A Sensor Network for Monitoring Soil Moisture and Temperature of Wheat Crops under Permanent Raised bed in Vertisols

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Abstract: *The newly emerged sensor network (SN) technology has spread rapidly into various multidisciplinary fields. Agriculture and farming is one of the fields which have recently diverted their attention to SN, seeking this cost effective technology to improve its production and enhance agriculture yield standard. The real time information from the fields will provide a solid base for farmers to adjust strategies at any time. This paper reports on the application of SN technology to improve wheat crop production in bed farming. By monitoring and understanding individual crop and its requirements, farmers can potentially identify the various fertilizers, irrigation and other requirements. To address this problem, a sensor network has been installed with a localization method of deploying sensor in the CIAE farm on a permanent raised bed planting to measure soil temperature, soil moisture, ambient temperature and humidity to help analyze the effect of these parameters on the growth of wheat plants. Using sensor network agricultural parameters like soil moisture, soil temperature, soil-water tension etc. are monitor for irrigation management system for better crop yield and increase the application efficiency of irrigation.*

Keywords: *Sensor Network, Agriculture, wheat field, raised bed planting.*

1. INTRODUCTION

In bed planting systems, wheat or other crops are planted on the raised beds in ridge- furrow system. This system is often considered more appropriate for growing high value crops that are more sensitive to temporary water logging stress. Farmers often raise crops such as cotton, maize-soybean and wheat on the raised beds. Recent work shows that system of raised bed planting of crops may be particularly advantageous in areas where groundwater levels are falling and herbicide-resistant weeds are becoming a problem. This tillage and crop establishment option also facilitates crop diversification and intercropping of wheat, chickpea and Indian-mustard with sugarcane, maize with potato, mint with wheat, rice with soybean, and pigeon pea with sorghum or green gram. Although bed planted wheat in rotation with soybeans covered more than 75% area under wheat by 1994 in Mexico. Change over from growing crops in flat to ridge-furrow system of planting crops on raised bed alters the crop geometry and land configuration, offers more effective control over irrigation and drainage as well as their impacts on transport and transformations of nutrients, and rainwater management during the monsoon season. In furrow irrigated raised bed (FIRB) system, water moves horizontally from the furrows into the beds (subbing) and is pulled upwards in the bed towards the soil surface by capillarity, evaporation and transpiration, and downwards largely by gravity. For developing a permanent system of bed planting, factors like irrigation and fertilizer management, crop residue management, inter-tillage and weed management must be considered together.

The newly emerged sensor network (SN) technology has spread rapidly into various multidisciplinary fields. Agriculture and farming is one of the industries which have recently diverted their attention to SN, seeking this cost effective technology to improve its production and enhance agriculture yield standard [1-6]. The real time information from the fields will provide a solid base for farmers to adjust strategies at any time. This paper reports on the application of SN technology to improve wheat crop production in bed farming. It also describes the design, development and implementation of an automated sensor network of soil moisture sensors and temperature sensor using a network technology for monitoring bed planting. By monitoring and understanding individual crop and its requirements, farmers can potentially identify the various fertilizers, irrigation and other requirements.

2. MATERIALS AND METHODS

2.1 Physical environment of the study area

The study was conducted during the *rabi* season of 2011-12 and 2012-13 at the Central Institute of Agricultural Engineering, Bhopal, India. The site was situated at 77^0 24' 10'' E, 23^0 18' 35'' N and at elevation of 495 m above mean sea level. The topography of the study area was mainly plane moderately well drained and falls under the Vindhya platue. The weather of the study area is sub-tropical. During the growing season of wheat, the mean 15 days average weather data were collected from the CIAE weather station. Soil samples were collected from 0 – 15, 15 – 30, and 30 –45 cm depth of the experimental plots randomly to determine soil moisture, bulk density and field capacity by oven dry method. The mean monthly maximum temperature is highest during May (40.7°C) and the mean monthly minimum temperature is lowest in January (10.4°C). The soil of study site is a noncalcareous Vertisol (Isohyperthermic Typic Haplustert) with sandy clay loam texture. The data on the other major property of soil are shown below:

Table 1: *Soil characteristics of experimental site:*

S. No.	Characteristic	Unit	Results		
1.	Cal. Carbonate	%	2.83		
2.	CEC	meq/100 gm	49		
3.	pH		7.94		
4.	EC	dS/m	<0.2		
5.	bulk density	g/cc	1.38-1.45		
6.	Soil porosity	%	62		
7.	Organic Carbon	%	0.62		
8.	Available K	kg/ha	24		
9.	Available P	kg/ha	459		
10.	Nitrogen	kg/ha	124		
11.	Particle size distribution		Sand	Silt	Clay
		%	16	30	54
12.	Texture		Clay (vertisols)		

2.2 Experimental Set-up

A field experiment was carried out for permanent raised bed cultivation of soybean-wheat cropping systems in vertisols during 2011-14. The experiment was laid out in split plot design with two planting systems (raised bed and flatbed) with three replications. In case of soybean vermi-compost was used as treatment in place of split dose of fertilizer application. Sowing of soybean was done during Kharif season and wheat during Rabi season. A wireless soil moisture sensor network (WSN) was developed and installed into the permanent raised bed to monitor the soil moisture and soil temperature

Network Transmission mechanism

The selection of the transmission mechanism is hardly conditioned by the characteristics of the environment where a sensor network is developed. In our case, the most of the region is open field. Consequently, the use of radio frequency based links becomes unavoidable. Among different available technologies and frequency bands (GSM, Bluetooth, Wi- Fi, ...), we chose the GSM links which give the network a better ubiquity. Figure 1 shows the organization of the wireless sensor network (WSN) experiment.

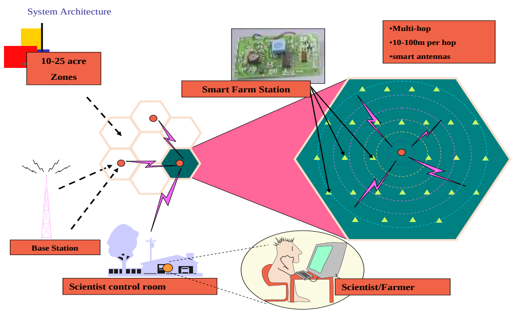

Fig 1: *Outline of a WSN system architecture deployment in a farm field*

After choosing the communication system, deciding network topology and fixing the position of the nodes, the hardware and software of each one and the development of the communication protocol is now explained. Each node is equipped with necessary electronics in or-der to provide soil moisture measurements, store the acquired data and control the communication with other sensors.

Installing the SN

A soil moisture sensor network (SN) was installed into the permanent raised bed irrigated field, with nodes placed into each of three management classes. The nodes (Crossbow Technology) with wireless mesh technology have a maximum communication range of up to 1 km in line of site, and are capable of acting as sleeping routers to conserve power. Sensors attached at each node were: (1) MP406 moisture sensors installed at 5 cm and 15 cm to monitor volumetric soil moisture content (v/v), (2) a temperature sensor

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installed at 10cm and 15 cm soil depth to monitor soil temperature, and a rain gauge was also attached to one node to monitor irrigation and rainfall events. Data is relayed to a base station every fifteen minutes, processed in real-time, converted to the necessary format and immediately made available through a 3G cellular modem via Internet to a web page, available for simultaneous remote access by end users. A total of 30 sensors boards similar to Mica2 motes (see Fig- 2), are installed in a parcel for monitoring the wheat crop in permanent bed. The nodes are manually localized so that a map of the parcel can be created. The nodes are equipped with sensors for registering the temperature, soil moisture and relative humidity. To maintain sufficient network connectivity, 5 sensors-less nodes act as communication relays. To further improve communication, the nodes are installed at a height of 20cm while the sensors are installed in the field at a depth of 5, 15 cm. The humidity of the soil is a major factor in the development of the micro climate. A number of sensors that measure soil humidity are thus also deployed in the field. The node records the temperature and relative humidity every minute. For energy-efficiency considerations, the nodes are reporting data only once per ten minutes. To further save energy, the data sent over the wireless links is minimized by using delta encoding. The nodes use TinyOS as operating system. Data is thus sent using the multihop routing protocol. In addition, the nodes are reprogrammable over the air using Deluge. The data collected by the nodes is gathered at the edge of the field by a so-called field gateway and further transferred via WiFi to a simple PC for data logging, in Fig- 1.

The final node implementation is depicted in Fig- 2. The RF module as well as the electronics board and the batteries are installed into a watertight box. The solar cell is placed onto the box enclosure. The box is then attached to a 3 meters mast, also holding the antenna, and close to it. The particular arrangement and final installation configuration hardly depends on the ground conditions.

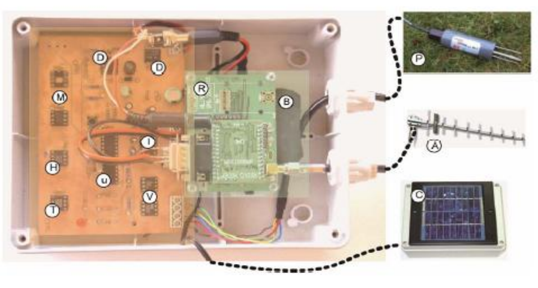

Fig 2: *Detailed sensor implementation*

The Software Communication Protocol

For a proper function of the network, all nodes must be synchronized in order to correctly correlate the measurements as well as to optimize the communication protocol by reducing unnecessary waiting times. In the network, each node will be identified by a unique software address. These nodes should operate in a standby (low power consumption) mode when neither measurement nor transmission activity is required. The whole network will be regulated by a PC, directly connected to the central node. This particular node will initialize the network, synchronize it, and store the data collected from all the nodes. Additionally, an error detection/correction protocol is also considered in this communication system.

In this sense, a Medium Access Control (MAC) based protocol [7], adapted to hierarchic networks has been developed. The transmitted ASCII messages are arranged in a particular format, containing the fields: origin and target address, type of command, data length, message identifier and error checking.

Commands fall in one of the following categories:

(1) Transmission acknowledgement (ACK/NACK);

(2) Shutdown activation/deactivation;

(3) Measurement start;

(4) Data asking;

(5) Data sending;

(6) Synchronization;

(7) Reset.

Initially, the network is in a standby state. A personal computer directly connected to the central node, initializes the network. Then, synchronization and start measurement commands are sequentially sent to the network. These commands travel hierarchically through the net-work until reaching all the nodes. Sometime after, and in the same way, the computer sends commands asking for data. Then, the stored data from the performed measurements travel back from the end nodes to the central one. All the data are then organized by the PC, allowing the subsequent analysis.

3. RESULTS AND DISCUSSION

The diagram of the overall system is shown in **Fig- 1**. As explained before, all collected data are centralized by a PC, connected to Internet. This way, the soil moisture data access can be done by different devices through internet and the data server. After successfully writing and testing of the process/ algorithm we have developed a WS network with a soil moisture sensor (MP406), an air temperature sensor grouped together in a data logger in wheat crop shown on permanent bed condition in the field (Fig-4). These sensors are connected to radios which are programmed by developed process/ algorithm to send data back at designated intervals to a radio base station (Scientist room) to receive signals from the outlying radio field stations. The network is designed in such a way that any future expansion of new sensors will be accommodated. The cable leads of all four sensors were connected to an SMD4-P smart interface (ICT International), which in turn was connected to the data logger at the field edge. The soil temperature (Model TM4) was also monitored and was used to correct the SMP calibrations. The data logger was powered by a solar panel and the controller was powered by 24 V AC. It not only stores all the information coming in, but controls how often the readings are made and transmit data to desktop computer through telemetry system. Data logger is connected to a modem which downloads the information using the mobile phone network (AirTel) onto a ftp server. Specialist software, some of which has been developed for data downloading through telemetry, archives and manipulates the data and presents it for prediction for irrigation. A solar panel for power monitor has been installed to give continuous power source to data logger and modem. A range of water, soil and temperature parameters were successfully monitored using sensors linked to the developed telemetry network Fig. 3.

Fig 3: *Developed telemetry based WS network system with data logger*

The soil moisture sensor was calibrated by comparing measured field soil moisture and recorded soil moisture through sensor. Soil moisture data collected through telemetry system has been calibrated with reference to oven method. The calibration curves for average values of measured soil moisture through telemetry and soil moisture data through oven method is shown in Figure 4. The results from measurement of absolute volumetric soil water percent (VSW%) from field soil samples using telemetry based SN with respect to oven method has been found that collected soil moisture data are as per oven method for a vertisol (Figure 4). The variation of temperature in wheat crops on permanent bed (a) above ground, (L) at 10 cm inside soil (K) at 15 cm inside soil were successfully recorded using network for full rabi season of wheat crops (Fig. 5.). The variation of soil moisture in full season of wheat crops on permanent bed and flatbed were also recorded using network (Fig. 6). In the fig 6. It can be found that whenever recommended irrigation were given to the crops a sharp increase of soil moisture was recorded using network. This indicates that network system is working properly in the design. The soil parameter after harvesting the wheat crops is also recorded and given in table 2.

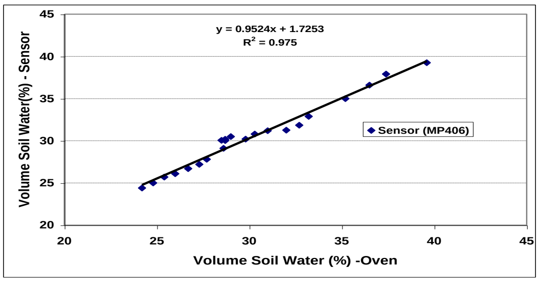

Fig 4: *Calibration of MP406 measurement of VSW% using soil samples as a standard*

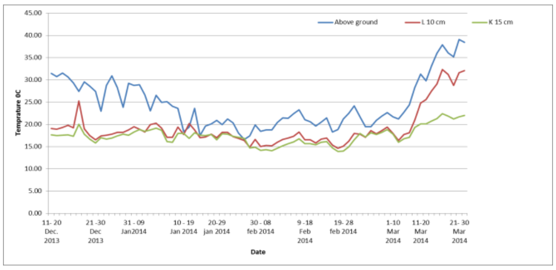

Fig 5: *The variation of temperature in wheat crops on permanent bed (a) above ground, (L) at 10 cm inside soil (K) at 15 cm inside soil recorded using network*

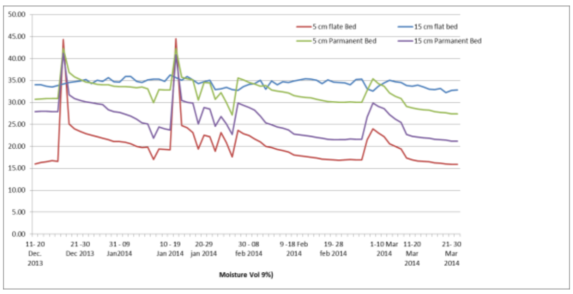

Fig 6: *The variation of soil moisture in wheat crops on permanent bed and flatbed recorded using network*

4. CONCLUSIONS

In the present study, we have successfully designed and implemented a sensor network for temperature and soil moisture monitoring using GSM links in permanent raised bed wheat. By sampling each defined unit, a low density of sensors has been achieved. This fact has used to prove the possibility of using a wireless automated system and that it is a better water management system that leads to water savings when irrigating plants. The suggested wireless automated soil moisture and temperature monitoring system appears to perform well in maintaining the normal growth of wheat plants while saving in the amount of water.

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