A BJT Based Soil Moisture Sensor for Irrigation Monitoring

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A soil moisture sensor is an integral aspect of the various precise irrigation techniques. This paper focuses on a BJT based soil moisture sensor which can be implemented in a large array spreading throughout an irrigated field. Soil conductivity depends on the moisture content around the probes. This is particularly useful for monitoring moisture levels around roots of crops planted in an organized manner. The network architecture allows real time monitoring. A microcontroller is used to scan the array of sensors for output values by operating a switch IC, to calculate the moisture percentage value corresponding to the voltage output of each sensor, to display the percentage moisture value or to operate the valves in drip irrigation or sprinkler systems. The whole architecture is easy to implement and cost-effective. The paper also shows the results of the experiments conducted using this sensor to highlight the effect of the potash and urea fertilizers on the soil properties.

Keywords: Soil Moisture Sensor, Network Architecture, Potash Fertilizer, Urea Fertilizer, Water Retention, Water Absorption.

1. INTRODUCTION

Various studies have shown that rain fed agriculture, as practiced in many parts of India, is less productive than the irrigation based agriculture. The highest yields obtained from irrigation are more than double the highest yields from rain fed agriculture. Moreover the irrigation techniques also needs to take into account efficient use of the precious water resources[1], and best practices especially for using ground water. Micro-irrigation technologies have the ability to use water more efficiently in irrigated agriculture. These technologies can improve productivity with increased crop yields[2]. Some of these technologies include drip irrigation and sprinkler systems. In a drip irrigation system, measured quantity of water is applied slowly but directly to the plant roots where it is needed, rather than sprayed everywhere. It can among other things, reduce disease problems associated with high levels of moisture on some plants. Sprinkler system on the other hand, is a method of applying irrigation water in a manner similar to rainfall. Water is distributed through a system of pipes usually by pumping which is then sprayed into the air and it breaks up into small water drops which fall to the ground.

As irrigation requirements are crop specific, a soil moisture sensor is required, to know the percentage moisture level at various points across the irrigated land. Moreover the sensor should be able to work in array architecture (network) which allows scanning of the array to obtain voltage values from each sensor. A microcontroller can be used for this purpose. The microcontroller can also be used to display any specific sensor output onto LCD Screen or to operate various valves of the drip or sprinkler systems according to the moisture values across specific regions of the irrigated field.

The sensor utilizes the concept of variable resistance (across sensor probes) offered by the soil when different amount of moisture is present in it. The BJT based sensor gives a voltage output corresponding to the conductivity of the soil between the sensor probes. The sensor and the network architecture are easy to implement and cost effective, and enhance the functionality of the drip or sprinkler systems.

The results of the experiments conducted using the sensor also show that the two inorganic fertilizers under study (urea and potash) absorb some amount of soil moisture. The fertilizers, in addition showed some moisture retention property.

2. THE SENSOR DESIGN AND FUNCTIONING

The sensor is constructed using a transistor 2N2222 a 10Kohm variable resistance pot, 100 ohm resistor and two soil probes as shown in Fig. 1. The soil probes consist of two thin copper wires each of 5cm length which can be immersed into the soil under test. The circuit gives a voltage output corresponding to the conductivity of the soil. The soil between the probes acts as a variable resistance whose value depends upon the moisture content in the soil.

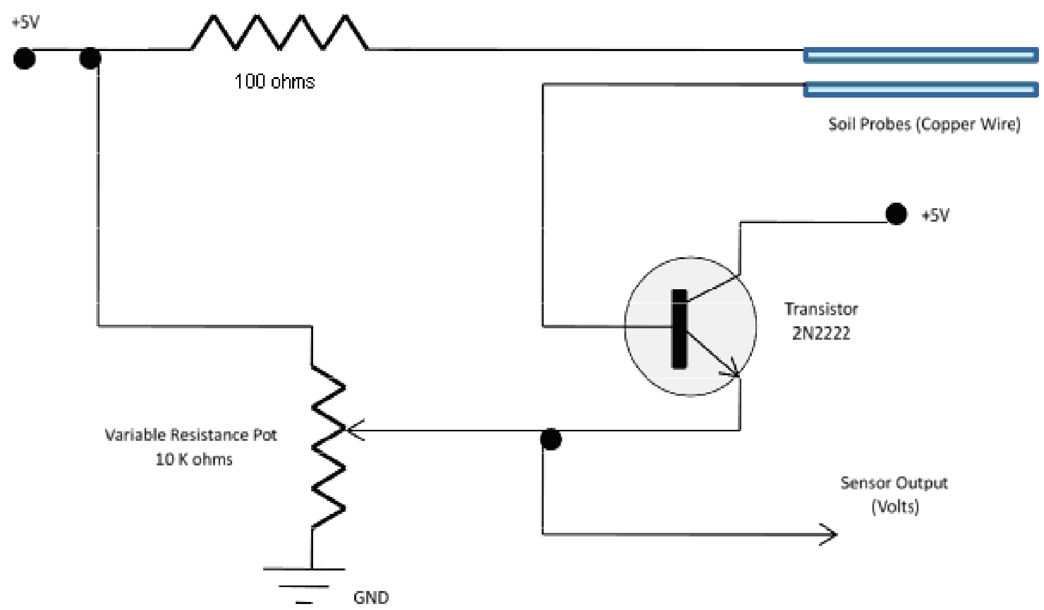

Fig. 1: The Soil Moisture Sensor Circuit

The transistor shown above is in common emitter configuration. The transistor is being used as a common emitter amplifier. To keep the transistor in the active region, the base-emitter junction is forward-biased and the collector-base junction is reverse-biased (the active region of the common-emitter configuration can be employed for voltage or current amplification). By using 100 ohm resistance and the variable resistance the base-emitter junction is brought to forward-bias condition. The resistance across the soil probes can vary from infinity (for completely dry soil) to a very little resistance (for 100% moisture in soil). This variation in the resistance across the probes (R_S) leads to variation in the forward-bias voltage which leads to corresponding variation in the input base current (I_b). For common emitter configuration,

$$I_c = \beta \,.\, I_b,$$

and $$I_e = (\beta+1)\, I_b;$$ where β = current amplification factor.

Hence a small variation in the base current leads to a large variation in emitter current[3] and hence in emitter voltage, which is taken as the voltage output of the sensor. The variable resistance pot can be used to vary the sensitivity of the sensor.

3. IMPLEMENTATION IN AN ARRAY

The sensors can be implemented in an M×N array[4] without requiring any amplifier. This is the primary requirement in the irrigated fields or greenhouse farms where the crops are implemented in a certain pattern. The array of sensors can obtain voltage values corresponding to the moisture around roots of each of the planted crop. The array of sensors needs to be given power supply and the output of each sensor, need to be taken from their respective positions in the field to the Analog to Digital Converter (ADC).

As a solution to these requirements, the four sensors can be implemented in an M×N rectangular array as shown in Fig. 2(a). Only four sensors were built, but this architecture is feasible for very large arrays, as is the case in greenhouse farms. Switches S_1, S_2, S_2 and S_b in the above network can be used to select individual sensor out of the four sensors. Switches S_1 and S_2, supply 5V to the sensors falling in two rows. Turning switch S_1 'ON' will power Sensors 1 and 2. Similarly turning switch S_2 'ON' will power Sensors 3 and 4.

Now the output of Sensors 1 and 3 are connected together to switch S_a and the output of Sensors 2 and 4 are connected together to switch S_b. S_a and S_b are connected to a single common output line which goes to the ADC of microcontroller. For an array of M×N, if any sensor (M, N) has to be selected, then using the horizontal and the vertical switches, the output from the desired sensor can be obtained.

The switches were implemented using an analog multiplexer/demultiplexer IC 4053 (containing three switches, each providing multiplexing among 2 channels). For 2×2 array, two (out of three) switches of the IC were used, demultiplexer to provide supply voltage to two rows (S_1 and S_2), and second as a multiplexer to obtain a single common output from the network.

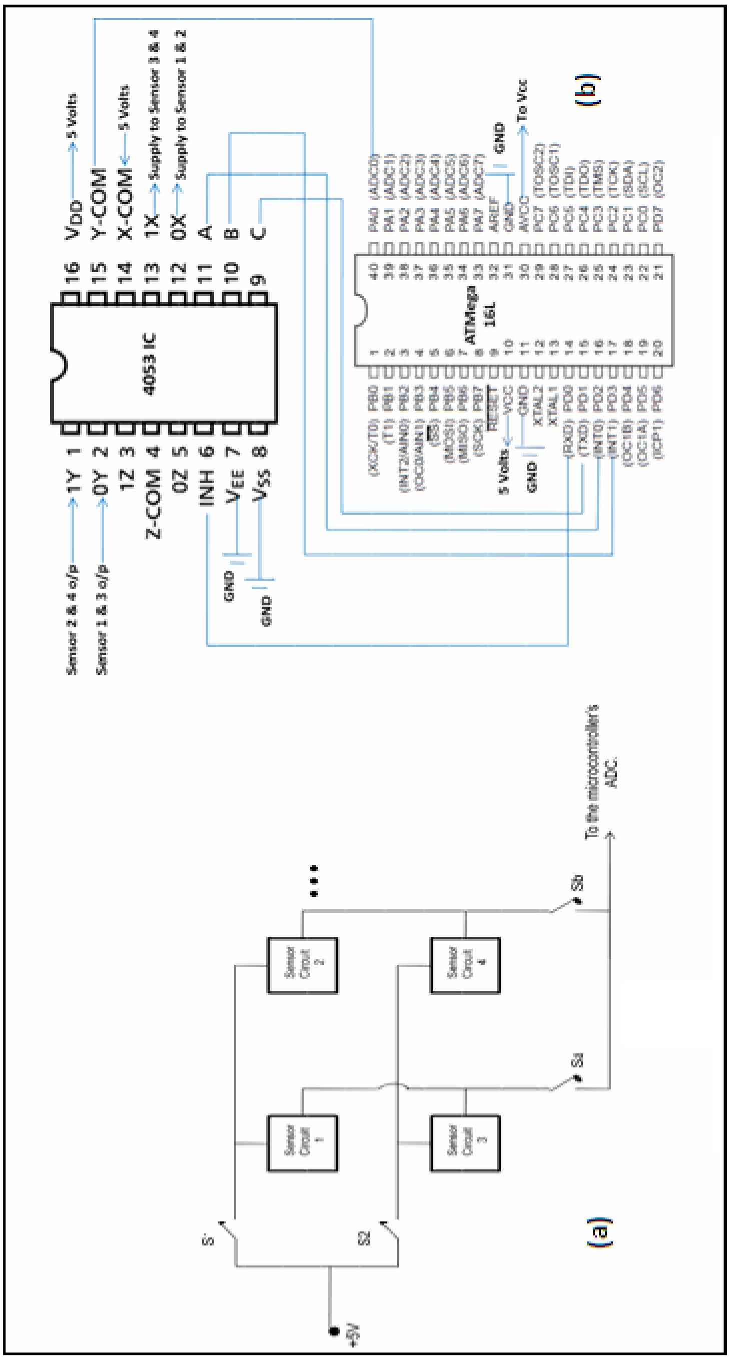

Fig. 2: (a) The Network Archiecture for Sensors and (b) The Circuit Connections

A microcontroller (Atmel AVR ATmega16) was used to give control signals to 4053 IC (Fig. 2(b)), to logically operate the switches, and hence perform a scan of the whole array, obtaining output voltage from each sensor. The microcontroller was also used to calculate the corresponding moisture percentage value of the obtained voltage values from each sensor, and to display them onto an LCD Screen. The inbuilt Analog to Digital Converter (ADC) of the microcontroller was used to convert the voltage at the common output line of the array into its digital equivalent. The calculation of amount of moisture (in percentage) was carried using a standard table containing the voltage values for 1% - 100%. There was a considerable drop in supply voltage due to the 4053 IC; hence the voltage output of sensor while in network was less than that of individual sensor.

4. CALIBRATION OF THE SENSOR

Standard device like Hygrometer is used for measurement of moisture. In our experiments, a relative method was used. We had taken dry soil as 0% moisture (probes in air) while 100% moisture was taken as equivalent to complete immersion of probes in water. After adding unit amount of water at a time, the voltage output reaches voltage corresponding to 100% approximately.

5. OBSERVATIONS

As shown in Fig. 3, the output is roughly linear for 10ml or 16.13% ([10/62]×100) and above. The steep rise in the initial phase shows rapid change in soil resistivity as it absorbs water. A slight variation in output was noticed between identical sensors.

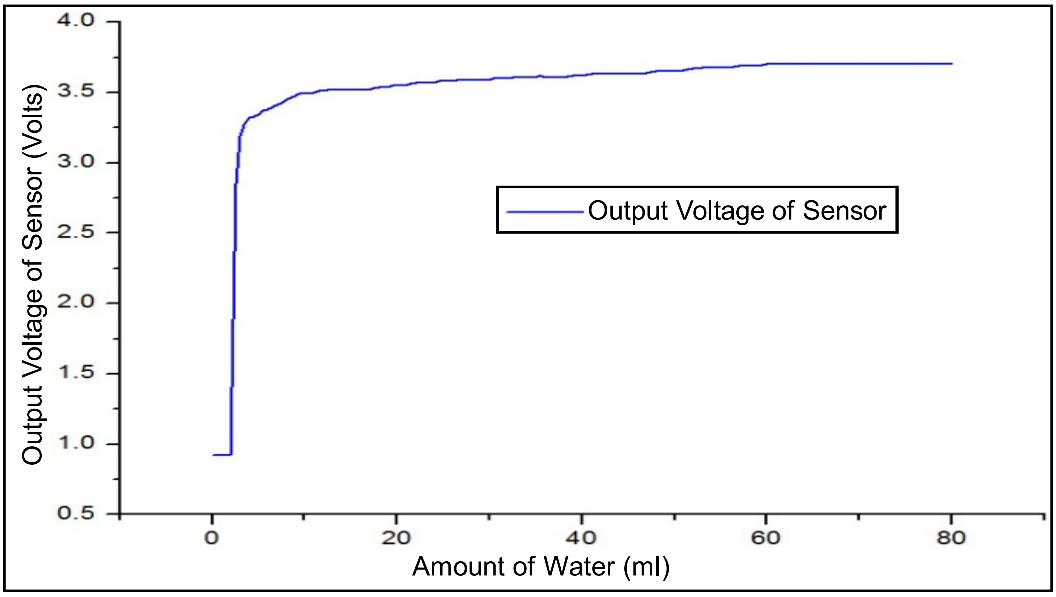

Fig. 3: Variation of Sensor Output with the amount of Water added to Soil

6. EFFECTS OF POTASH AND UREA FERTILIZERS ON SOIL PROPERTIES

Most potash fertilizers are KCl crystals having 52% Potassium (K) and 48% Chloride (Cl). Chemical formula for urea is $CO(NH_2)_2$ having 20% Carbon (C), 6.6% Hydrogen (H), 26.7% Oxygen (O), and 46.7% Nitrogen (N). Urea and potash are highly soluble in water. Water solubility of urea is 1100g/l and that of potassium fertilizer varies between 316g/l to 347g/l[5].

Experiments were conducted using the sensor on garden soil. The soil in the container weighed 142gm. Using a burette, water was added 0.5ml at a time. In second case, 6gm of potash fertilizer was mixed thoroughly with dry soil sample with weight same as in the previous was followed to obtain sensor output values experiment. With the probes inserted into this mixture taken in the container, the same procedure corresponding to the amount of water added into soil. Afterwards, to same amount of soil, 6gm of urea fertilizer was added and mixed thoroughly. The same procedure was repeated.

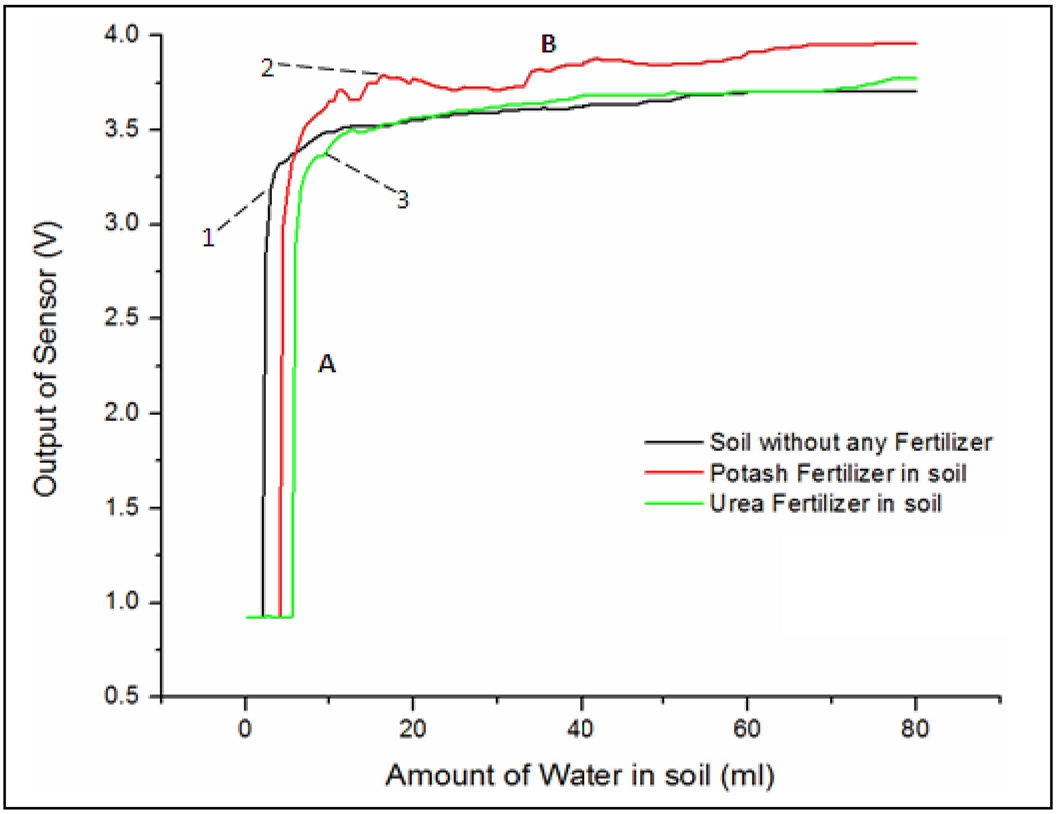

Fig. 4: Sensor Output Variation obtained for Soil without any Fertilizer, Soil with Potash, and Soil with Urea

The results of the three experiments are depicted in the graph shown in Fig. 4. The sensor is giving the voltage values according to the moisture between the sensor probes. Curve 1 shows the sensor voltage output variation when no fertilizer was added to the soil sample. Curve 2 and 3 depicts the sensor output variation when potash and urea fertilizers respectively, were added. Region A clearly shows the 'water absorption property' of the fertilizers. When initially, the soil is completely dry, all the three curves show 0.92V. Then Curve 1 rises suddenly to a high value at water content of 2.5ml or moisture of 4.03% ([2.5/62]×100). Curve 2 rises at water content of 4.5ml or moisture of 7.26% ([4.5/62]×100). Curve 3 rises at 6ml or moisture of 9.68% ([6/62]×100). This immediate rise in the sensor output happens as soon a path of conduction is established between the sensor probes due to the water added to the soil. Clearly this phenomena is delayed in case of potash fertilizer, and there is even more delay in case of urea fertilizer. This indicates that potash fertilizer has a property of absorbing some amount of moisture when added to the soil. Similarly, urea also absorbs moisture more than that of potash fertilizer and hence shows more delay than the potash fertilizer in detecting moisture. Since the fertilizers were initially within completely dry soil, they started absorbing moisture as soon as water was added, and the formation of the conducting path between the soil probes was delayed due to lack of moisture in the soil between the probes. Thus, initially the moisture absorption by fertilizer did not contribute to the soil moisture. Hence the delay occurring between the curves in region 'A', explains the water absorption property of both potash and urea fertilizers with urea absorbing more water than potash fertilizer.

Region 'B' shows the 'water retention property' of the two fertilizers. Curve 2 is lying much above curve 1, but curve 3 is only slightly above curve 1. Though organic fertilizers typically enhance the water retention property of the soil[6], but our experiments show that inorganic fertilizers such as potash and urea also help the soil to retain some amount of water. In case 1, when soil without fertilizer was used, the curve is an indication of amount of water retained by normal soil. When potash fertilizer was added, more moisture was retained between the soil probes, resulting in increased conductivity giving higher voltage values at the sensor output and hence curve 2 is above curve 1. In case of urea fertilizer, water retained was only little more than that in case 1, hence curve 3 is only slightly above curve 1. Hence water retained by potash fertilizer is much higher than that of urea fertilizer.

7. CONCLUSION

The sensor and the network architecture readily fulfill the requirements of the vast irrigated fields, and elps in real time monitoring of the moisture content around the roots of the individual planted crop. The size of the network (array) is not fixed but can extend to large arrays. Each network has only single common output line which goes to a single pin of ADC of the microcontroller. There are only 8 input pins in ADC of 'ATmega16' microcontroller, hence eight such networks can be operated by a single microcontroller. Only constraint which can limit the size of the network is the time taken by the microcontroller to scan the network.

Also, experiments done using this sensor show the water absorption property of the fertilizers also show enhancement of water retention property of the soil. Hence, the fertilizers should not be added to completely dry soil as this could result in absorption of slightest remaining moisture and even sucking up of water from the roots[7], this can even happen when excess of fertilizer is used

Future works will progress toward using a very low 'ON' resistance multiplexer/demultiplexer, programming and using the microcontroller to operate the drip or sprinkler systems by opening or closing valves as per the moisture percentage values obtained from the sensors in any particular region (water requirement being different for different crops, one can fix threshold accordingly).

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