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Fuzzy-Based Irrigation Improvement System for Nigerian Agricultural Fields

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Abstract
Efficient water management in agriculture is crucial for ensuring sustainable crop production and addressing the global water crisis. Traditional irrigation systems often suffer from inefficiencies, leading to water wastage, uneven crop yields, and increased costs. This paper proposes a fuzzy-based irrigation improvement system that leverages advanced machine learning algorithms, Internet of Things (IoT) devices, and real-time environmental data to optimize water usage in agricultural fields. The system integrates sensors to monitor key parameters such as soil moisture, temperature, humidity, and weather forecasts. Fuzzy logic algorithms analyze this data to determine precise irrigation schedules and water requirements, minimizing wastage and ensuring optimal hydration for crops. The system also employs predictive analytics to adapt to changing environmental conditions and crop growth stages. Key benefits include significant water savings, increased crop yield, reduced operational costs, and enhanced sustainability. Additionally, the system can be scaled and customized to suit different types of crops, soil conditions, and geographical locations. This approach demonstrates the potential of fuzzy logic in transforming traditional farming practices into a data-driven, resource-efficient paradigm. Future developments will focus on integrating renewable energy sources and blockchain for enhanced transparency and efficiency. This fuzzy-driven solution promises a sustainable future for agriculture by addressing the dual challenges of water scarcity and food security.

***Keywords**: Evapotranspiration; fuzzy, irrigation; Fuzzification; Defuzzification; IoT*

1.0 Introduction

Agriculture plays a vital role in the economy of countries throughout the globe producing raw materials for industries and fulfilling the increasing needs of the immensely growing population pressure (Dorsun *et al*., 2014). However, despite great agricultural importance, productivity is not up to the mark and farmer's gains are not substantial (Ed-Dahhak *et al*, 2018). Several issues are anticipated responsible like high cost of production, inflation, poverty, agricultural risks, inadequate access to finance, inadequate availability of inputs and most noteworthy, climatic change, putting a huge threat to water availability, which is the prime source of irrigation in agriculture (Abu *et al*., 2019).

Water is a very important and crucial factor for crops (Gorves-Melendez, 2017). With increasing municipal and industrial demands for water, its allocation to agriculture is decreasing steadily (Nolz *et al*., 2019). The major agricultural use of water is for irrigation, which is affected by decreased supply (Eteng et al., 2018). Therefore, innovations are needed to increase the efficiency of the use of water that is available (Allen *et al.*, 2020).

Irrigation is the application of water for growing crops (Ifeagwu and Adebayo, 2024a). In crop production, it is mainly used in dry areas and during a shortage of rainfall to protect crops (Anand *et al.*, 2018). If a high volume of water is used for irrigation, it causes some problems such as damage by water erosion, water wastes, and plant diseases, if the irrigation water is insufficient, other different problems such as soil aggregation etc, occur (Goumopoulos et al., 2020). The key to proper irrigation is the consumption of the optimum volume of water for the appropriate life period of the plant (Bharatwaj *et al*., 2021). In the field of agriculture, the use of a proper method of irrigation and its control is important (Adebayo and Ifeagwu, 2024) Automation of irrigation system has the potential to provide maximum water use efficiency by monitoring soil moisture and other crop parameters at optimum level (Borse *et al*., 2017). Irrigation has traditionally resulted in excessive labour and non-uniformity in water application across the field (Khriji et al., 2021). Hence an automatic irrigation system based on Internet of Things (IoT) control is required to reduce labour cost and to give uniformity in water application across the field (Ifeagwu and Adebayo, 2024b).

Fuzzy logic is an approach to computing based on "degrees of truth" rather than usual true or false (1 or 0). Boolean logic on which modern computer is based. Fuzzy logic seems closer to the way human brains work (Kia et al., 2019). It may be seen as the way reasoning works. Fuzzy logic has the advantage that the solution to a problem can be cast in terms that human operators can understand so that their experience can be used in the design of the controller (Chakchouk et al., 2018). This makes it easier to mechanize tasks that are already successfully performed by humans (Chaudhary *et al*., 2017).

This paper describes the use of a fuzzy logic approach for irrigation of agricultural fields, which leads to the effective utilization of various resources like water and electricity and hence becomes a cost-effective system for the expected yield.

2.0 Block Diagram of Proposed System

The block diagram for the proposed system model is shown in Figure 1. It has four input parameters: temperature, humidity, net radiation, and wind speed, whose measurement is performed by a DHT11 sensor. The sensor collects the measured parameters, processes them, and sends the measured values to the evapotranspiration block which computes the actual value of evapotranspiration.

These analogue signals are converted by the ADC into digital data. According to the evapo transpiration result obtained from the evaporation model, the microcontroller system could control the amount of water needed by a plant by using fuzzy control rules to limit the opening and closing of the irrigation system valve. The output which is the quantity of water needed by the plant is decided by the fuzzy logic controller.

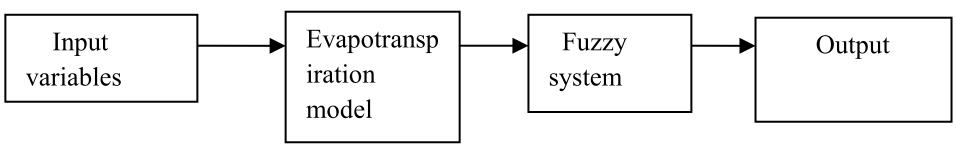

Fig 1: Block diagram of proposed system model

A. Input Variables

The input parameters are defined as follows:

i. Temperature: The optimal growth of a plant assumes constant temperature. It can be controlled under various operating modes such as day and night modes and different modes for each stage of plant development, so the environmental temperature of the plant was monitored. The maximum temperature is 30.70C and the minimum is 22.70C for a week. The thermometer took the temperature readings.

ii. Relative Humidity: The humidity factor has a great influence on the crop. Excess moisture in bean plants affects its development, so it should not be given water when the humidity is high, however when humidity decreases, it is necessary to supply water to the plant. The dry and wet bulbs were placed inside the greenhouse to get the humidity readings.

iii. Radiation: This is the amount of sunlight received by the plant for a particular period, 4.14 hours/day. The pyranometer was placed inside the greenhouse to get the amount of heat.

iv. Wind Speed: The variable is 8.80km/hr. The anemometer was placed inside the greenhouse to get the wind speed.

B. Output Variable: The output is the amount of water needed for irrigation at a particular time.

C. Evapotranspiration Model: The input variables are fed to the evapotranspiration block which computes the actual value of evapotranspiration.

D. Fuzzy System: The fuzzy system identifies the logical interference flows from input variables to output variables. The fuzzification of input interfaces translates analogue input to the obscure. The fuzzy rule base contains linguistic control rules. The defuzzification in the output interface is translated into analogue variables.

In general, a Fuzzy Logic System (FLS) is a nonlinear mapping of an input data vector into a scalar output. An FLS maps crisp inputs into crisp outputs, and this mapping can be expressed quantitatively as y = f(x). It contains four components: fuzzifier, fuzzy rules, inference engine, and defuzzifier.

Fuzzy logic allows the inclusion of expert knowledge in a control system.

Fuzzification: A fuzzy logic system contains sets used to categorise input data. There are the Gaussian and triangle fuzziness methods. Linguistic variables are recognized and membership values for each variable are calculated in this step.

Decision-making unit: It is also known as the Inference unit, and is the core of the fuzzy controller. It generates fuzzy control actions applying the rules in the knowledge base to the current process state. It determines the degree to which each measured value is a member of a given labelled group. The FIS consists of fuzzy rules which are derived from information from experts or input-output learning of the system. Rules mimics‟ human reasoning. Mamdani method is generally used in fuzzy inference techniques. A fuzzy inference system uses rules to generate fuzzy outputs.

Rule base unit: They are decision rules that are applied to each set. It consists of a collection of fuzzy IF-THEN rules. In this step, fuzzy rules are constructed for different inputs to perform different actions. Fuzzy inputs are associated with fuzzy output by fuzzy rules.

Defuzzification: Defuzzification is a process of conversion from a fuzzy set to a crisp number. For crisp input value, there are fuzzy membership for input variables, and each variable causes different fuzzy output cells that will used to activate or to be fired. The output will change into a crisp value from this procedure of defuzzification. Defuzzification can be done by different methods but the most common technique is the centroid method.

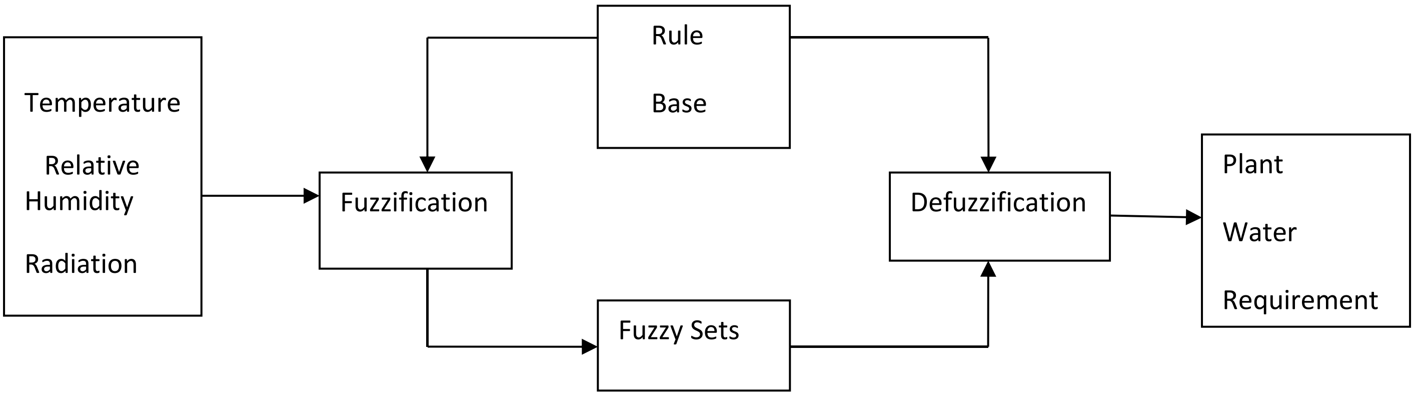

Fig 2: Developed Fuzzy Model for Irrigation Controller

Figure 2 explains the structure of the fuzzy logic controller for an irrigation system. The input variables (temperature, humidity, radiation, wind speed) and output variables (water) are fuzzified using the trapezoidal membership function. Mamdani's inference engine and rule base make the best decision for each situation. After the application of a centroid defuzzification, the controller gives a possible output.

a. Fuzzify Inputs

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. The input is always a crisp numerical value limited to the universe of discourse of the input variable (in this case the interval between 0 and 10) and the output is a fuzzy degree of membership (always the interval between 0 and 1). So

fuzzification doesn't amount to anything more than table lookup or function evaluation.

The fuzzy sets are used to represent four inputs of the irrigation controller (temperature, relative humidity, radiation and wind speed). They model the linguistic terms and classification of features and the classification of irrigation controller segments. The linguistic terms classifications are: Temperature {cold, normal, hot}, Humidity {low, medium, high, extremely high}, Radiation {minimum, maximum}, Wind Speed {minimum, maximum}.The linguistic term for the output, Water {less, medium, more}.

b. Defuzzify

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number crispness recovered from fuzziness at last. As much as fuzziness helps the rule evaluation during the intermediate steps, the final output for each variable is generally a single crisp number. So, given a fuzzy set that encompasses a range of output values, we need to return one number, thereby moving from a fuzzy set to a crisp output.

2.1 Mathematical Analysis of the Proposed System

(a) Determination of Reference Crop Evapotranspiration (ETo)

The reference Evapotranspiration (ETo) was computed based on Penman's equation and modified by Allen *et al.* (2020) to predict the crop water requirement (FAO, 1986). The equation is given as follows:

$$ETo = c\{W * Rn + (1 - W) - f(U) * (ea - ed)\} \quad (1)$$

Where;

ea is the saturation vapour in mbar, ed = actual vapour pressure in mbar , W = temperature and altitude dependent weighting factor, c= adjustment factor for ratio U day/U night, for RH max and for Rs, $f(U)$ = wind function with U in km/day

$$ed = ea * \frac{RH}{100f(U)} \quad (2)$$

The wind function is given by:

$$f(U) = 0.27(1 + U\frac{1}{100}) \quad (3)$$

Where;

$f(U)$ = wind function with U in km/day

Rn = total net radiation in mm/day or

$$Rn = 0.75Rs - Rnl \quad (4)$$

$$Rs = \left(0.25 + 0.50\frac{n}{N}\right)Ra \quad (5)$$

Where;

Rs = incoming shortwave radiation in mm/day

Ra = extra-terrestrial radiation in mm/day

n = mean actual sunshine duration in hours/day

N = maximum possible sunshine duration in an hour/day.

Rnl = net longwave radiation

$$Rnl = f(T) * f\left(\frac{n}{N}\right) * f(ed) \quad (6)$$

Where;

$f(T)$ = function of temperature

$f(ed)$ = actual vapour pressure

$f(n/N)$ = sunshine duration

(b) Determination of Maximum Evapotranspiration (ETm)

Crop evapotranspiration (ETcrop) refers to conditions when water is adequate for unrestricted growth and development (Allen *et al*., 2020) *i.e.*, when soil water is not limited, also called water requirements in mm/day or mm/period. Crop evapotranspiration (ETm or ETcrop) was determined as:

$$ET\ crop = ETo * Kc \quad (7)$$

The kc value at each stage of the growth stages was converted to monthly Kc as:

$$\frac{Kc}{month} = \frac{kc\ growth\ stage * N}{30} \quad (8)$$

Where N = number of days the growth stage lasted in a month and each month was assumed to have 30 days. Crop evapotranspiration (ETcrop/ month) was obtained as the product of the monthly mean ETo in mm/day and the kc for the crop over every 30 days. Seasonal ET crop values were calculated by summing the monthly values.

(c). Determination of Irrigation Water Requirement (IR)

This is the difference between ETm and Effective Rainfall (ER) using the formula of Brouwer and Heibloem. Effective Rainfall (ER) is calculated as follows:

$$ER = 0.8r - 25, if\ R > \frac{75mm}{month} \quad (9)$$

Or

$$ER + 0.6R - 10, if\ R < \frac{75mm}{month} \quad (10)$$

Where;

ER = Effective rainfall or the part of the precipitation that is infiltrated and stored in the root zone and which plants can depend on to satisfy the water needs.

R = monthly rainfall.

When the actual evapotranspiration (ETa) is less than the maximum evapotranspiration (ETm), there is a moisture deficit. To know when to irrigate, irrigation interval (IN) was calculated

$$IN = P * D * Sa \quad (11)$$

Where P = Soil water depletion factor for crop groups and maximum (ETm)

D = Rooting depth (0.6m)

Sa = Total available soil water, 60 mm/m for coarse textured soil as is found in PortHarcourt soils.

The potential yield response to water supply

$$1 - \frac{Ya}{Ym} = Ky * 1 - \frac{ETa}{ETm}.. \quad (12)$$

Where

Ky = Yield Response Factor

Ya = Actual Yield Harvested (tonnes/ha)

Ym = Maximum Harvested (tonnes/ha)

ETa =Actual Evapotranspiration (mm/day)

6ETm = Maximum Evapotranspiration (mm/day)

To calculate ETa at different water deficit

$$ETa = ETm - \%\ water\ deficit\ of\ ETm. \quad (13)$$

3.0 Materials and Method

3.1 Materials

The work was done at the Institute of Agricultural Research and Development of the University of Port Harcourt, Nigeria. PortHarcourt is located in Southern Nigeria at latitude 4.824167 and longitude 7.033611. PortHarcourt is located in the humid forest zone of Nigeria with an altitude of 7 m above sea level. Annual rainfall in Port Harcourt is 2808 mm. January is the driest month with 54mm of precipitation while June is the wettest month with 364mm of rainfall. The soil is sandy clay loam. The plant was housed in a greenhouse.

The materials and their specifications for measuring climatic conditions in a fuzzy logic-based irrigation System ensure high accuracy, durability, and seamless integration in a fuzzy-driven irrigation system for optimizing water usage and improving crop yield. The materials are:

1. Temperature Sensors

Material: Thermistors, RTDs (Resistance Temperature Detectors), or Thermocouples

Specifications:

Range: -40°C to 125°C (air); -20°C to 60°C (soil)

Accuracy: ±0.5°C

Response Time: <10 seconds

2. Humidity Sensors

Material: Capacitive or Resistive Humidity Sensors

Specifications:

Range: 0% to 100% Relative Humidity (RH)

Accuracy: ±2% to ±5% RH

Response Time: <8 seconds

3. Soil Moisture Sensors

Material: Capacitive or Resistive Probes, Time-Domain Reflectometry (TDR) Sensors

Specifications:

Measurement Range: 0% to 100% Volumetric Water Content (VWC)

Accuracy: ±3% to ±5% VWC

Probe Length: 5–20 cm

4. Rain Gauges

Material: Tipping Bucket or Optical Rain Gauges (Stainless Steel/Plastic Housing)

Specifications:

Resolution: 0.2 mm per tip

Measurement Range: 0–500 mm/hour

Accuracy: ±2%

5. Wind Speed and Direction Sensors

Material: Anemometers (Cup or Ultrasonic) and Wind Vanes (Plastic or Metal Construction)

Specifications:

Wind Speed Range: 0 to 60 m/s

Accuracy: ±0.5 m/s

Wind Direction Range: 0° to 360°

Accuracy: ±5°

6. Solar Radiation Sensors

Material: Photovoltaic Cells or Pyranometers (Silicon-based Detectors)

Specifications:

Measurement Range: 0 to 1500 W/m^2

Spectral Range: 400 to 1100 nm

Accuracy: ±5%

7. Integrated Weather Stations

Material: Aluminum/Plastic Housing with Multi-Sensors

Specifications:

Data Output: Digital (RS232/RS485, Wi-Fi, or LoRa)

Power Source: Solar panel or battery

Operating Temperature: -40°C to 70°C

8. Data Logging and Communication

Material: Microcontrollers (e.g., Arduino, Raspberry Pi) and IoT Modules (e.g., LoRa, Zigbee)

Specifications:

Storage: ≥16GB SD Card or Cloud Connectivity

Communication Range: Up to 10 km (LoRa), 50–300 m (Wi-Fi/Zigbee)

Power Consumption: 1–5 W

9. Power Supply

Material: Solar Panels, Rechargeable Lithium-ion Batteries

Specifications:

Solar Panel Output: 5–20 W

Battery Capacity: 2000–10000 mAh

Voltage: 3.7V to 12V

10. Cloud Integration

Material: Edge Devices (e.g., NVIDIA Jetson), Cloud Platforms (AWS IoT, Google Cloud)

Specifications:

Processor: GPU or TPU with at least 1 TFLOPS performance

Cloud Storage: ≥1 TB

Data Analytics: Real-time processing with latency <1 second

3.2 Method

3.2.1 Model for the Propose System

The graphical user interface (GUI) tools provided by the Fuzzy Logic Toolbox in Matlab were used. The five primary GUI tools for building, editing, and observing fuzzy inference systems in the Fuzzy Logic Toolbox: the Fuzzy Inference System or FIS Editor, the Membership Function Editor, the Rule Editor, the Rule Viewer, and the Surface Viewer were used. The FIS Editor handles the high-level issues for the system: The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable.

The Rule Editor is for editing the list of rules that define the behaviour of the system.

The last two GUIs are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. The Rule Viewer is a MATLAB-based display of the fuzzy inference diagram shown at the end of the last section. Used as a diagnostic, it can show (for example) which rules are active, or how individual membership function shapes are influencing the results. It’s a very powerful window full of information.

The Surface Viewer: This tool can display how the output depends on any one or two of the inputs—that is, it generates and plots an output surface map for the system. Some of the GUI tools have the potential to influence the others. For example, if you add a rule, you can expect to see the output surface change.

3.2.2 PROCESS FLOWCHART

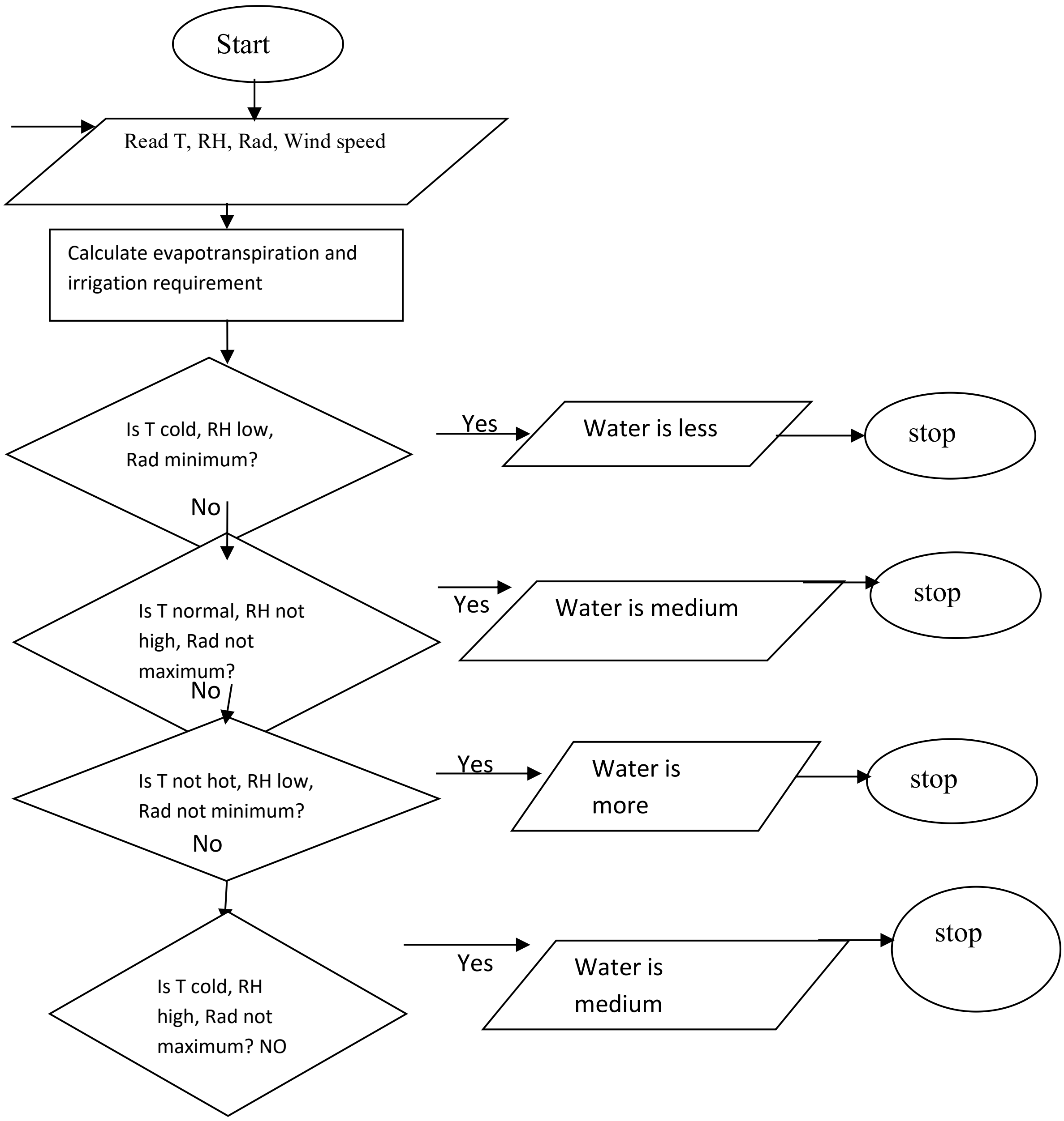

Fig 3: Process flow chart

Figure 3 is the process flow chart. On start-up, the machine with the help of its sensors takes a reading of its environment with Temperature (T), Relative Humidity (RH), Radiation (Rad) and Wind speed as the required input variables. These variables are then passed through a calculation process to ascertain the irrigation water requirements. The results of these calculations are further processed through the preinstalled fuzzy rules.

If the resultant variables meet the condition of the first rule the output is displayed showing the equivalent irrigation water requirement and the process is completed. If however the variables fail to meet the conditions of the first rule, it is then passed through the second fuzzy rule. The process is completed as soon as any of the conditions of the fuzzy logic are met; otherwise, it is passed through the next until a condition is met. Failure to meet any conditions restarts the process all over again.

4.0 Results and Discussion

4.1. The Fuzzy Inference Editor

In Figure 4 the four block diagrams by the left represent the four input variables (temperature, relative humidity, radiation and wind speed). The block diagram on the right represents the output variable, water. It shows the name of the system and the type of inference used, which is Mamdani style inference.

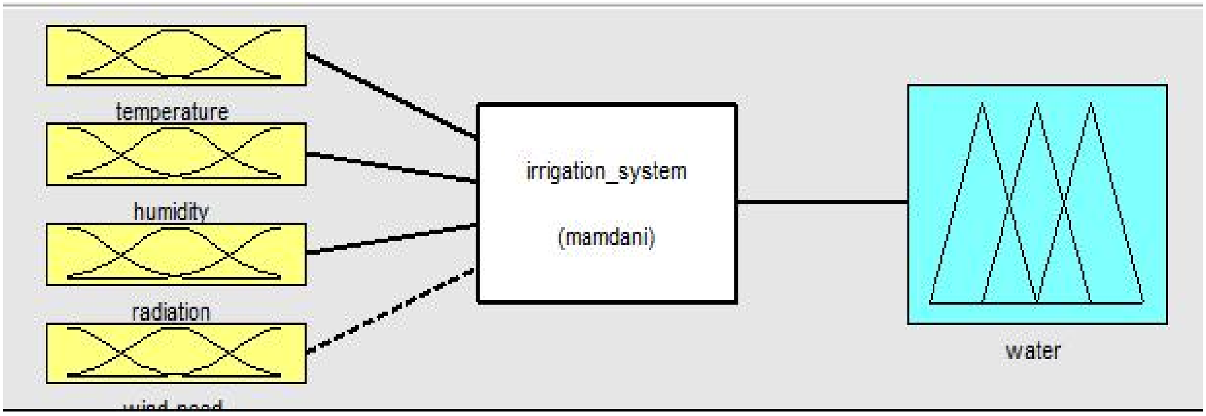

Fig 4:Fuzzy inference editor.

4.1.1 Membership Function Plots

Figures 5-9 show the membership function graphs of the input and output variables. The variables are identified and membership values for each variable are calculated. It defines the shape of all the membership functions associated with each variable.

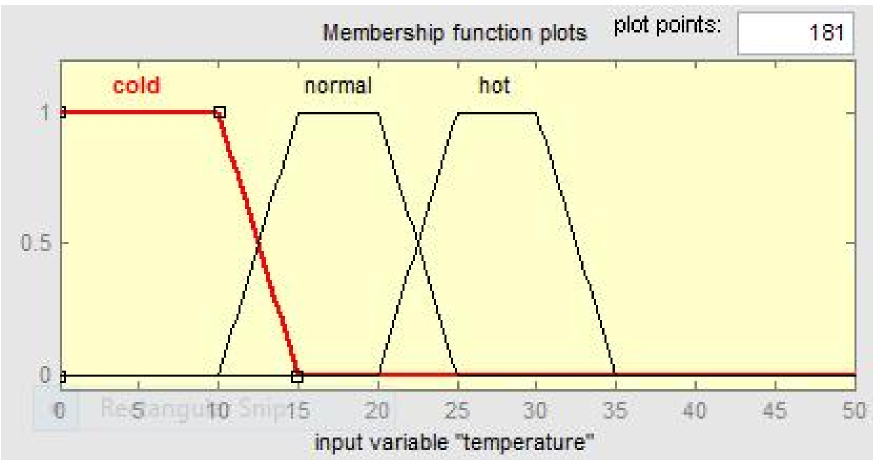

Fig 5: Temperature Membership function graph

The result obtained from the input variable, the temperature membership function graph is shown in Figure 5. The limits of the variable range are [0-50]. The membership functions of temperature are represented as [cold, normal and hot] with variables each of [0 0 10 15, 10 15 20 25, 20 25 30 35].

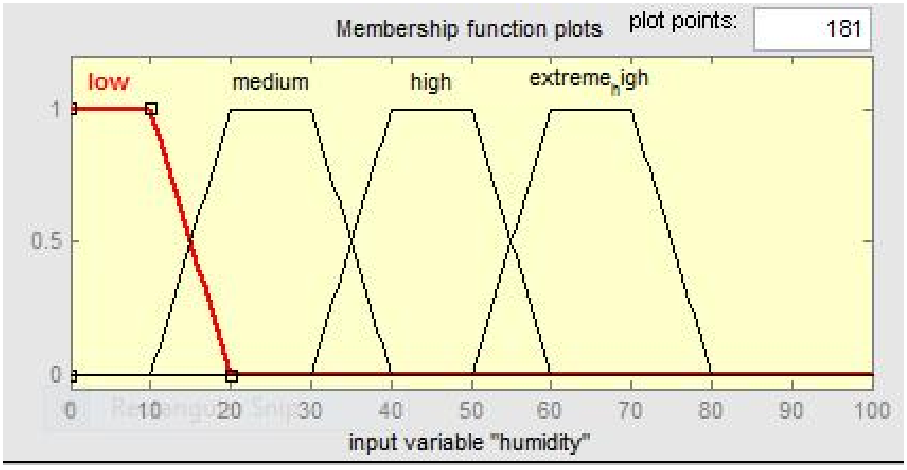

Fig 6: Humidity membership function graph

The result obtained from the input variable, the relative humidity membership function graph is shown in Figure 6. The limits of the variable range are [0-100]. The membership functions of temperature are represented as [low, medium, high and extreme high] with linguistic variables each of [0 0 10 20, 10 20 30 40, 30 40 50 60, 50 60 70 80].

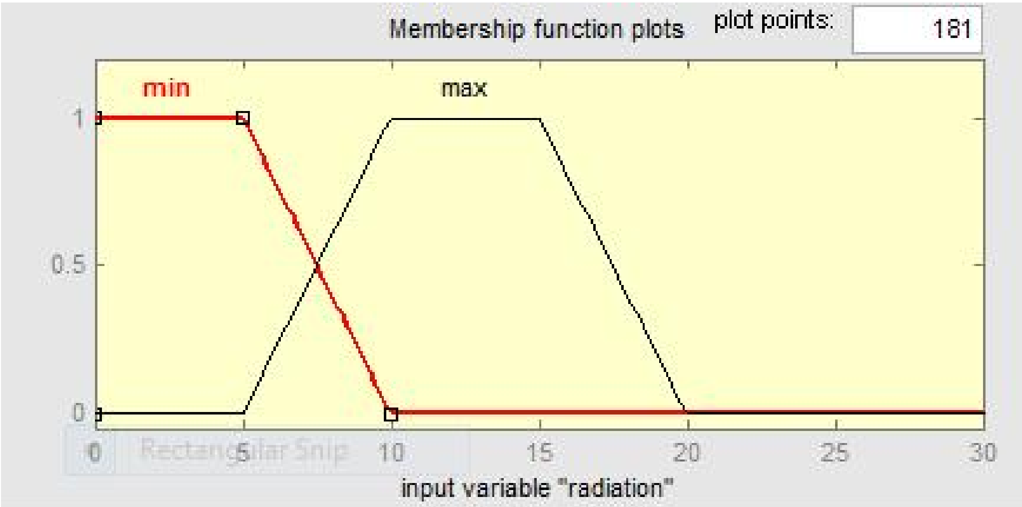

Fig 7: Radiation Membership function graph

The result obtained from the input variable, the radiation membership function graph is shown in Figure 7. The limits of the variable range are [0-30]. The membership functions of temperature are represented as [minimum and maximum] with linguistic variables each of [0 0 5 10, 5 8 10 15].

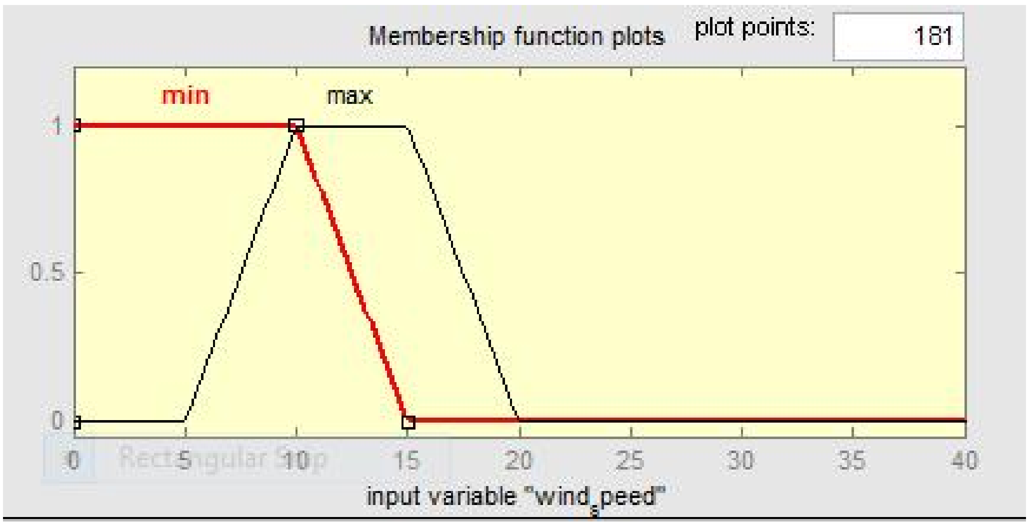

Fig 8: Wind Speed Membership function graph

The result obtained from the input variable, the wind speed membership function graph is shown in Figure 8. The limits of the variable range are [0-40]. The membership functions of temperature are represented as [minimum and maximum] with linguistic variables each of [0 0 8 15, 8 15 20 20].

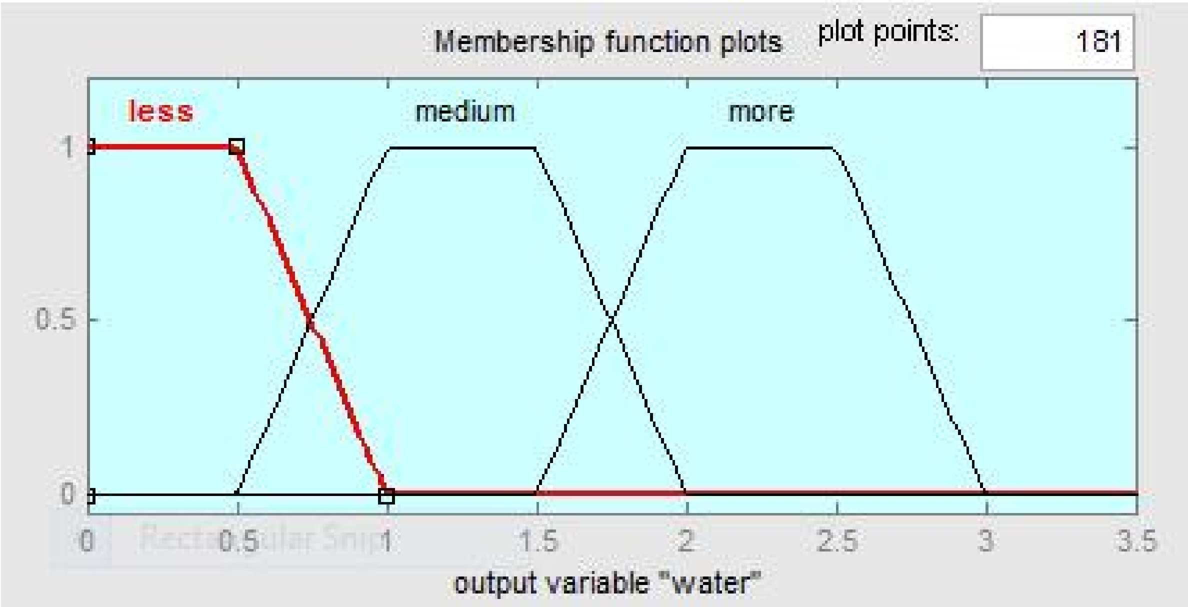

Fig 9. Water Membership Function graph

The result obtained from the output variable, the water membership function graph is shown in Figure 9. The limits of the variable range are [0 - 3.5]. The membership functions of temperature are represented as [less, medium, more] with linguistic variables each of[0 0 0.5 1, 0.5 1 1.5 2, 1.5 2 2.5 3].

4.1.2 Fuzzy Algorithm

Figure 11 shows the list of rules that define the behaviour of the system. It uses the IF- THEN to analyse the relationship of the inputs to the output. The rules are:

1. If the temperature is cold humidity is low radiation is minimum and wind speed is minimum then water is less.
2. If temperature is normal humidity is high radiation is maximum and wind speed is maximum then water is medium.
3. If the temperature is hot humidity is medium radiation is minimum and wind speed is minimum then water is more.
4. If the temperature is cold humidity is extremely high and radiation is maximum and wind speed is maximum then water is less.

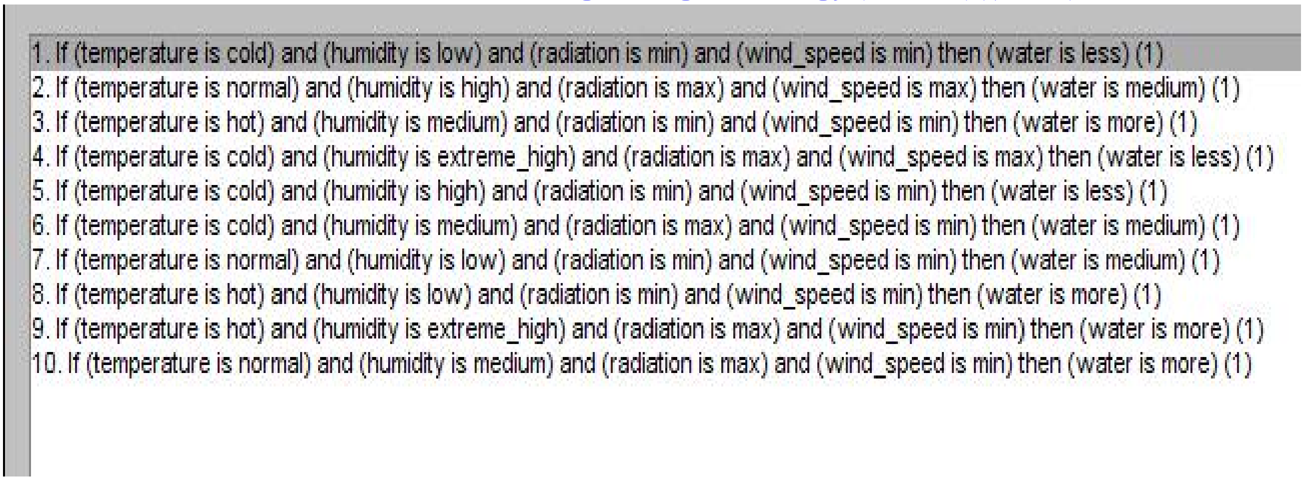
1. If (temperature is cold) and (humidity is low) and (radiation is min) and (wind_speed is min) then (water is less) (1)
2. If (temperature is normal) and (humidity is high) and (radiation is max) and (wind_speed is max) then (water is medium) (1)
3. If (temperature is hot) and (humidity is medium) and (radiation is min) and (wind_speed is min) then (water is more) (1)
4. If (temperature is cold) and (humidity is extreme_high) and (radiation is max) and (wind_speed is max) then (water is less) (1)
5. If (temperature is cold) and (humidity is high) and (radiation is min) and (wind_speed is min) then (water is less) (1)
6. If (temperature is cold) and (humidity is medium) and (radiation is max) and (wind_speed is min) then (water is medium) (1)
7. If (temperature is normal) and (humidity is low) and (radiation is min) and (wind_speed is min) then (water is medium) (1)
8. If (temperature is hot) and (humidity is low) and (radiation is min) and (wind_speed is min) then (water is more) (1)
9. If (temperature is hot) and (humidity is extreme_high) and (radiation is max) and (wind_speed is min) then (water is more) (1)
10. If (temperature is normal) and (humidity is medium) and (radiation is max) and (wind_speed is min) then (water is more) (1)

Fig 11: Fuzzy algorithm

4.1.3 The Rule Viewer

In Figure 12, the 10 rules are represented in block form. Each row of plots represents a rule. The first four blocks represent the input rules, and the last block represents the output rule. Each rule is a row of plots and each column is a variable i.e. temperature, humidity, radiation, wind speed and water at a particular quantity(26.2, 79.8, 5.08, 8.8). The output block shows how the output of each rule is combined to make an aggregate output and then defuzzified, i.e. it is turned to crisp values. The input values are displayed and the calculation of the required water quantity is automatically given by fuzzy logic. The thick line in the last row of the output block shows the calculated output value, which is the defuzzified output value for water (2.25).

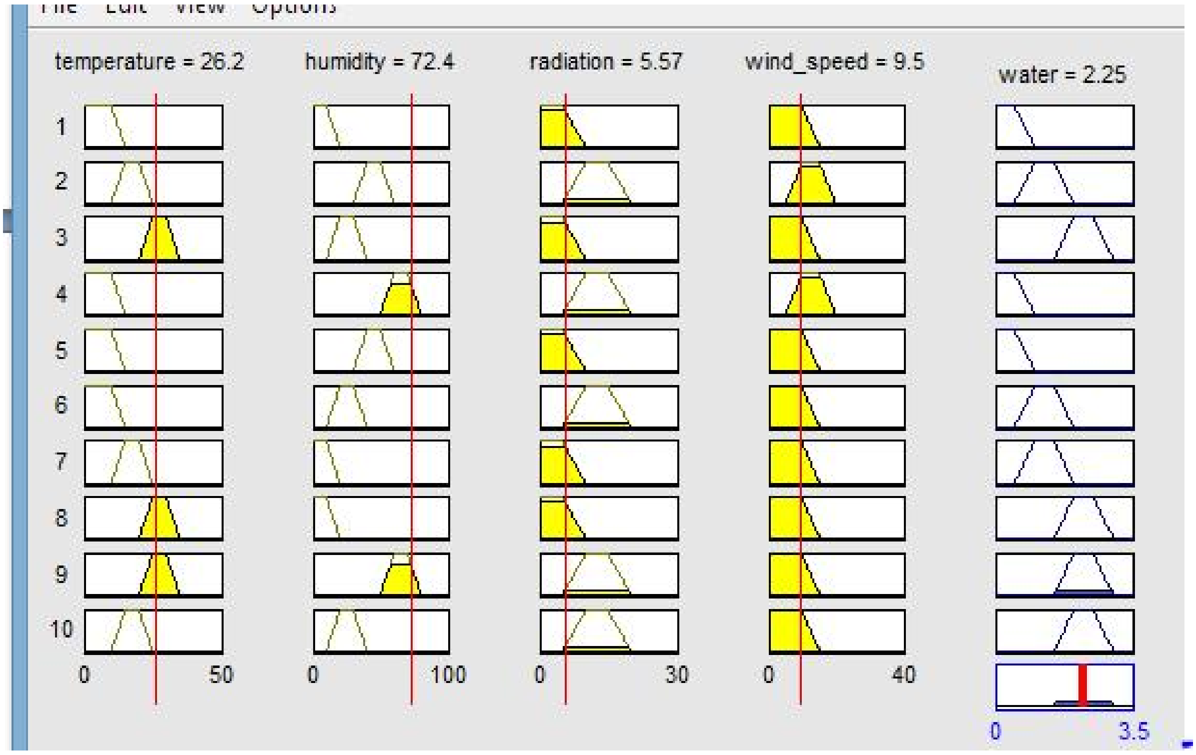

Fig 12: Rule Viewer

4.1.4 The Surface Viewer

The surface viewer represents the 3 dimensional function graph plot which shows the relationship between the input variables and output variables. The shape of the graph will determine its importance for each variable in the fuzzy system. It gives the relationship between two inputs and one output at a time while the rest of the inputs remain constant.

a. Input variables (Temperature and Humidity) with Output variable (Water)

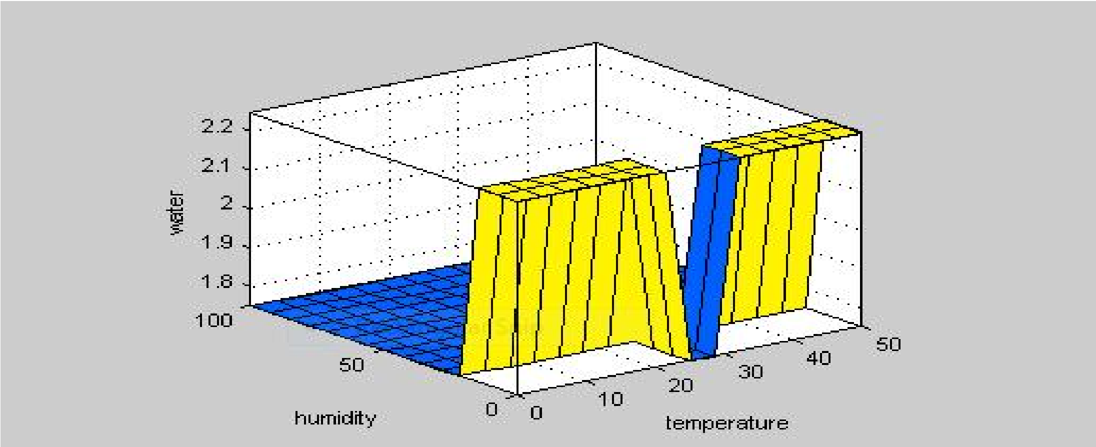

Fig 13. 3D Simulation for Input variables temperature and humidity with output water

b. Input variables (Temperature and Radiation) with Output variable (Water)

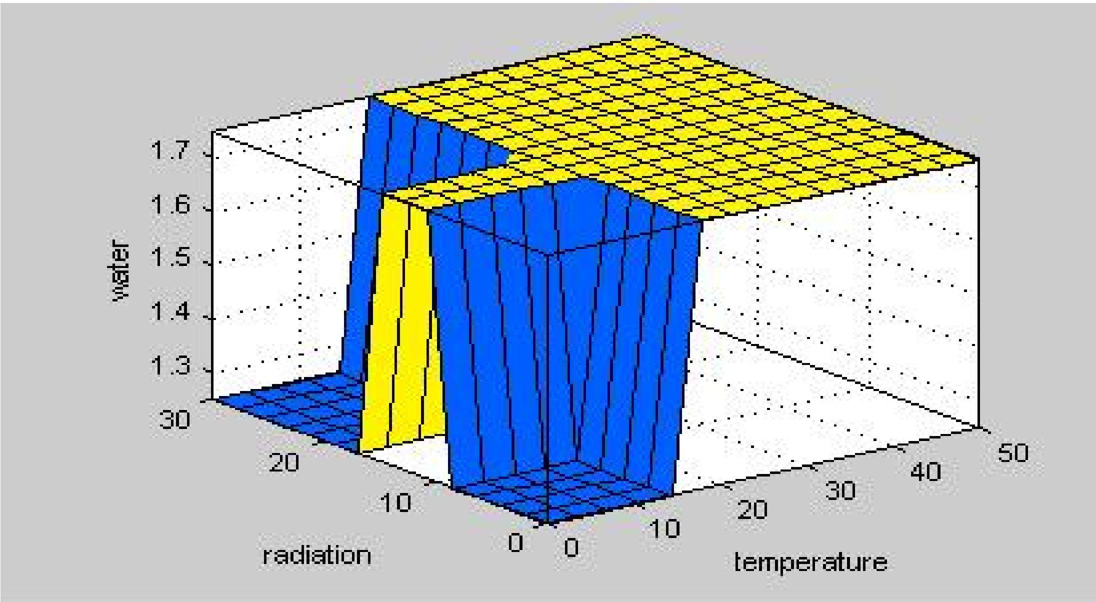

Fig 14: 3D Simulation for input variables Temperature and Radiation with Output Water

c. Input variables (Temperature and wind speed) with Output (Water)

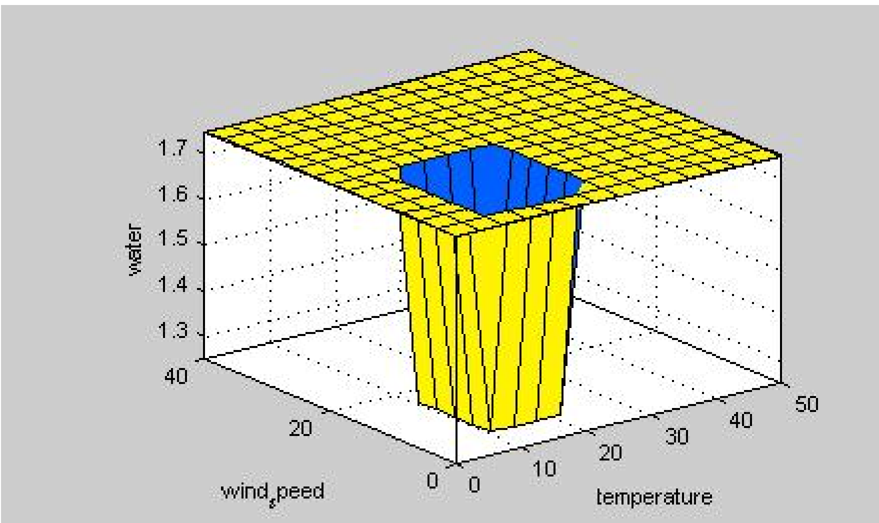

Fig 15: 3D Simulation for input variables Temperature and Windspeed with Output Water

d. Input variables (wind speed and humidity) with Output variable (Water)

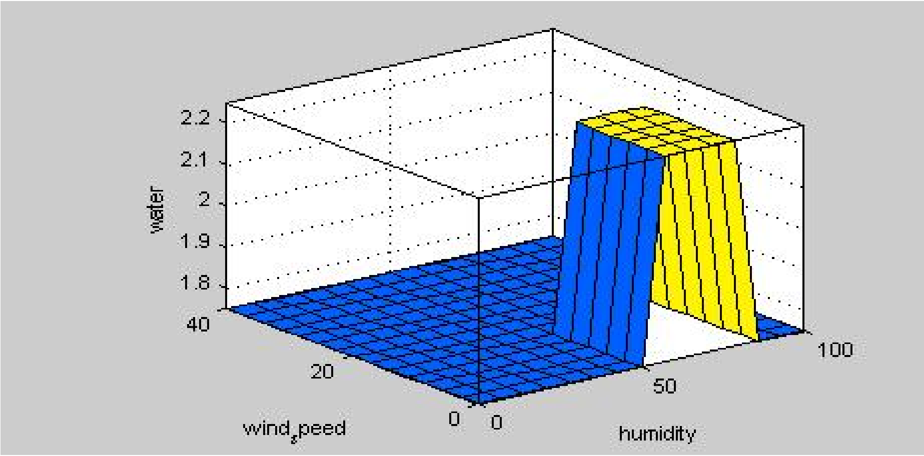

Fig 16: 3D Simulation for input variables windspeed and humidity with output water

Table 2 shows the irrigation water requirement simulation result obtained from fuzzy logic.

The above table gives the simulated fuzzy results of the irrigation water requirement gotten from the input readings.

Table 2: Simulated Fuzzy Result

Temp	Relative Humidity	Radiation	Wind	Irrigation Water Requirement
26.75	79.86	5.08	8.8	2.24
26.20	72.43	5.57	9.50	2.25
26.20	78.07	5.50	8.80	2.25
27.50	73.51	5.60	8.70	2.25
25.63	74.00	5.55	9.00	2.25
28.63	76.00	5.55	9.10	2.25
29.43	72.00	5.90	9.00	2.25
28.75	57.86	5.19	8.80	2.25
26.20	72.43	5.57	9.50	2.25

4.1.5 Determination of Irrigation Water Requirement of Beans

Equation (14) shows the quantity of water needed for the irrigation of bean plants for one month based on data collated.

Where Irrigation Requirement(IR)

Effective Rainfall (ER)

R (Monthly Rainfall) = 56.25mm/month

Maximum Evaporation (ETm)

Reference Crop Evaporation (ETo)

Crop Coefficient (Kc)

ETo = 111.60mm/month

Kc = 0.24

R = 56.25mm/month

To find Maximum Evaporation

$$ETm = ETo * Kc. \quad (14)$$

= 111.60*0.24

= 26.78mm/month

Seo finds Effective Rainfall

$$ER = 0.6R - 10. \quad (15)$$

= (0.6*56.25) – 10

= 33.75 – 10

= 23.75mm

To find Irrigation Requirement

$$IR = ETm - ER \quad (16)$$

=26.78 – 23.75

=3.034mm

The irrigation water requirement for beans for one month is 3.03mm.

Figure 17 is a graph of the irrigation water requirements of beans for weeks. In the second week, the crop requires the highest quantity of water and requires the least amount in the third week.

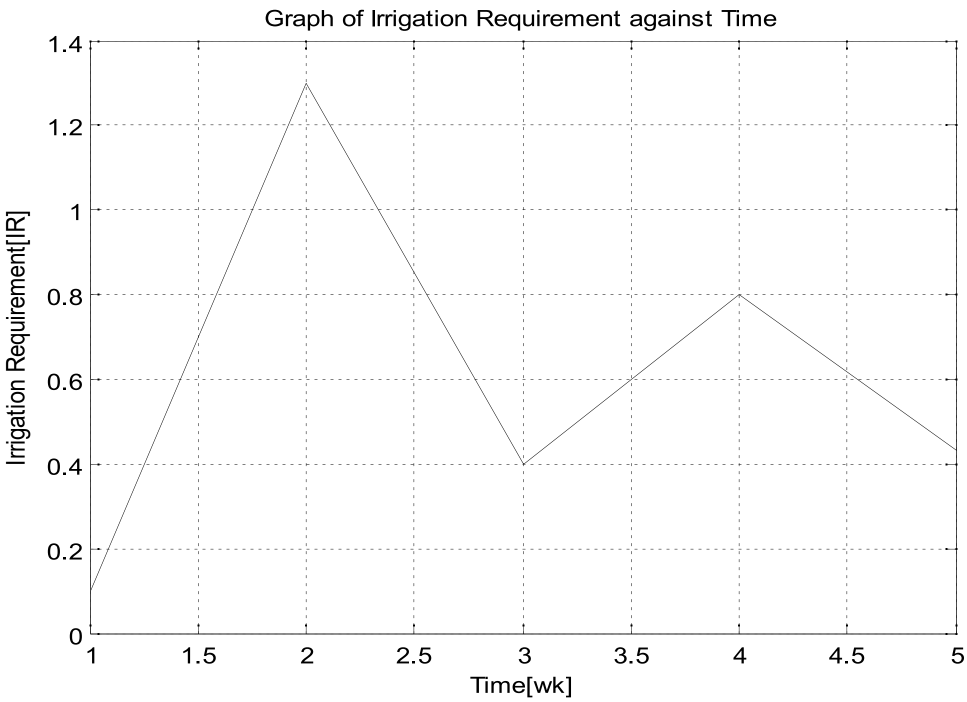

Fig 17: Plot of irrigation requirements against time

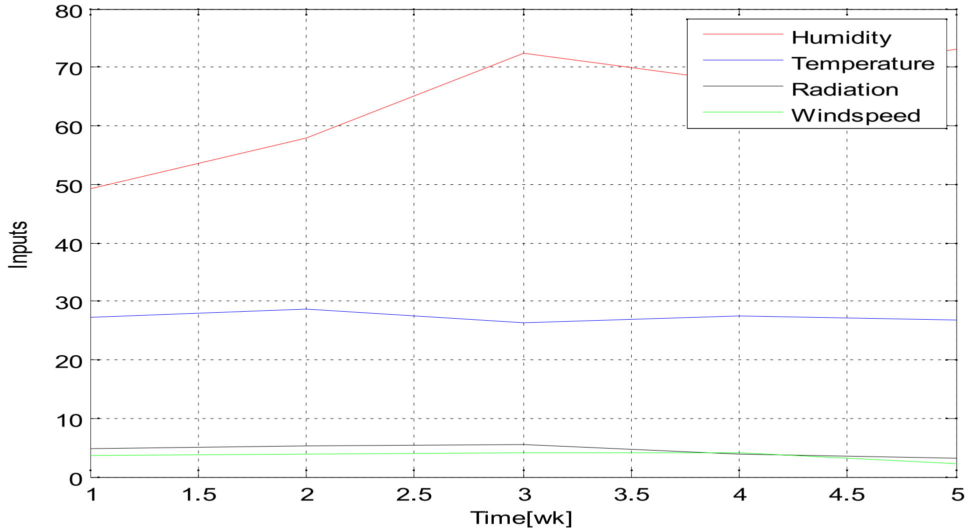

Fig 18: Input variables against time

The plot in Figure 18 indicates the data on temperature, relative humidity, radiation and wind speed. In the plot, the humidity in the crop environment went from low to high then medium, the environmental temperature was normal, and the radiation and wind speed were at minimum.

4.2 Analysis

This system contains a fuzzy logic controller with temperature, relative humidity, radiation and wind speed as input parameters and irrigation water requirement as the output. One of the simulated results of the inputs and output for the fuzzy logic controller of this work is: Temperature= 26.2, Relative Humidity= 72.43, Radiation=5.57, Wind Speed= 9.5, irrigation water requirement= 2.25

The simulation result for the irrigation water requirement = 2.25

The calculated irrigation water requirement determined from the data collated = 3.03.

The difference between the calculated irrigation water requirement and the simulated fuzzy result is 3.03-2.25 = 0.78

From the above results, the difference between the calculated irrigation water requirement and the simulated fuzzy irrigation water requirement for soybean crops is 0.78. The difference is small, therefore the proposed system is efficient in managing and reducing water wastage during irrigation.

5.0 Conclusion

This paper is based on improving irrigation using fuzzy logic. So, the aspect handled is a determination of the irrigation water requirement of a bean plant. The already existing traditional method result was compared with the simulated fuzzy logic result.

Based on the above method and after the data was analyzed, for the fuzzy logic controller, the simulated irrigation water requirement for beans was 2.25mm for one month, while the calculated irrigation water requirement was 3.03mm for a month. So, we have been able to deduce from the result that fuzzy logic can help reduce water wastage during irrigation.

Fuzzy logic is said to be an intelligent and easy method applied to irrigation systems. It calculates, simulates, reasons and produces the exact amount of water required for plant intake at specific times. It saves time, cost, and labour and reduces water wastage during irrigation. The system is also flexible, you can always change the value of variables and get accurate results.

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