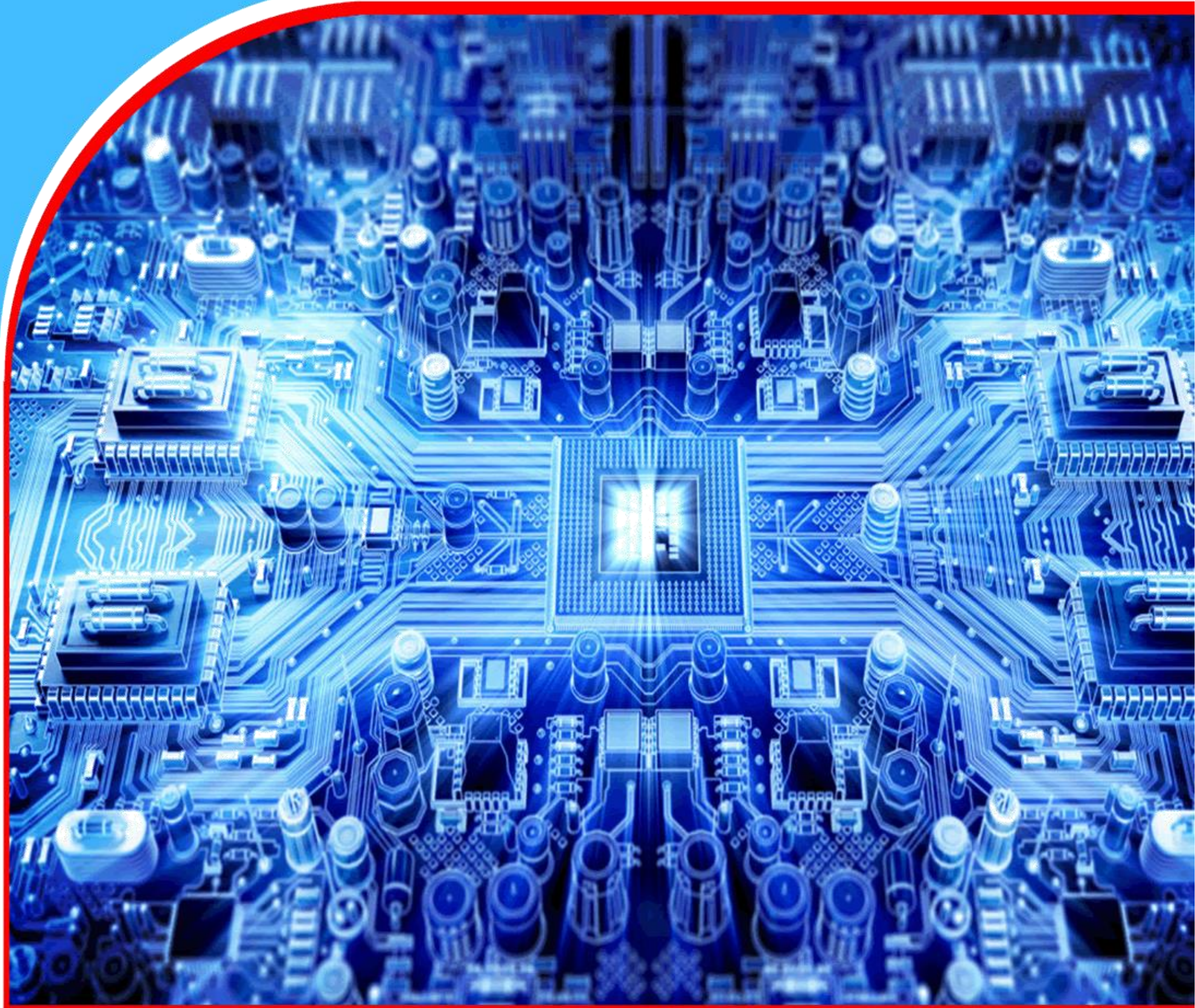

Decision Support System and Fuzzy Logic Controller for Capillary Irrigation System

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Abstract

Purpose: Different irrigation systems exist and they all possess various degrees of benefits in enhancing food sufficiency. In this study however, the enhancement of capillary irrigation system through an integrated fuzzy logic controller with Decision Support System (DSS) to ensure improvement in water saving for irrigation thereby improving crop yield towards food security was examined and achieved.

Methodology: An integrated fuzzy logic controller with Decision Support System (DSS) for capillary irrigation system was adopted for the enhancement of water saving for irrigation. By using this method, the challenges of irrigation management which is prevalent with capillary irrigation system is minimised using the fuzzy logic controller. An Internet of things (IoT) based weather station for computation of potential evapotranspiration (PET), for measuring rainfall and a VH400 moisture content sensor for monitoring the volumetric water content of soil, were some facilities used to control the water level depth (WLD) autonomously through a fuzzy controller simulated in MATLAB and implemented on Arduino Mega.

Findings: The soil moisture content (SMC) depicts that fuzzy controlled water level depth (WLD) is able to compensate reduction of water in crop medium that took place due to plant water uptake which changes daily. The result proves that dynamics of water supply depth has substantial effects on the water absorption flow rate, wetting pattern, soil water content and cumulative infiltration which are proportional to the water supply depth decrement.

Unique Contribution to Practice: An integrated fuzzy logic controller with Decision Support System (DSS) is a new technique proposed for managing capillary irrigation system as it offers enhanced water saving capacity (irrigation volume) based on crop demand.

Keywords: *Fuzzy logic, fibrous capillary, internet of things, decision support system, irrigation system*

1.0 INTRODUCTION

It is imperative to note that the demand for freshwater is on the increase due to rapid growth in global population but the effect of global warming and climate change poses devastating threat on water saving and food security (Action Aid, 2019). Consequently, various irrigation systems have been utilised by different kinds of farmers all over the world with consequential challenges of associated high amount of water consumption from different sources, hence, the need for increased focus on improvement in the efficiency of water saving and plant yielding through proper integration system using internet of things (IoT) and advance control theory concept in irrigation management.

Furthermore, for plant growth and development, appropriate water supply is essential towards ensuring precision irrigation. However, when rainfall is inadequate, extra water for irrigation must be given to crops (Brouwer, 1990). The quantity of water needed for irrigation on plants depend on the method of irrigation, water requirement of the plant to be cultivated and soil type. Different irrigation methods have effects on the nutrients of the soil, infiltration rate of the soil, evaporation, water absorption pattern of the plant and deep percolation.

Surface irrigation which distributes water to the surface of the soil using gravity allows the unrestricted flow of water without any form of sensing and control action; however, the water saving capacity of surface irrigation is low due to massive evaporation and the corresponding uncontrolled excess irrigation volume and huge labour cost are some limitations that have made surface irrigation unsuitable as precision irrigation system (Ghodake and Mulani, 2016; Yonts, 1994; Xiaoping *et al.,* 2004; Gillies *et al.,* 2017).

Sub-surface irrigation (classified as capillary and drip) and sprinkler irrigation are considered modern irrigation system because they can be precisely monitored, scheduled and controlled, and they also offer higher water saving and yielding output (Nalliah and Sri Ranjan, 2010; Zainal *et al.,* 2014; Li *et al.*, 2018). Capillary irrigation as a sub-surface irrigation works based on the soil capillary action to gradually supply water from the water source directly to the root zone (Wesonga *et al.*, 2014; Cai *et al.,* 2017; Semananda *et al.*, 2018). In a recent study, horizontal and vertical fibrous capillary interface for transfer of water from bottom of supply tank to the root zone of the plant was proposed (Rahman *et al.*, 2019). It was further reported that horizontal fibrous capillary offers high water saving potential and better yield on their test crop when compared to the vertical fibrous capillary.

Similar researches on capillary irrigation showing enhanced water efficiency has also been reported (Masuda, 2008; Kinoshita *et al.*, 2010; Ferrarezi and Testezlaf, 2016; Kamal *et al.,* 2019). However, it has been observed that the upward movement of water via capillary action irreversibly accumulates salts in the soil media, and the salinity of water in the soil is not negligible unless water leaching occurs, hence proper monitoring and control of water supply to the capillary interface is achieved (Fujimaki *et al.*, 2018). Drip irrigation is a highly economical watering method for plants otherwise known as trickle. It supplies water slowly through narrow tubes to provide dripping of water to the soil near the root of plants through the emitter (Brouwer, C., 1990). This method of irrigation reduces water loss due to evaporation, which is often caused by the effect of wind and surface runoff (Bhalage *et al.,* 2015; Rekha *et al.,* 2015; Pramanik *et al.*, 2016).

Also, research has shown efficient fertigation, enabling precise supply of nutrient to the plant and thus reducing nutrient leaching (Elasbah *et al.*, 2019). The cost of accessories such as piping, head trickle, emitters is high especially for large area of farm land implementation (Bralts & Edwards, 1987). However, the persistent supply of water at the soil surface contributes towards water loss due to the evaporation process if not properly controlled, hence a good knowledge of the distribution patterns of water in the plant root zone is necessary for proper installation of the drip system of irrigation. Also, there is need for regular maintenance of the emitters to avoid any blockage that might affect the water supply to the plant (Ravina *et al.*, 1992).

Furthermore, Sprinkler irrigation as a type of surface irrigation is similar to the pattern of precipitation on plant. The water sprinkling is done using the spray head and long piping system so as to ensure large coverage area for the sprinkled water. The advantage of their usage is that they have the tendency to irrigate large area of land due to its large coverage. However, these types of irrigation method require a high operating expense due to the high equipment costs of sprinkler head and pipes during installation as well as the energy needed for pumping water such as engine oil and electricity. In a windy environment, sprinkler irrigation is susceptible to high water losses due to evaporation and wind drift (Zhu *et al.*, 2018; Zhao *et al.*, 2009). Moreso, regular maintenance is crucial for effective irrigation using sprinkler because worn nozzles and leaking pipe connections decrease uniform water saving.

This paper therefore focuses on the enhancement of capillary irrigation through integration of decision support system and fuzzy logic controller to ensure improvement in water saving for irrigation thereby improving yield for enhanced food security.

2.0 EXPERIMENTAL PROCEDURE

A weather station enabled with internet and data logger was located within Fluid Mechanics laboratory in the Department of Mechanical Engineering Technology, Kogi State Polytechnic Lokoja, Nigeria. The weather station was used to collect all the weather variables such as rainfall, air temperature and humidity, solar radiation, wind direction and speed, and potential evapotranspiration. In application, potential evapotranspiration (PET) measures loss of water from plant as well as soil surface into the environment (Adnan *et al.*, 2017). The computation of potential evapotranspiration (ET_O) was achieved through the FAO-56 Modified Penman-Montieth equation based on weather data measured using the Davis vantage Pro 2 weather station as present in Eq. 1.

$$ET_O = \frac{0.408\Delta(R_n) + \gamma \frac{900}{T+273} U_2 (e_2)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where

PET = Potential evapotranspiration (mm/h)

Δ = Slope of saturation vapour pressure (kPa°C-1)

Rn = Acceptable net radiation of reference crop canopy surface (W/m^2)

λ = Latent heat of vaporization (kPa°C-1)

T = Mean air temperature in Celsius

U_2 = Mean daily or hourly wind speed at 2-m height (ms^{-1})

e_2 = Stream pressure of saturation vapour (kPa)

2.1 System Design

Figure 1 shows a block diagram for the general system architecture of the proposed solution. The system consists of capillary irrigation which provides a simple method to measure water consumption with input such as soil moisture content (SMC), potential evapotranspiration (PET) and rainfall to control the water level depth in a tank, thus, allowing the determination of daily plant water uptake through the transportation of water using negative pressure from bottom to top of the growing medium (in a coco pit) greenhouse with a capillary interface. The SMC is the amount of water that is stored in the soil and the availability of water present in the soil to provide root water uptake, and measured using a capacitance type soil moisture sensor (VH400). The possible range of the SMC for the coco pit medium in the greenhouse is between 0% and 100%. The system flow chart described in Figure 1 is then followed by Fuzzy Logic Controller algorithm development for decision making.

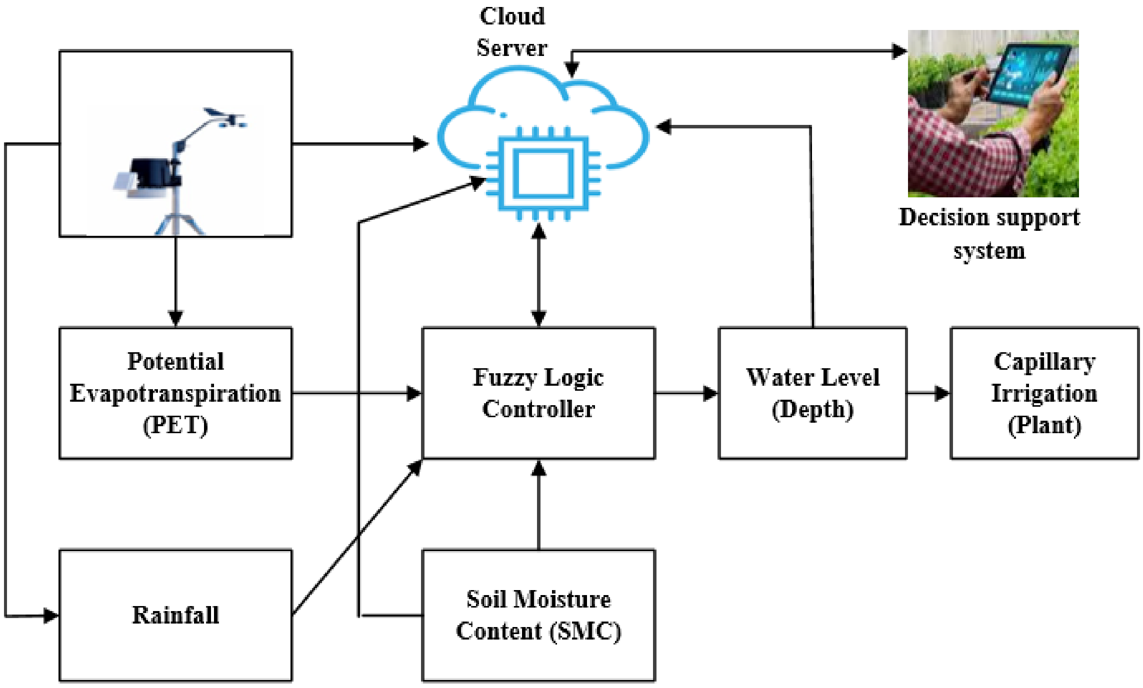

Figure 1: Block diagram for fuzzy logic controlled capillary irrigation system

In this study, the IoT Decision Support System (DSS) which denotes an application layer is comprised of developed user platform for data visualisation, analytics and remote control of embedded controller. The design and development of an android mobile app and interactive webpage for data visualisation and analytics was achieved using android studio, php scripting with CSS scripting, respectively. PhpMyAdmin tool of MySQL was deployed to develop the database for data storage. The web IoT framework that was developed contains php scripts that enables the deployed fuzzy logic controller on Arduino Mega board to send, store and retrieve data from the MySQL database to update sensed data on the embedded boards to be visualised in real time on the DSS.

2.2 Irrigation Monitoring Using Decision Support System (DSS)

The DSS is based on an application of IoT used in connecting devices, collecting data and for remote monitoring and control over a long distance. In this study, the IoT applications were deployed for monitoring and collection of data. The irrigation system controller has installed Wi-Fi shield which transferred data from the activity site into a server. Therefore, data from the weather station, soil moisture content, water level of the water supply tank (depth) and water resource tank were transferred at an interval of 10 minutes into the server.

2.3 Fuzzy Logic Controller Design

Fuzzy control of the water supply depth management was developed by using a fuzzy expert system shown in Fig. 2, and this was further implemented on Arduino Mega Microcontroller. The reference of evapotranspiration (ET_O) was calculated on an hourly basis for the weather station and the crop coefficient (Kc) measurement was based on water balance. The potential evapotranspiration value was estimated using the measured weather variables while the soil moisture content was measured using VH400 soil moisture sensor. Three fuzzy input systems were used as the adaptive engine, and they include the soil moisture content (SMC), potential evapotranspiration (PET) and rainfall (RAIN). In practice, a fuzzy system was designed on the basis of experience shared by farmers for optimal irrigation management.

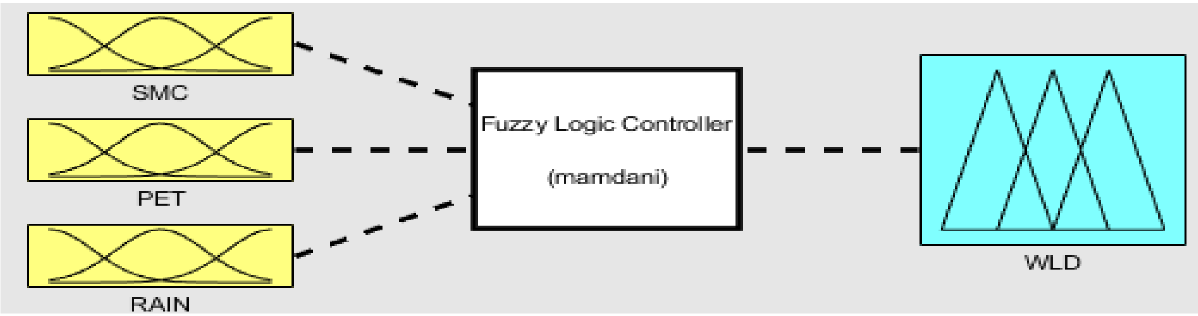

Figure 2: Fuzzy irrigation system model

The membership graphs for Fuzzy Logic presented in Figure 3, Figure 4 and Figure 5 represents the membership inputs of SMC, PET and RAIN, respectively while Fig. 6 shows the membership function of outputs of the Water Level Depth (WLD) while the fuzzy rules were provided by human expert. The algorithm chosen in this study is based on Mamdani system in which the membership function has a triangular and trapezoidal shape. The membership function values define rules from the MATLAB simulation, and was applied for Arduino fuzzy logic coding. However, the defuzzification process for this study used a centroid technique method.

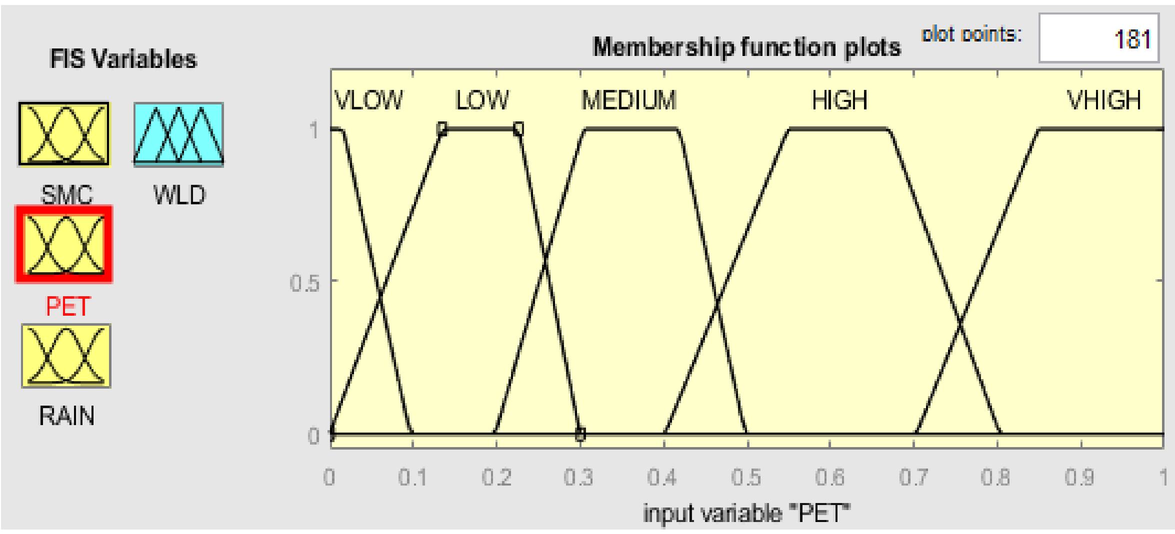

Figure 3: Membership value of input (PET)

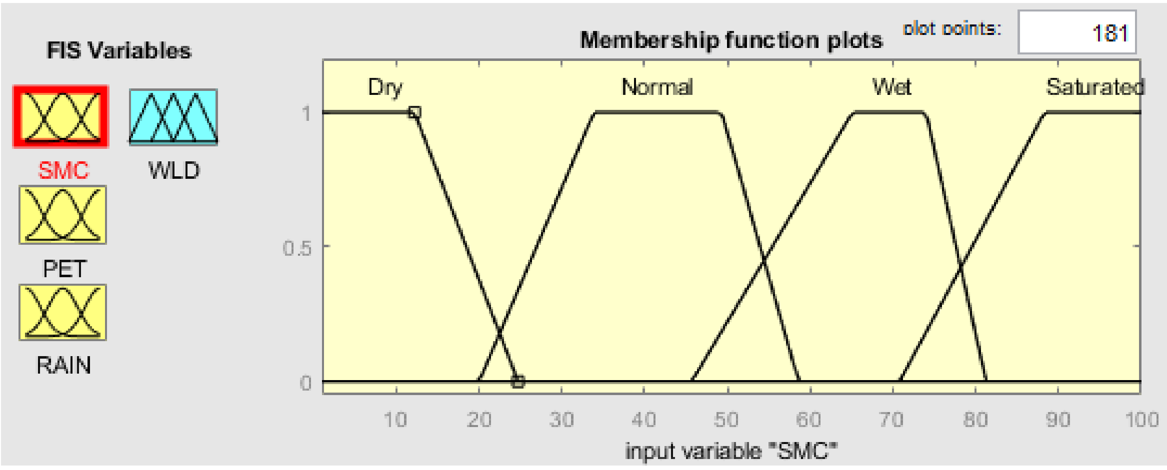

Figure 4: Membership plot of input (SMC)

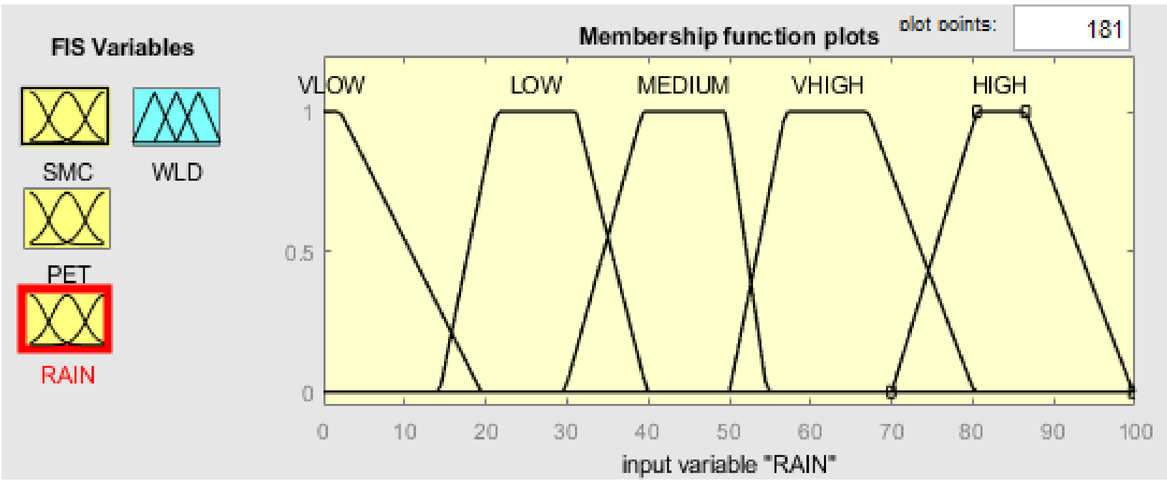

Figure 5: Membership function of input (RAIN)

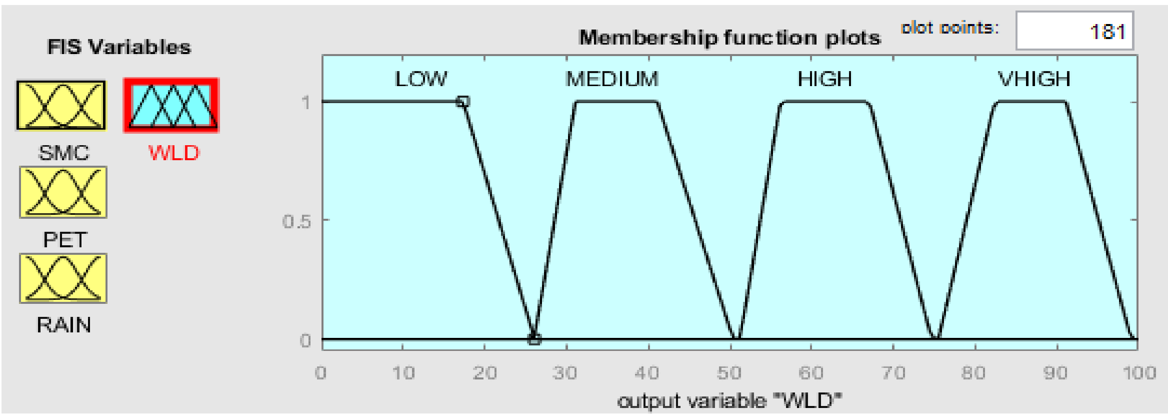

Figure 6: Membership function of output (Water Level Depth, WLD)

2.4 Fuzzy Rule Viewer System

Figure 7 shows the output produced by the fuzzy system when the value of PET = 0.5 mm/h, SMC = 50.5%, Rain = 50 and WLD = 50. By using rule viewer, the evaluation of irrigation management can be achieved prior to it been deployed on an Arduino board to ensure that the fuzzy system design is able to supply water based on the criteria of human expertise.

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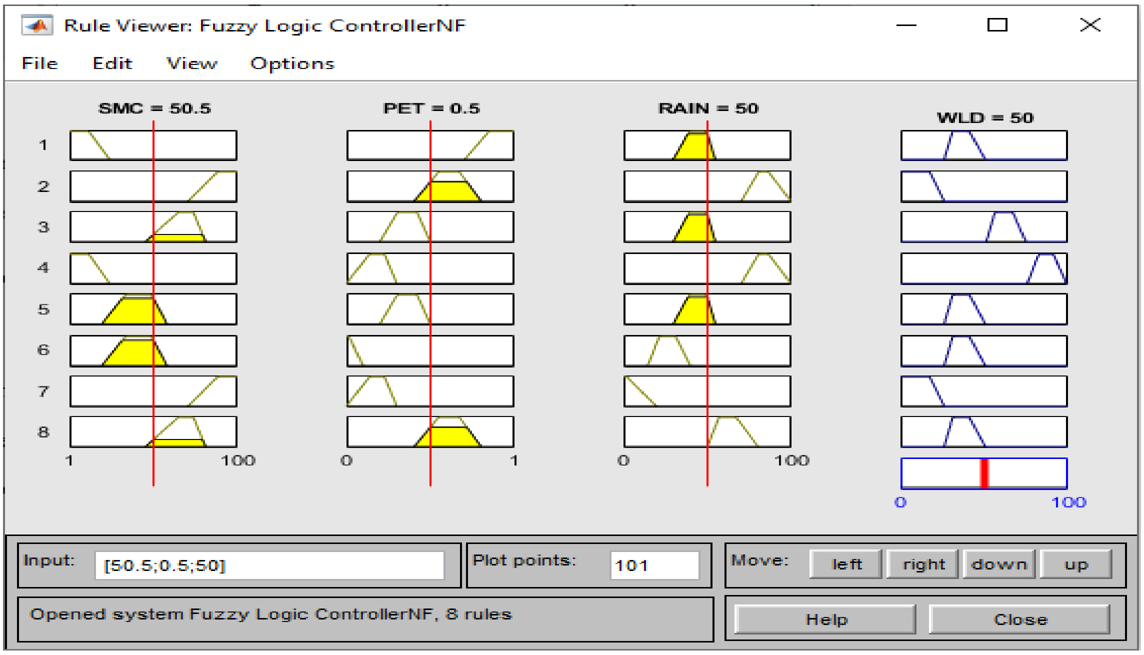

Figure 7: Fuzzy rule viewer system

In Figure 8, the fuzzy rule surface viewer system with three dimensional (3D) curves represent mapping from PET and SMC to WLD. It was clearly observed from the patterns of irrigation system in the 3D curves that high PET and low SMC will decrease WLD. The yellow colour shows high plant water uptake and blue colour for low plant water uptake.

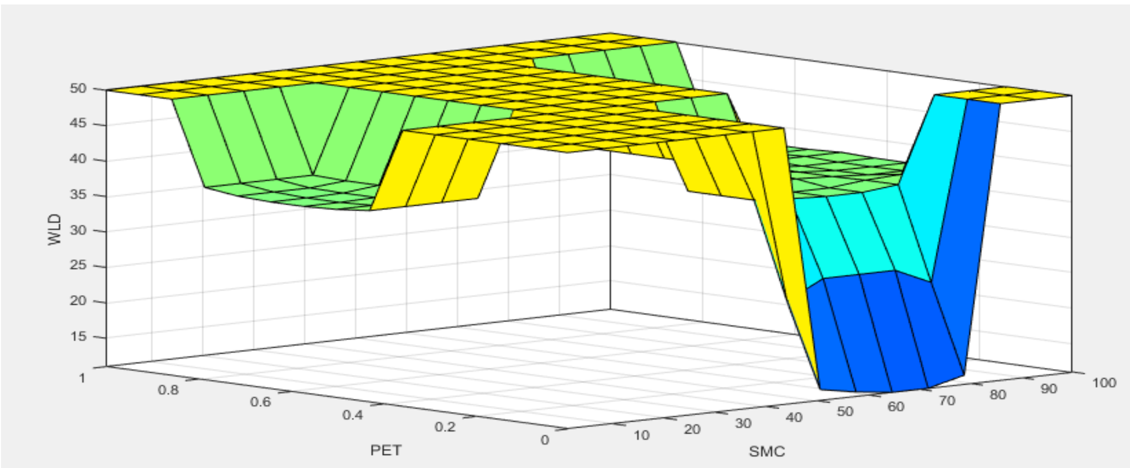

Figure 8: Relationship between Potential Evapotranspirationt (PET), Soil Moisture Content (SMC) and Water Level Depth (WLD) in Three Dimmensional (3D) Surface Viewer

2.5 Fibrous Capillary Irrigation System Design

Figure 9 shows the fibrous capillary irrigation system which consists of a weather station and an experimental set up for the cultivation of vegetables. This experiment was conducted from 1st December 2022 to 23rd December 2022 inside an adopted greenhouse. In this study, the supply of water directly to the root zone of the plant was controlled by fuzzy logic controller to ensure effective management of water supply depth. The transportation of water to the root zone of the plant was achieved using a fibrous capillary interface which was buried inside the plant growing medium. In practice, the water level was observed to have risen in the centre of the growing medium (in a coco pit) through the fibrous strip.

Figure 9: Experimental setup for the fibrous capillary irrigation system

In the fuzzy controlled fibrous capillary irrigation setup presented in Figure 9, a level platform was used to ensure that the water level of every plant container has the same position with the water supply tank. In this study, the infiltration of water to the soil at the fibrous interface was achieved by a capillary rise at an optimal water supply depth level which was determined by the fuzzy control system using water supply depth tank; the ultrasonic distance sensor (US-015) was used to control and monitor the water level in the water tank; the water resource tank was used to measure the daily water consumption; a capacitance-type soil moisture sensor (VH400) was used to measure the soil moisture content (SMC) in the pot; a Raspberry Pi integrated with camera was installed to capture the experimental setup as well as the vegetable plant that was grown, the camera was scheduled through the Crontab menu of the Pi to capture images of the setup and then send it to the database to be displayed on the dashboard; a weather station (ATMOS 41) was used to measure energy balance, which is the potential evapotranspiration (PET). In addition, data extracted from the experimental setup in Figure 9 were displayed and updated in real-time on the developed DSS dashboard presented in Figure 10 for remote monitoring of the setup and control of the capillary irrigation.

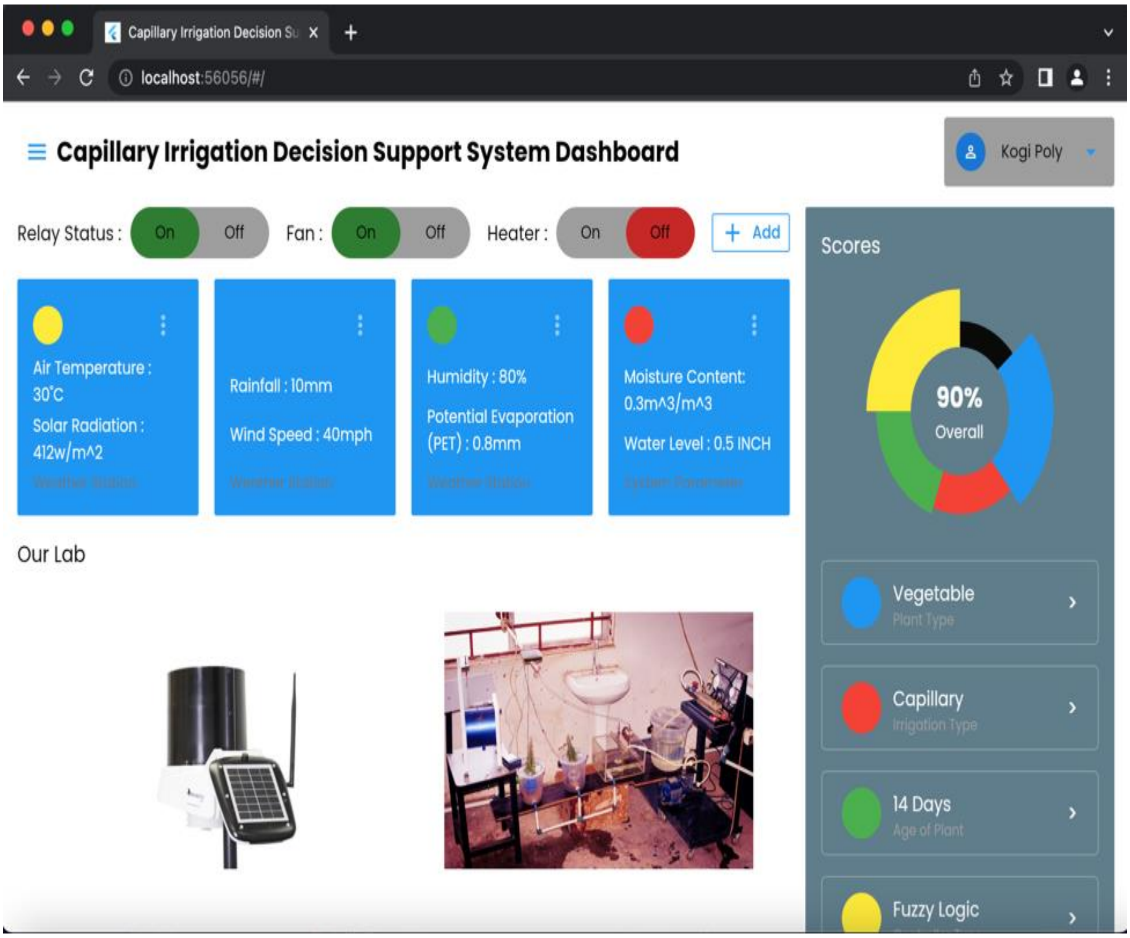

Figure 10: Decision supported system for the fibrous capillary irrigation system

In Figure 11, the flowchart of the fuzzy controller used for the control of capillary irrigation is as presented. To estimate the water level depth (WLD), the controller was setup to determine amount of water required to be supplied based on the crop water demand. The first operation controller obtained the data from the weather station and soil water content; the data obtained was analysed to show the crop water uptake. The controller sampling time was set at every 2 hours to store data at the cloud server and for visualisation on the DSS. After the two hour operation, the data sampling consisting of six data was used to calculate the average feed at the input fuzzy expert system. The actual evapotranspiration and available water content to process fuzzy expert system were used to estimate WLD. Once the controller had determined the WLD, the process of checking WLD depth at the tank began. If the WLD requirements were more than the current water supply depth at the tank, the water pump will be switched on until the water level at WLD tank achieves the required level. The water level is always maintained at a required level until a new level is required. If the WLD level requirements are less than the current WLD, the water level will be left without taking any action to allow the level decrease naturally by plant water uptake. All the data will be stored in the cloud server every 2 hours for evaluation by the monitoring system and for measuring water consumption.

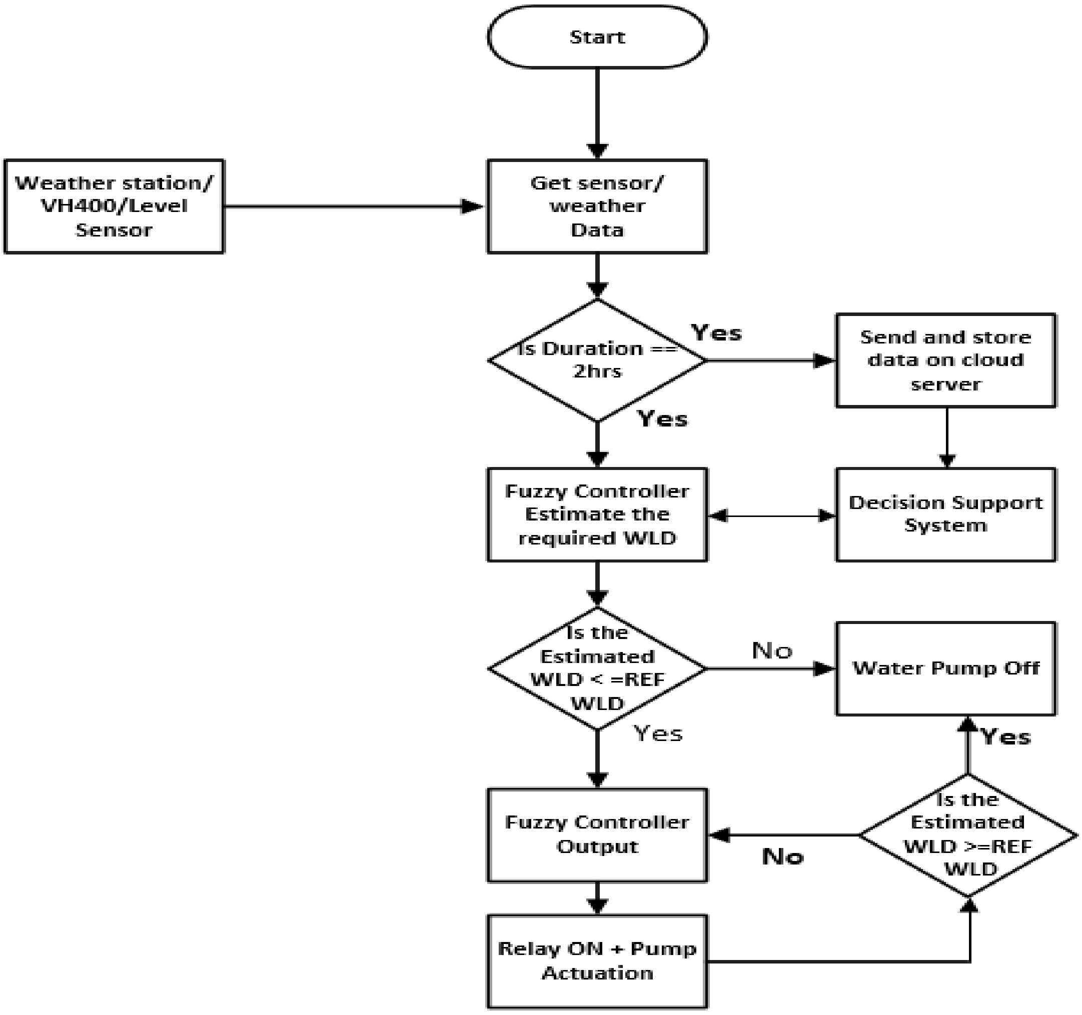

Figure 11: Flowchart of the fuzzy controlled irrigation system

3.0 RESULTS AND DISCUSSION

The daily environmental condition of potential evapotranspiration (PET), air temperature and other parameters were recorded during the experiment conducted from 1st December 2022 to 21st December 2022 and the data were presented in Fig. 12 and Fig. 13. It further shows that the average weather condition was relatively fine during the duration of the experiment. The solar radiation and reference evapotranspiration were measured at 0 W/m^2 during the night and higher during the afternoon period. The potential evapotranspiration (PET) recorded the highest value within this period compared with other days. The trend presented in Fig. 13 for air temperature are similar to the trend observed on the graph presented in Fig. 12 for PET. However, the average maximum temperature and minimum temperature measured in Fig. 13 were 35 ^oC in the afternoon period and around 24 ^oC at night, while the humidity decreases in the afternoon as temperature increases.

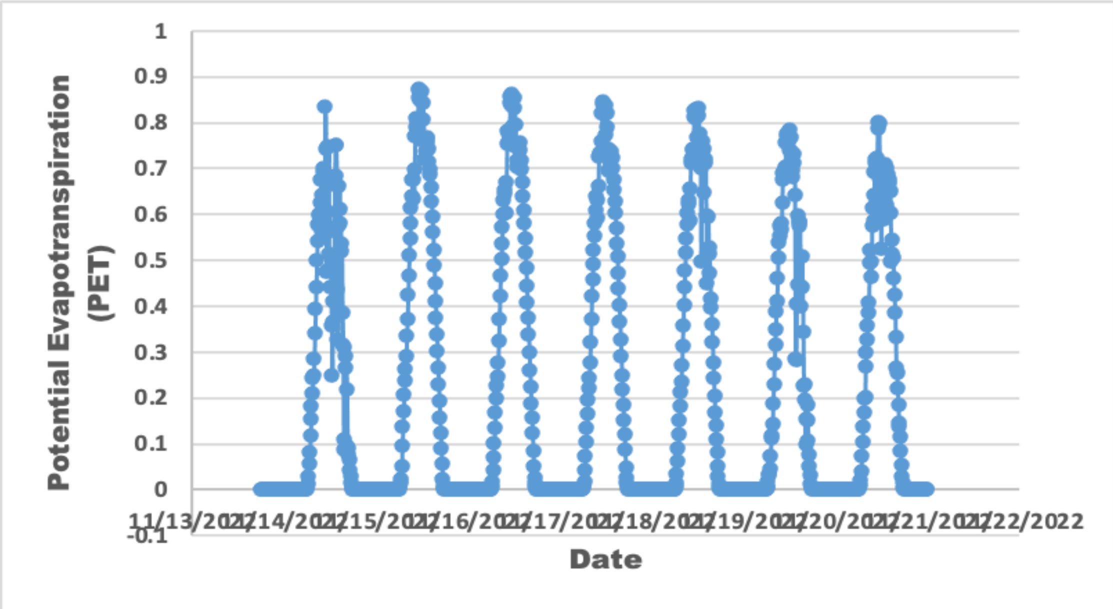

Figure 12: Potential evapotranspiration (PET) (mm/h)

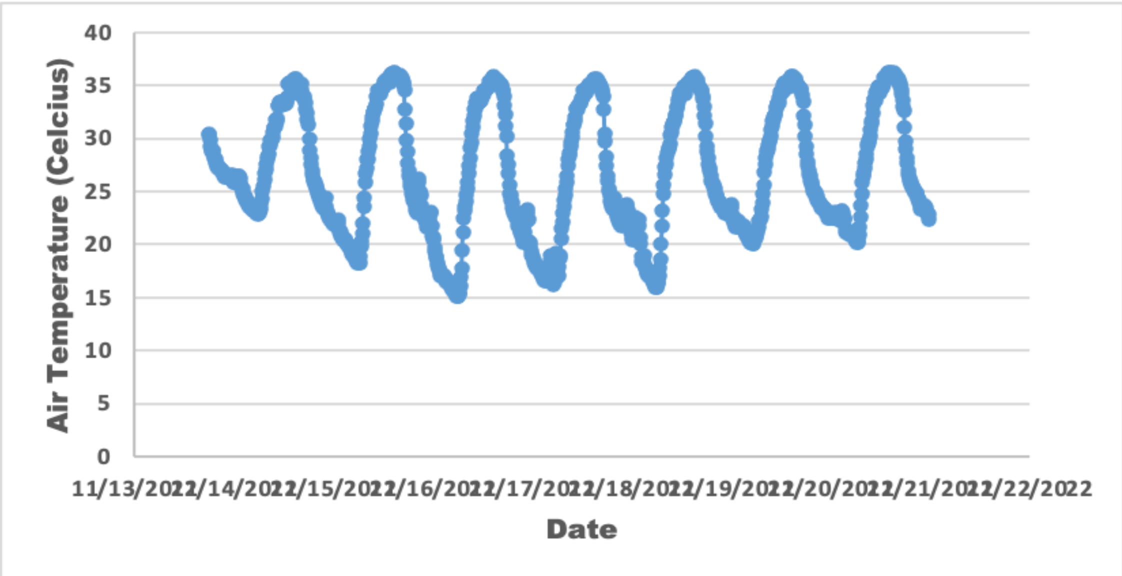

Figure 13: Daily air temperature (°C)

Figure 14 shows the dynamic changes in the soil moisture content (SMC). Similarly, Fig. 15 shows performance of the capillary irrigation system. It further shows the water consumption trend of the fibrous capillary irrigation system, which was controlled using fuzzy logic expert system. As this experiment is ongoing, the vegetable plant been used as test crop is at the mid stage of its life cycle as at this moment.

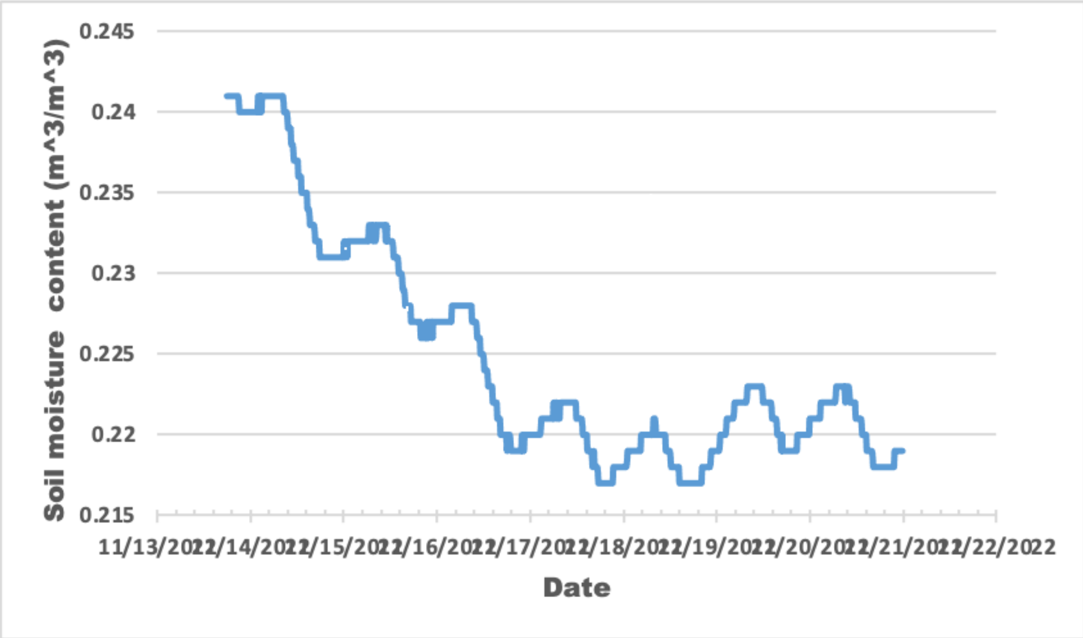

Figure 14: Soil moisture content (m^3/m^3)

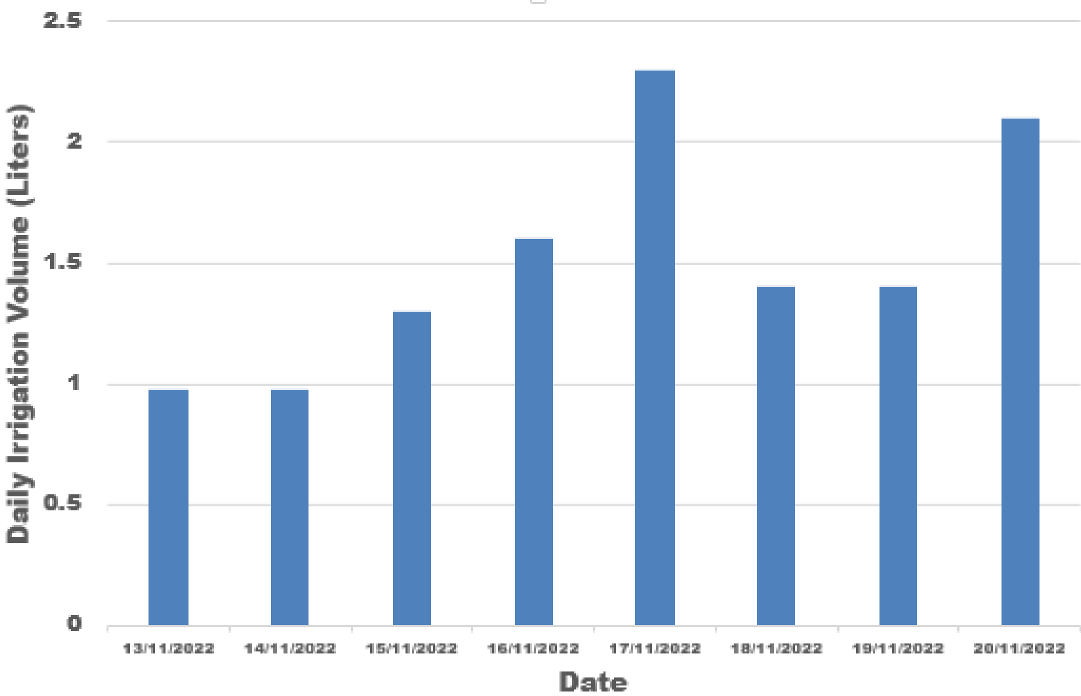

Figure 15: Daily irrigation volume (litres)

CONCLUSION AND RECOMMENDATION

This study proposes an efficient capillary irrigation management system by using fuzzy logic control strategies and DSS platform for real-time monitoring of water level for enhancing the wetting zone at the centre root zone. The achieved data shows that fuzzy logic controller was suitable for regulating the soil moisture content used as the growing medium. This irrigation system has shown more advantages in terms of water saving and leaching compared to other irrigation methods. This study has however shown that the fuzzy water supply depth could also preserve water during the watering event compared to the other irrigation systems.

Capillary irrigation has shown the important role of irrigation in enhancing food availability, sustainability and sufficiency through controlled water saving mechanism. However, lack of adequate funding for setting up this modern irrigation system which also includes equipment maintenance cost and personnel cost can discourage farmers from patronising this irrigation system. This study therefore recommends further research on capillary irrigation as well as the other methods of irrigation systems to establish the adoption of local content approach for fabricating improved component parts using reverse engineering and other scientific methods acceptable in product manufacturing.

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