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Efficient Soil Health Monitoring and Irrigation Management System Using Fuzzy Logic

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Abstract: The need for sustainable agriculture is acutely felt due to ever increasing global water crisis. Efficient irrigation management is crucial in this regard. The proposed system employs a network of soil moisture sensor distributed over a agricultural field, where continuous acquisition of real time data on soil moisture levels is done. Soil moisture measurement is a vital parameter in terms of precision agriculture, which affects the irrigation scheduling for ensuring optimal crop growth. Traditional methods related face challenges adapting to changing soil patterns at different conditions. The system proposes application of fuzzy logic algorithm for processing of data. Key advantages of using fuzzy logic in soil moisture measurement include improved precision in moisture detection, enhanced ability to make more informed irrigation decisions. The proposed system delivers a model for promoting water conservation, enhancing crop productivity and maintaining soil health.
Keywords: Sustainable agriculture, soil moisture sensors, precision agriculture, fuzzy logic, water conservation.

I. INTRODUCTION

Precision agriculture ensures use of technology to optimize crop yield and adequate resource utilization. The critical factors in this regard are soil nutrient and water utilization. The methodology involves collecting data such as soil moisture, temperature, humidity, electrical conductivity for the purpose of irrigation scheduling. For measuring the nutrient levels in the soil NPK sensor is also to be integrated. The system utilizes concept of Fuzzy logic where various conditions involved in the input variables are evaluated for arriving at a certain outcome. In digital logic there is existence of only 0 or 1. But Fuzzy logic takes care of the intermediate stages.
The advantages of using fuzzy logic in this context are extensive. It allows for incorporation of expert knowledge and empirical data into the decision making process, facilitating more flexible and adaptive management strategies. Fuzzy logic can model non-linear relationships and interactions between different soil health factors, providing a comprehensive understanding of soil conditions. The paper discuses the addition of fuzzy logic system into the designing and implementation of the soil health management and irrigation scheduling system for availing better results.

II. OBJECTIVES OF THE PROPOSED SYSTEM

1) Optimization of water use by adoption of irrigation scheduling mechanism.
2) Improvement in soil health monitoring by facilitating data driven agricultural practices.
3) Facilitation of user-friendly interface to interact with the farmers.
4) Validation of performance of the system through field trails.

III. IMPACT OF THE OBJECTIVES

Irrigation scheduling concerns with determining the timing and amount of water to be applied to crops. Through irrigation scheduling farmers can optimize the inputs such as water and fertilizers. By supplying water adequately and precisely to crops farmers can increase yields, reduce wastage of water and lower the cost of inputs. It can further aid in contributing to promoting climate resilient agriculture by enabling farmers to adopt to changing weather patterns and reduced water availability.
With the help of data driven approach for measurement of soil nutrients, farmers can optimize fertilizer application, ensuring crops receive the right amount of nutrients at the right time. Improper fertilizer application to crops can lead to nutrient run-off resulting in contamination of water resources. By ensuring targeted dose of nutrients to crops, proposed can contribute in reducing water pollution. It can further increase the efficiency by reducing the wastage and lowering the need of excess fertilizers.
Facilitation of user-friendly interface can help farmers to access information regarding crop management, soil health, water requirement to the crop thus leading to improved decision making. It can help farmers with limited technical skills.
Validation of the proposed system through field trials underlines the effectiveness of smart irrigation, soil health monitoring system. It can encourage farmers to adopt to new technologies.

Validated trials can attract investment in agricultural technology. It provides a valuable source of knowledge for farmers, agricultural researchers and educators. Knowledge transfer can help to build skilled workforce in agriculture.

IV. STATUS OF RESEARCH

Research on fuzzy logic for water saving in drip irrigation system in which the system optimized the usage of water and fertilizers based on soil humidity and temperature in the field. Water pipe valves were opened for duration of the time determined by fuzzy logic. The results showed that the system could quickly and accurately calculate water demand for the amount of crops which provided a scientific basis for water-saving irrigation. The system also served as a method to optimized the amount of fertilizer used [1]. Implementation of irrigation using fuzzy logic method in which the irrigation optimizes water usage for agriculture. Open loop fuzzy logic control system was implemented using mamdani control system. Simulation was done using Matlab and Simulink. Results showed that fuzzy logic system was simulated correctly and that mamdani type of fuzzy logic control system optimizes water usage for crops. [2]. Research on solution to control irrigation time based on the fuzzy logic method was taken where Fuzzy Logic Controller (FLC) was built on the NODEMCU controller board which was connected to the DHT22 sensor and soil moisture sensor. Parameters of temperature and water content in the soil were used as input for fuzzy logic to determine the duration of irrigation time. The developed fuzzy logic design showed small error rate, it was integrated with internet of things in greenhouses [3]. Smart irrigation system was developed using light intensity sensors, LM 393 soil moisture sensor, temperature and humidity sensor. For designing of the fuzzy controller for water pump triangular and trapezoidal functions were applied. The inputs which were soil moisture data, temperature was divided into three values such as low, medium and high. The water pump flow controller was implemented using trapezoidal function which gave the rate of flow as very low, low, medium and high [4]. There are several studies focusing on prediction of N-P-K nutrients to crops. Image based data analysis combined with machine learning technique was employed to treat corn with fertilizer [5]. A system which includes a mobile gadget that measures pH, and use that information to determine to N,P, K levels was developed which can forecast which crops will be most suitable by using the categorization method to the data gathered from the sensors[6]. A wheat fuzzy expert system was developed that suggested the correct amount of N, P, K fertilizer for the soil. The three inputs variables which are N, P, K were divided into three, four, and two sets, respectively. Triangular shapes were use to represent the input variables, the system presented development of fuzzy logic based N, P, K prediction system that employed microcontroller based embedded fuzzy logic control [7]

V. RESEARCH GAP

Standardization and Consistency: There is lack of standardization frameworks for implementing fuzzy logic in soil health monitoring and irrigation systems. This inconsistency can lead to varying results and make it challenging to compare findings.

Data quality and availability: The effectiveness of any system relies on quality of data. Many existing soil health monitoring systems have limited data points. This can lead to inaccurate or incomplete information for decision making.

Real time monitoring and automation: Due to challenges in automation, sensor accuracy and reliable communication networks that are challenges in system that can autonomously adjust irrigation schedules based on real time data.

User interface and accessibility: User interfaces can be complex and may require specialized manpower to operate. This can create hindrance in adoption by the farmers.

Generation of approximate results: The existing systems outcome for soil health monitoring are not precise they give results in the range of certain values, further in the irrigation scheduling mechanism facility of either switching ON or OFF of the pump is available or the intermediate steps between ON and OFF are less.

Parameters such as soil electrical conductivity not taken into consideration. As soil electrical conductivity has effect on the measurement of the soil moisture values. By not taking it into account efficient system cannot be designed.

VI. HYPOTHESIS BASED ON ANALYSIS OF GAPS

The application of fuzzy logic for the soil health monitoring and irrigation management will lead to increase in agricultural productivity as compared to traditional methods. Smart irrigation system will result in decrease in water usage in agricultural sector as compared to conventional irrigation systems as with the help of sensors dynamic adjustment of water delivery can be done. The valve position of the water pump can be controlled according to the results generated by the fuzzy logic controller. This can lead to avoiding over as well as under irrigation. By adoption of smart soil health monitoring system, the environmental impact can be reduced by controlling the excessive use of fertilizers.

User friendly interface will enable the farmers the ease of access to the information. Along with required quantity of fertilizer dose, information regarding which fertilizer is suited can be also given to the farmers which will help them to adopt the system as early as possible.

VII. MAJOR EXPECTED OUTPUTS OF THE PROJECT

1) Efficient water usage: Reduction in water use through precision irrigation, by using sensors and controlling valves to optimize the water supplied to the crops.
2) Reduced environmental impact: Lower chemical runoff due to better soil nutrient management, reducing contamination of water and soil degradation.
3) Better data driven decision making: Generation of valuable data on soil health, water use enables handling of complex data sets and produce appropriate action.
4) Scalable and customizable solutions: System can be adapted to different type of crops, soil types and varied climatic conditions.
5) User friendly interfaces and automation: Development of interfaces for farmers to interact and automation of irrigation processes to reduce human intervention and allowing remote monitoring.

VIII. IMPLEMENTATION OF THE SYSTEM

1) *For Soil Nutrient Monitoring:*

NPK sensor which works on the principle of the light absorption principle are to be used. NPK sensor module consists of LED and LDR module. The incident light from the LED is absorbed by the soil in different proportions and wavelength according to the percentage of the NPK present in the soil. LDR converts the light into current, which is fed into the signal conditioning unit for converting into voltage for further processing by the microcontroller. As there are three quantities N, P, K the quantity in which they are available in the soil can be quantified as low, medium, high, very high. The set of conditions generated in this regard are 3^4 which is 81. Fuzzy logic conversion takes place in the microcontroller and corresponding result are generated indicating summary about the health of the soil. The system can be further integrated with the database of the available fertilizers in the market which are best suitable to the soil result obtained. The entire system has to be made IoT enabled, so that results can be viewed on the IoT platform, and subsequently alert message can be sent to the user. By this proper soil health monitoring can be done and information regarding best suitable fertilizer can be provided to the end user.

For irrigation scheduling

Soil moisture sensor, soil temperature sensor, soil humidity sensor, electrical conductivity sensor are used in this regard. As the variables available in this context are 4 and values corresponding to it are also 4 which are low, medium, high, very high. Thus set of conditions in this regard are 4^4 which are 256. On application of fuzzy logic different kind of outputs can be generated. For example: For simplicity consider only two values such as low and high and corresponding output are very dry, dry, normal, wet, very wet.

Table for fuzzy logic implementation for irrigation management

moisture	temperature	humidity	EC	Output
low	low	low	low	dry
low	low	low	high	dry
low	low	high	low	dry
low	low	high	high	dry
low	high	low	Low	very dry
low	high	low	High	very dry
low	high	high	Low	very dry
low	high	high	high	very dry
high	low	low	Low	normal
high	low	low	high	normal
high	low	high	low	normal
high	low	high	high	wet
high	high	low	low	wet
high	high	low	high	wet

high	high	high	low	very wet
high	high	high	high	very wet

According to the output generated the position of the valve of the pump can be controlled and rotated. Instead of opening and closing the valve of the pump completely, it can be done partially. Following is the table for rotation of the valve according to the output generated.

Table for rotation position of the valve

Output generated	Rotation of the valve
Very dry	$+60^0$
Dry	$+30^0$
Normal	0^0
Wet	-30^0
Very wet	-60^0

2) Integration of the Two System:
For obtaining accurate data for irrigation scheduling, number of sensors are to be used creating a WSN i.e. wireless sensor nodes. The senor nodes are to connected with low power and low cost controller. Data will be sent to main controller consisting of fuzzifier and defuzzifier block. Programming of the control valve and operating of the actuator is to be carried out. For soil nutrient management, data from sensors and low cost and low power controller is sent to main controller wirelessly. Creation of database of the available fertilizers with the amount of NPK content is to be created.
Testing of the system in the field:
On integration of the system actual testing is to be carried out in the ICAR-IIWM farm and in the farmers field. According to the field trials modification in the system is to be carried out. Creation of user-friendly interface helps in providing insights to farmers regarding which type of fertilizer is suitable for their type of soil.
For ensuring that system consumes low power, integration of rain sensor with the system is required. So that any occurrence of rain is noted and the sensors can be pushed into power saving mode for that day. If there is precipitation beyond certain range there will be no need to irrigate the land.
The flowchart of the proposed system is given below:

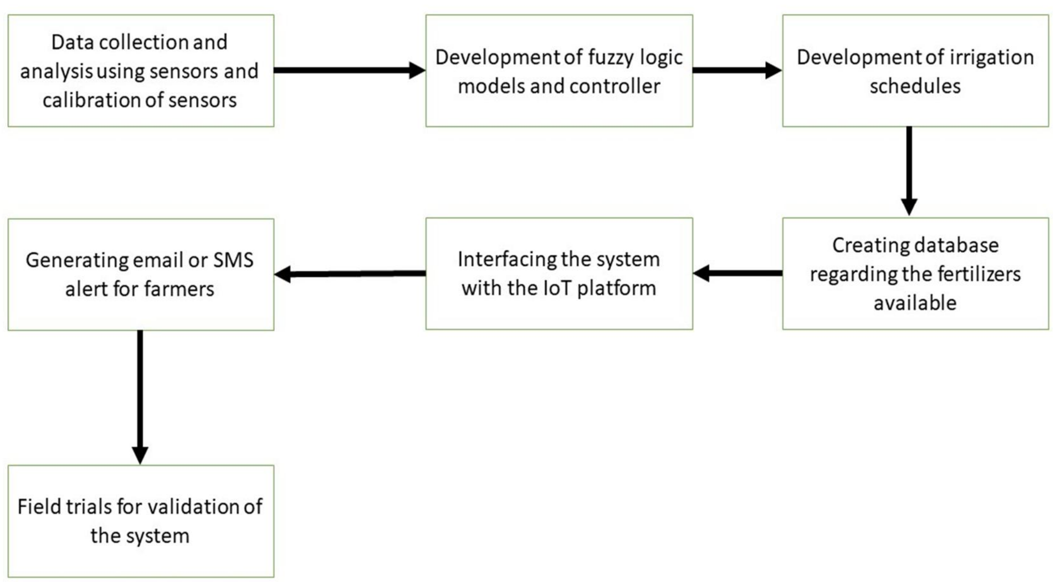

Fig.1. The Flowchart of the activities to be carried out

The block diagram of the proposed system is given below.

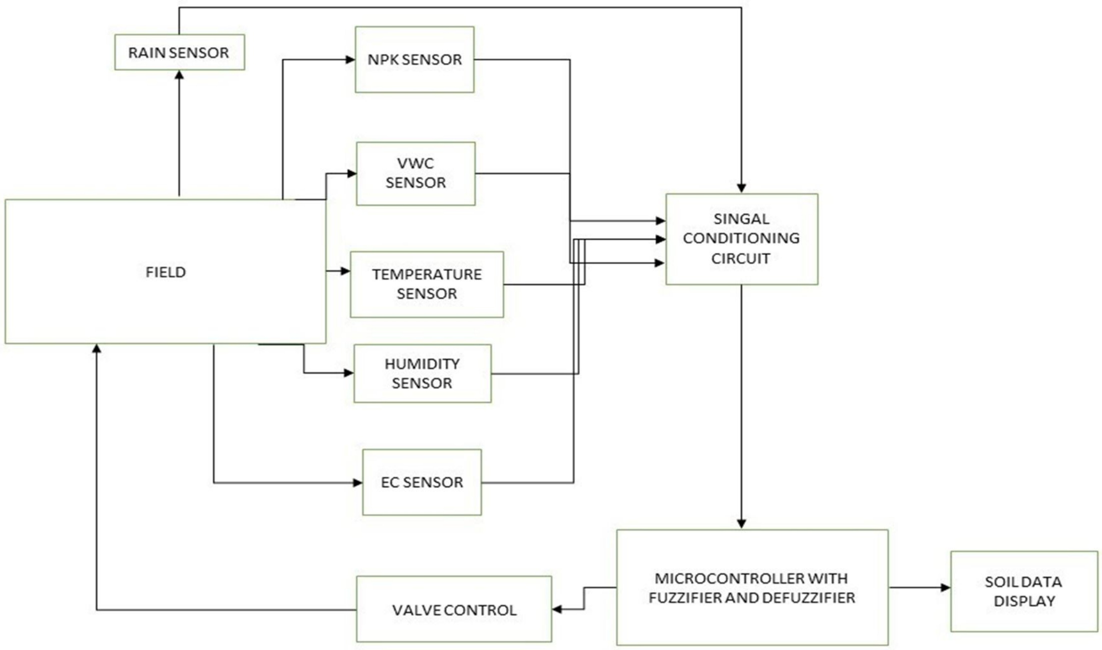

Fig.2. Block diagram of the proposed system

IX. CONCLUSION

The integration of fuzzy logic into soil health monitoring and irrigation scheduling presents remarkable advancement in the field of precision agriculture. The proposed approach can address the inherent complexities involved with traditional methods. The flexible nature of fuzzy logic helps in carrying out comprehensive study for enhancing agricultural productivity and sustainability. The system will capable of handling the imprecise and uncertain data turning it into more accurate assessment for measuring soil parameters and more precise irrigation scheduling. Continued research and development in this area can further refine the technology and expand its capabilities and accessibility for farmers.

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