Automated crop independent furrow irrigation system

N.V. Bhusnar [1*], P.S. Varade[2], P.R. Yawale[3], P.K. Bhadane,[4] A.D. Shaligram,[5]**

[1,2,4] Dept. of Electronic Science, Modern College Shivajinagar Pune, 05, India
[3] Dept. of Electronic Science, B.G. College Sangvi, Pune, 27, India
[5] Dept. of Electronic Science, Savitribai Phule Pune University, 07, India

Abstract

Excessive irrigation causes adverse effects on the physical, chemical, and biological properties of soil, resulting in a decrease in the fertility of soil. Therefore, appropriate selection of irrigation method is very important. Among these, furrow irrigation is found to be the best suitable alternative because of its high efficiency and low water consumption. The present work deals with design, development and simulation studies of a low-cost, fully automated, crop-independent, IoT-based furrow irrigation system. The system is designed by placing an array of wireless sensor nodes to investigate an adequate quantity of furrow flow rate and optimize it as per the requirements using a cloud computing platform. The designed system is advantageous in terms of saving water, benefiting crops and subsiding soil degradation. The moisture sensors were deployed in the crop field with the help of a signal conditioning circuit interfaced with a microcontroller integrated Wi-Fi module (ESP8266-NodeMCU). The said module was also connected to a solenoid valve to regulate the inflow rate and the ThingSpeak cloud computing platform. The WinSRFR 5.1.1 simulation tool was used to estimate the adequate amount of flow rate suitable for the crop and soil type. The cloud platform was used to acquire, store, and process data so as to forecast the ideal soil moisture levels for future control, crop development, and soil health. The studies were carried out at a depth of 100 mm and by varying furrow length (50 to 150 m) in steps of 50m for four different soil types, namely coarse sand soil, sandy loam soil, silt loam soil, and black cotton ploughed soil, which are commonly observed in India. Details are presented.

Keywords: Furrow Irrigation, Automation, Internet of Thing (IoT), ThingSpeak, WinSRFR

1. Introduction

Long-term excessive irrigation affects the physical, chemical, and biological properties of soil, leading to soil degradation. Excess irrigation water causes problems like deep percolation, chemical leaching, soil erosion, salinization runoff, etc. For better crop health, an efficient irrigation system considering the soil profile, availability, and storage of water is necessary. In recent years, surface irrigation methods have attracted the attention of all farmers rather than the conventional flat irrigation method. in surface irrigation methods. Of these, border irrigation, check basin irrigation, and furrow irrigation are the most common. Because of its high efficiency, less water contact (1/5th of the total land surface), reduction in evaporation losses, and prevention of soil erosion and salinization, furrow irrigation is found to be better for various crops. In furrow irrigation, the length of the furrow and stream size decide the infiltration and percolation of soil, seepage runoff [1,2]. Short irrigation intervals are a salient feature of furrow irrigation in which a small quantity of water (wet treatments) is dispersed at regular intervals of time instead of one-time large water circulation (dry treatments) [3,4]. In furrow irrigation system applications, efficiency plays an important role as it decides the root zone and is a function of input flow rate and furrow length. A high flow rate makes for minimum deep percolation and reduces loss of water below the root zone and increases application efficiency [5,6]. The higher furrow length does not significantly affect yield, but flow rate significantly affects yield and distribution efficiency. In furrow irrigation, the WinSRFR 4.3.1 simulation tool can be used to optimise furrow length and inflow rate [7,8]. Furrow irrigation uses various sensors and electronic communication systems to provide an adequate amount of irrigation based on soil conditions [9, 10]. In this a moisture sensor can be used to check the moisture level in soil, if it is low, then a microcontroller-based system is used to switch water pump ON so as to provide water to the plant. Further, the water pump will be automatically turned OFF when desired amount of moisture is present in the soil [11,12,13,14,15].

In the present work, we make a value addition to the existing system, such that the microcontroller is used to transmit the data to the ThingSpeak cloud through the IEEE 802.11 (Wi-Fi) interface for further analysis and processing. The ThingSpeak cloud web service based application programming interface (API) is developed for monitoring, processing, and taking decisions to control the inflow rate of the furrow irrigation system by actuating the solenoid valve as per the requirement. If the moisture level is observed to be more than 35%, the solenoid valve will be turned OFF, resulting in stopping water irrigation. The cloud platform is used to continuously monitor and record the moisture level in soil and necessary action is taken as per the algorithm. The data obtained is not only displayed by graphs on the API screen but also used for further processing. Another important objective of the present work is to determine the adequate amount of water to get proper soil moisture for a specified crop in root zone best suited for furrow irrigation. In order to achieve this objective, we have used WinSRFR 5.1.1 simulation software, to optimize the inlet flow rate for each furrow. Post simulation, the obtained inlet flow rates were fed to the microcontroller through a cloud platform-based API.

In a nutshell, the proposed system is designed, developed and simulated to assist farmers with adequate flow rates (litres/sec) in furrow irrigation suitable for various crops and soil types as every crop has a specific root zone depth for a particular type of soil. We have designed, developed, and simulated a low-cost, fully automated, crop-independent, IoT-based furrow irrigation system to save water, benefit the crop, and prevent soil degradation. Details are presented.

2. Materials and Methods

In this system, the WinSRFR 5.1.1 software tool was used to estimate the adequate amount of flow rate in litres per sec. Figure 1. shows the flowchart of the proposed smart furrow irrigation system. In this, we have crop type, soil type, and depth towards the input side, whereas we have estimated flow rate (liter/s) and calibrated control signalling for microcontroller on the output side. Towards the beginning, the farmer has to enter details about the crop type, soil type, specific depth into the system. Depending on the above inputs, the software will simulate an adequate amount of flow rate (in litres/sec). If the soil is ideal for the crop, then the flow rate for minimal water loss and the flow rate for optimal water loss will be estimated by the software. The estimated adequate flow rate will then be fed to the microcontroller via the ThingSpeak cloud-based platform. The flow rate was maintained by controlling the water solenoid valve, which is connected to the output side of the microcontroller via an optocoupler interface. The duty cycle is varied to maintain the desired flow rate. A flow metre is used to measure the flow of water in a field. The moisture sensor is used to measure the present soil condition, whether it is dry or wet, and sends data to the microcontroller (MCU) to take necessary action. The simulations were performed at 100 mm soil depth, with varying the furrow lengths from

50 to 150 m in steps of 50 m in four types of soils, namely coarse sand soil, sandy loam soil, silt loam soil, and black cotton ploughed soil, which are observed in India.

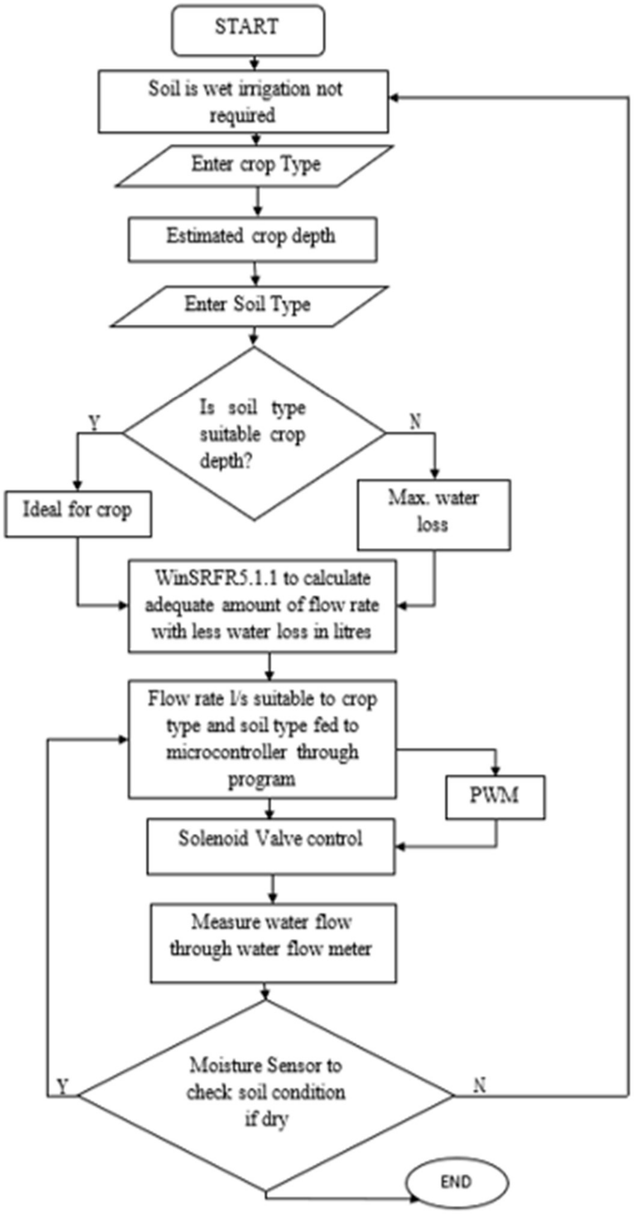

Figure 1: The flowchart represents the step-by-step flow of the proposed smart furrow irrigation system.

The hardware of the system is mainly composed of an array of wireless sensor nodes, comprising of moisture sensors, microcontroller integrated Wi-Fi module (ESP8266-NodeMCU), integrated power supplies, opto-isolators, solenoid valves, flowmeters, and a Wi-Fi router to service the internet, as shown in Figure 2. Initially, the moisture sensor is used to sense the moisture level in the soil. The output of the moisture sensor is then connected to NodeMCU with the help of a suitable signal conditioning circuit. The NodeMCU is synchronously connected to the ThingSpeak cloud platform to exchange the data as well as to receive controlling signals for the actuation of solenoid valve as per the desired flow rate. The flow meter was deployed at the output of the solenoid valve to monitor the output flow rate.

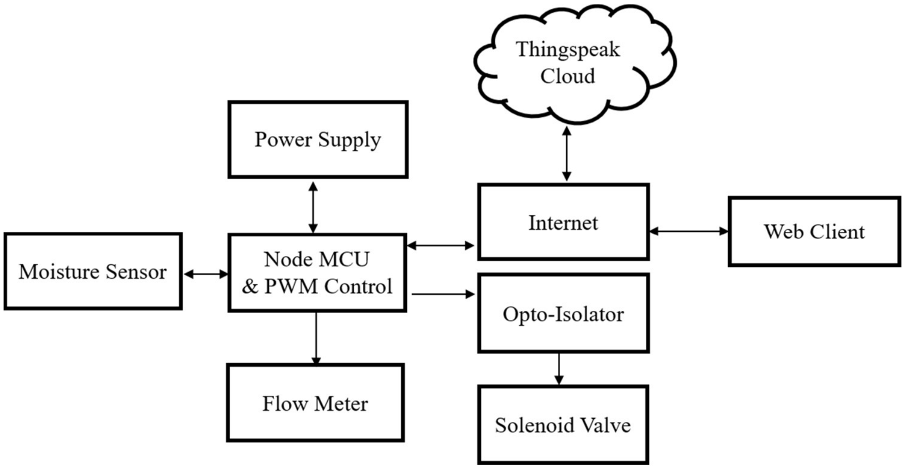

Figure 2: Scheme to represent an ESP8266-based wireless sensor node

Multiple such nodes were deployed in the farm field to monitor and control the flow rate, as shown in Figure 3. In such fashion, the flow rates were maintained as per results obtained from WinSRFR 5.1.1 software for the specified crop and soil type. Live data is monitored, plotted in graphs, and processed using the cloud-based ThingSpeak platform. The obtained data was further analysed and used iteratively for the betterment of the system.

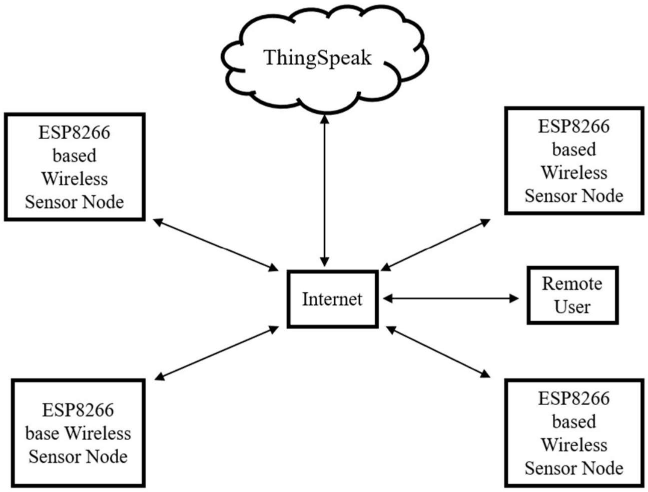

Figure 3: A typical structural block diagram of an IoT-based furrow irrigation system.

In order to establish secure communication between the ESP8266 NodeMCU and the ThingSpeak cloud platform, one needs to create an account on the ThingSpeak website. After the creation of an account, we need to create a channel with private or public access. Here we have selected private access. Following this, we obtain a unique channel ID along with two API keys; one writes an API key and the other reads an API key. The write API key is used by the MCU to write the data onto the channel, whereas the read API key is used to read from the channel. Figure 4 shows the flowchart explaining the step-by-step process that was followed to obtain sensor data on the ThingSpeak Cloud platform post the availability of the internet at the sensor node. Once the communication is established with the help of read and write API keys, the information is exchanged.

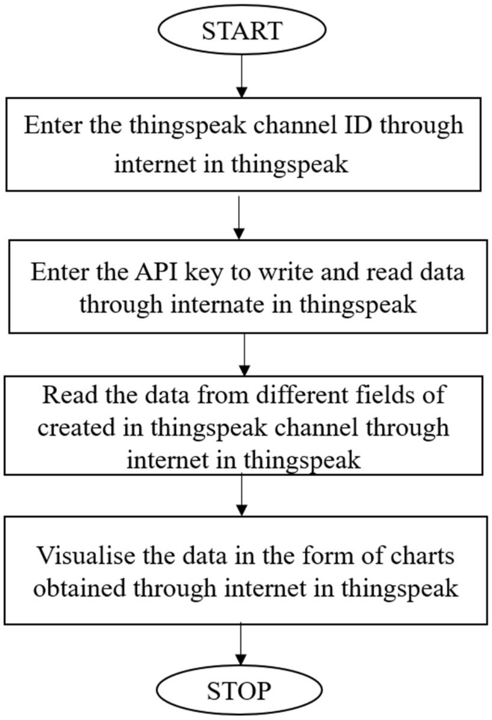

Figure 4: The flowchart depicts the steps taken to obtain sensor data in the ThingSpeak Cloud platform.

3. Results and Discussion

As discussed earlier, the studies were performed for four different soils, black cotton ploughed soil, silt loam, sandy loam, and coarse sand soil. Table 1. shows the soil types with an infiltration rate in mm per hour.

Sr. No.	Soil type	Infiltration rate (in mm/hr)
1	Black cotton ploughed soil	16
2	Silt Loam	10-20
3	Sandy Loam	20-30
4	Coarse sand soil	Over 30

Table 1. Infiltration rate in mm per hour for four different soil types.

Different crops have varying root zone depths, but the soil infiltration rate in mm per hour is different for the same crop root zone. Celery, onion, potato, radish, and wheat are the different crops with shallow root depths of up to 300 mm, and broccoli, beans, cabbage, carrot, cauliflower, cucumber, and peaper are the crops with medium root depths ranging from 300-600 mm. The simulation studies showed that soil moisture varies with effective root zone depth. Approximately 40% of the soil moisture is used in the first 25 % of the root zone depth as shown in Figure 4.

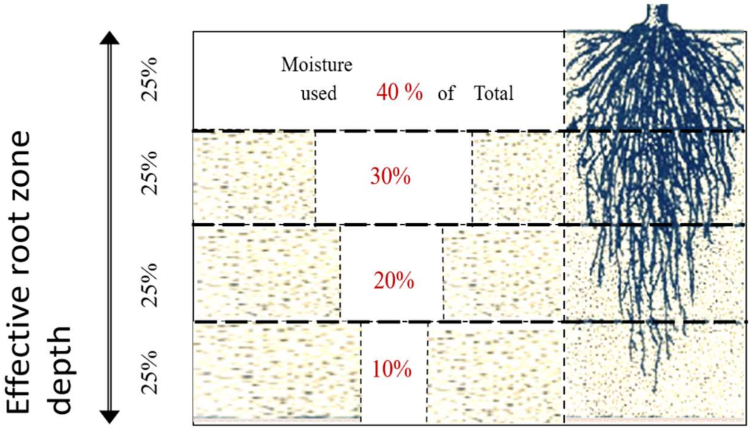

Figure 4: Moisture use in relation to the root zone and available moisture

The infiltration effect on four different soils was studied by the WinSRFR 5.1.1 software tool. For this, furrows considered system geometries with dimensions having a bottom width of 200 mm, a depth of 300 mm, and a top width of 800 mm for 0.5 hectare, 1 hectare, and 1.5 hectare fixed for four different soil types. An irrigation water depth of 100 mm was fixed for all simulations, and the time base cut-off method was used.

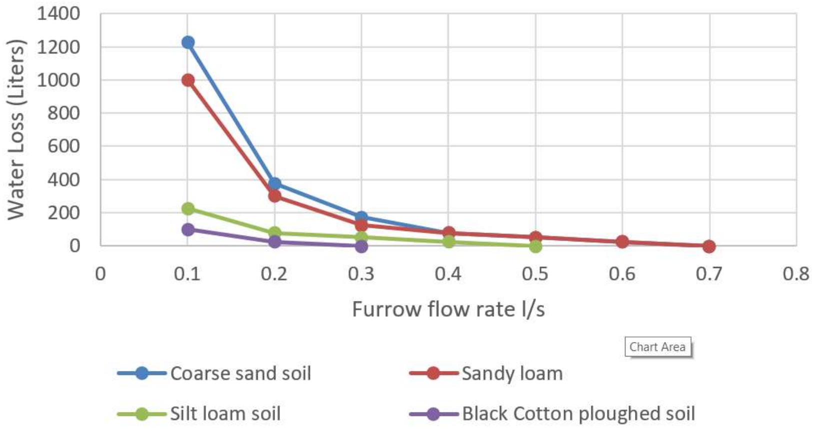

Figure 5: Furrow flow rate in (litre/sec) vs water loss (in litres) for furrow length 50m

To obtain an optimum flow rate in litres/sec with minimum water loss for 0.5 hectare, keep the furrow length at 50m and the width at 100m with a spacing of 1m between each furrow. Water loss was studied for different flow rates at a soil depth of 100 mm. For coarse sand soil, 0.1 litres per second for each furrow occurred, resulting in a maximum of 1,200 litres of water loss. When the flow rate was increased, water loss was reduced and for 0.7 litres/sec for each furrow, water loss occurred, with a minimum of 0 litres. For sandy loam soil, 0.1 litres per second for each furrow resulted in a maximum of 1000 litres of water loss, and when the flow rate was increased, water loss decreased to a minimum of 0 litres at 0.7 litres per second for each furrow. For silt loam soil, 0.1 litres per second for each furrow occurred, a maximum of 225 litres of water loss. However, as the flow rate increased, water loss reduced to 0.5 litres per second for each furrow, a minimum of 0 litres. Similarly, for black cotton ploughed soil, 0.1 litre/sec for each furrow caused a maximum of 100 litres of water loss; however, as the flow rate increased, water losses reduced and at 0.3 litre/sec for each furrow, a minimum of 0 litres.

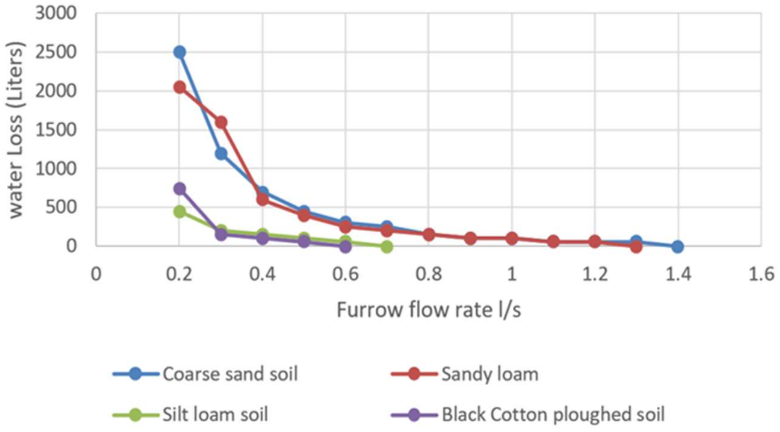

Figure 6: For a furrow length of 100m, the flow rate in litres per second is compared to the water loss in litres.

In order to achieve an ideal flow rate of litre/sec with the least amount of water loss over a length of 100 m, having a width of 100 m, and with a spacing of 1 m between each furrow, the experiment was expanded to 1 hectare. At a soil depth of 100 mm, water loss was investigated for a range of flow rates. For soil made of coarse sand, there was a maximum water loss of 2500 litres at a rate of 0.2 litre per second for each furrow. Although water loss decreased as the flow rate increases, a minimum of zero litres per furrow occurred at 1.4 litres/ per second. In the same way, for black cotton ploughed soil, 0.2 litre/sec for each furrow resulted in a maximum of 750 litres of water loss and when the flow rate was increased, water loss reduced to a minimum of 0.6 litre/sec for each furrow.

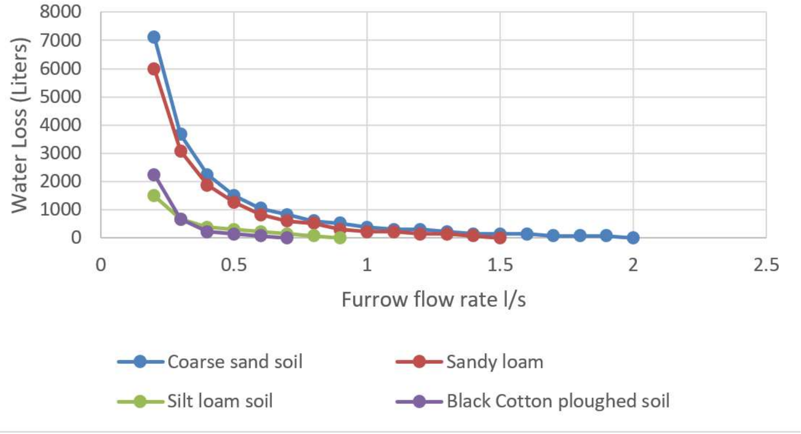

Figure 7: For a furrow length of 150m, the flow rate in litres per second is compared to the water loss in litres.

In this way, the experiment was extended to 1.5 hectare to obtain an optimum flow rate of litre/sec with minimum water loss for a length of 150 m, having a width of 100 m, with a spacing of 1 m between each furrow. Water loss was studied for different flow rates at a soil depth of 100 mm. For coarse sand soil, 0.2 litre/sec per furrow resulted in a maximum of 7125 litres of water loss; however, as the flow rate increased, water loss decreased, and 2 litre/sec per furrow resulted in a minimum of 0 litres. For sandy loam soil, 0.2 litre/sec for each furrow occurred, resulting in a maximum of 6000 litres of water loss.

However, as the flow rate increased, water loss reduced and at 1.5 litre/sec for each furrow, water loss occurred, with a minimum of 0 litres. For silt loam soil, 0.2 litre/sec for each furrow occurred, a maximum of 1500 litres of water loss. However, as the flow rate increased, water loss reduced and at 0.9 litre/sec for each furrow, a minimum of 0 litres was observed. Similarly, for black cotton ploughed soil, 0.2 litre/sec for each furrow resulted in a maximum of 2250 litres of water loss; however, as the flow rate increased, water loss reduced and at 0.7 litre/sec for each furrow, water loss occurred to a minimum of 0 litres. The above simulation results show the effectiveness of the proposed low-cost, fully automated, crop independent, IoT based furrow irrigation system.

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