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Simple Parallel Probe as Soil Moisture Sensor for Sandy Land in Tropical-Coastal Areas

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ABSTRACT

One potential land in marginal areas able to be utilized for keeping the sustainability of agriculture in Indonesia is coastal areas. However it requires optimum treatment, especially in using the water for plants efficiently due to the factors of land characteristics and climate. This paper describes the use of simple and low-cost soil moisture probe for sandy land in the coastal area. The probe is a parallel plate which separated at a certain distance. The principle is based on soil electrical conductivity, which delivers the electrical current from one plate to another. Two designs (single and double) and two distances (3 mm and 5 mm) of probes were tested to measure the sandy soil at the moisture content of 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. It was found that the resistance of probes was inversely proportional to water content, but not linear. The best fit of probe resistance (X) to the moisture of sandy soil (Y) was of the 5 mm double parallel probe, with the equation Y = -10.33 ln(X) + 128.13 (R^2 is 0.9199) and non-linearity of 62.88%. The probes and a built soil moisture logger/ controller were applied for sandy soil of

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Shallot cultivation land at coastal area in Empurancak Beach, Jepara (located about 150 m from the foreshore).

Keywords: Coastal area, parallel probe, sandy soil, soil moisture content

INTRODUCTION

In a developing country, like Indonesia, the decrease of agricultural land also occurs as an impact of a large number of land conversion functions becoming industrial or residential areas (Anandita & Patria, 2016). One potential land that can be utilized for agriculture is marginal land in the coastal area. Indonesia is an archipelagic country that has many islands, wide beaches, and coastal areas. Many marginal lands are scattered across islands which most not been explored and managed properly (Hutomo & Moosa, 2005). The development of coastal areas as agricultural land has strategic potency to overcome the decrease of agricultural land and to keep food sustainability as well.

However, the natural conditions of tropical-coastal area, such as the climate (dry and hot), the physical properties of soil (very high percolation and low water holding capacity), and hydrological conditions, require farmers to always monitor and keep the availability of water for plants intensively (Ray et al., 2014). Unfortunately, many farmers often give the water to plants irregularly either the amount or the time. The watering is not based on the availability of water in the soil. Meanwhile, the way to get water is mostly traditional and the watering is very costly.

Therefore, a simple device able to measure the soil moisture content *in-situ* rapidly and reliably is needed which can be applied in automated irrigation for water use efficiency. Irrigation is based on the soil moisture. Efficient irrigation will lead the least amount of water used directly to the plants to replenish the moisture of the root zone before water stress adversely impacts the plant. Automated irrigation systems can help to optimize water use by using soil moisture content and plant-specific information to provide irrigation application amount and timing decisions. Efficient irrigation conserves water and reduces potential leaching of agrichemicals (Ray et al., 2014; Sample et al., 2016).

The moisture of the soil depends upon various factors such as type of soil whether sandy, clay, or loam, and type of salts present in the soil such as iron, manganese, calcium, phosphorus, nitrogen and sulfur. It also depends upon temperature (Sample et al., 2016).

Soil water content can be measured directly or indirectly. Direct measurement is laboratory-based measurement. It is commonly known as the gravimetric method, measuring its weight as a fraction of the total soil weight. However, it is impracticable in the field. Recently there are many indirect methods/measurements that have been developed over the years to determine the soil moisture for automatic irrigation systems. They include tension-measurement, neutron scattering measurement, spectrometric measurement (such as infra-red, near infra-red, and visible spectrometers), galvanic cell, dielectric/electromagnetic measurement (such as Time Domain Reflectometry, Frequency Domain Reflectometry, Time Domain Transmissometry, ADR, and Capacitance), and resistivity measurement (such as gypsum block, four-probe resistance, and ohm-probe electrode) (Bittelli, 2011; Gaikwad et al., 2015; Robinson, 2014; Sample et al., 2016).

Presently most commercial soil water sensors available today infer soil dielectric properties either from measured soil capacitance or impedance. It is based on the soil dielectric permittivity as the basis for determining soil water content. However mostly their techniques are costly and difficult to be adopted by farmers. Among others, resistance-based technique offers a simple, lower cost and reliable solution. Principally it is based on the conductivity properties of water contained in the soil. This paper presents an application of "easy self-made" resistance-based probe to measure the moisture sandy soil in tropical areas. Some constructions of the probe to examine its reliability were tested.

METHODS

Design of Soil Moisture Probe

The design of the soil moisture probe is shown in Figure 1. It is a parallel probe, which is separated at a certain distance by an acrylic block which keeps the probes apart. The probe is made of single-layer PCB coated by solder wire. Solder wire, made of silver-tin alloy, has high conductive properties and strength to being buried in the soil for a long time. It does not get corroded easily in the sandy soil. The length (L) and width (W) of the probe are 10 cm and 1 cm, respectively. The tip of the probe is made into a triangular shape, so that the probe can be easily inserted into the soil. The design is based on the probe construction of Tyagi et al. (2011).

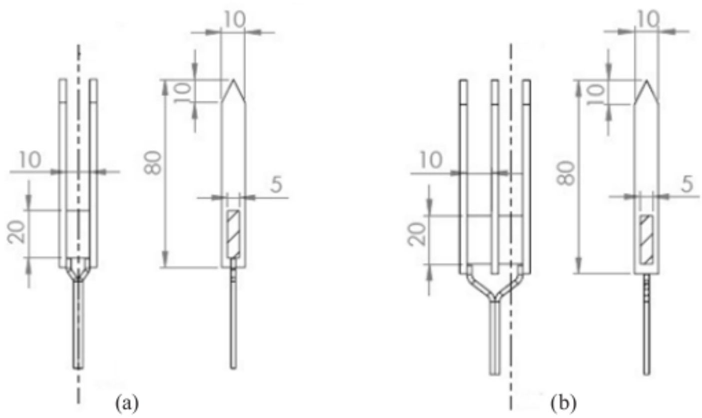

Figure 1. Design of 5 mm soil moisture probes: (a) single parallel and (b) double parallel, scale in mm

Two types of probes (i.e. single parallel and double parallel) with two distances of probes (i.e. 3 mm and 5 mm) were constructed and tested. Basically, double parallel probe is two parallel single probes joined in series. The distance of the probe is separated by 3 mm or 5 mm acrylic. Two cables are mounted as pinouts of the probes to be connected to the circuit of the sensor. A simple DC voltage divider is used as a conditioning circuit, with 56 kΩ fixed resistor to all probes.

The principle of the probe is the determination of soil moisture by measurement of electrical resistance of soil and porous media imbedded in the soil. Hence, a simple circuit of the voltage divider was applied as a conditioning circuit to convert the resistance of probe into direct voltage proportionally. And, an acquisition unit based on Arduino Mega2560 was built to acquire the array of probes which employ RTC-1302 as timer and 3.5 inch LCD 320x480 pixels as display. The data of measurements were logged into SPI-SD Card. The firmware of Arduino Mega2560 was built under Arduino Software (IDE) 1.8.12. Figure 2 shows the schematic of soil moisture measurement.

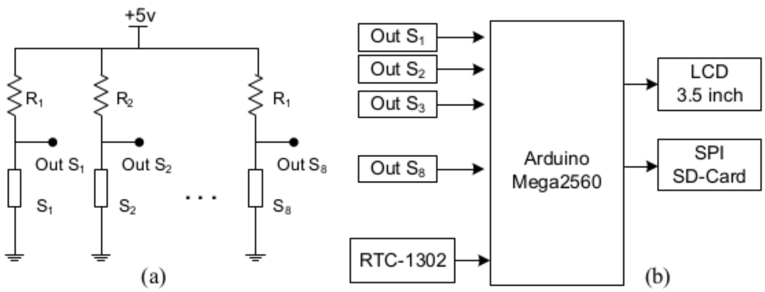

Figure 2. (a) Sensor circuit (where R is fixed 56 kΩ, S is soil moisture probe), and (b) diagram of soil moisture measurement

Sample of Sandy soil and Measurement Steps

Sandy soils were taken from coastal areas in Empurancak Beach, Jepara, Central Java, Indonesia. It is located at 6°29'09.7" S, 110°41'46.6" E. The water content of sandy soil was conditioned into the desired condition. Figure 3 shows the samples of sandy soil in certain water content. The Soil Water Content (SWC) is expressed in a dry-weight base. It is defined with the gravimetric method by measuring its weight as a fraction of the total soil weight as shown in Equation 1, where W_W is the weight of water and W_S is the weight of solid soil.

$$SWC = \frac{W_W}{W_S} x100\% \quad [1]$$

Samples of sandy soils were prepared to represent the soil condition from dried to saturated conditions, namely 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. The sample of sandy soil used was 1 kg for each experiment. The steps to prepare the sample of sandy soil in a certain value of SWC is as follow: firstly dry the soil using a drying oven at a temperature of 105°C and weight the soil repeatedly until the weight of the soil is constant (there is no difference of weight between any two consecutive measurements), which means that there is no water contained in soil (0% SWC). Secondly the weight of water added was calculated into the soil to get the desired value of SWC and finally adding water until evenly mixed.

After preparing the soil in particular SWC, the measurement of the probe to the SWC was done by means of the Arduino Mega2560 based-soil moisture acquisition device. The probes were placed inside the sandy soil horizontally. The sampling of resistance acquisition was set every two seconds in one minute. The measured resistance of probe was stored in a micro SD-card according to the date of measurement.

The tested treatments of the probe were the types of probe (i.e. single parallel and double parallel) and the distances of probes (i.e. 3 mm and 5 mm). Thus there were four kinds of probes tested. Each probe was made as many as eight units and the resistance of probe measured simultaneously using the built soil moisture acquisition device. Each measurement was repeated five times. Regression analysis was used as the statistical method to interpret the correlation between the resistance of probe and soil moisture. The flowchart of testing process is shown if Figure 4.

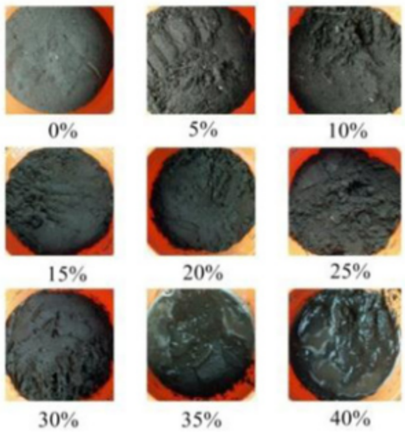

Figure 3. Samples of sandy soil in various water moistures

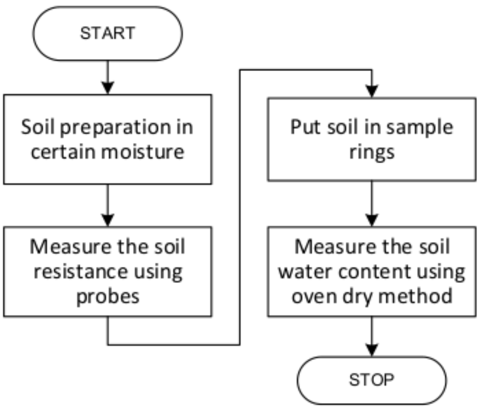

Figure 4. Testing process of the probes to moisture of sandy soil

RESULTS AND DISCUSSION

The Single and Double Parallel Probes

The shape and dimension of single and double parallel probes are shown in Figure 5. They are simple and hand-made probes. Basically, double parallel probe is two parallel single probes joined in series. The probe transfers the electron from one probe to another and soil acts as the barrier of electron flow regarding to SWC of sandy soil. The value of probe resistivity is then obtained by acquiring the changes in voltage. It is an indirect method that measures another variable that is affected by the amount of soil water, and then it relates its changes to the SWC changes, through physically-based or empirical relationships called calibration curves (Bittelli, 2011).

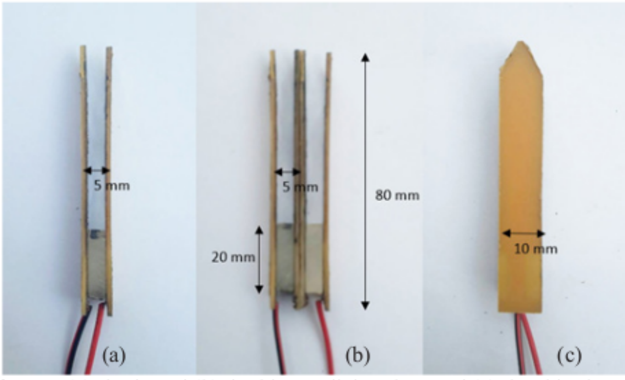

Figure 5. Photo of 5 mm (a) single and (b) double parallel probes, and (c) the side shape of probe

The electrical resistance of soil material is highly sensitive to small variations in water content and forms the basis of the parallel probe technique of measuring the soil moisture. Comparing to the gypsum block technique, the parallel probe gives simplicity and direct measurement to soil material. Gypsum block installation requires coring, taking considerable time and effort (Robinson, 2014). The main disadvantage of the gypsum block is that each block has different characteristics, depending on its shape and composition of materials, thus needing to be calibrated individually. And, the calibration tends to change gradually over time, limiting the accuracy and life of the gypsum block (Robinson, 2014; Zazueta & Xin, 1994).

Figure 6 and Figure 7 show the apparatus and diagram of measurement of sandy soil moisture respectively. The soil moisture probes were applied for Shallot cultivation. The probes were put horizontally 10 cm inside the soil. A 12-volt battery was used as a power supply to provide a constant DC voltage. The battery was recharged by the solar panel system.

Response of Simple Probe Sensor to Water Content

Soil samples from the field used for a sand-specific calibration were done under laboratory conditions, to ensure the reliable measurements. At the beginning, the resistivity of soil was investigated under dry and saturation states. When SWC was at 50%, it seemed that the sandy soil was at saturated condition. It was found that the electrical resistance of

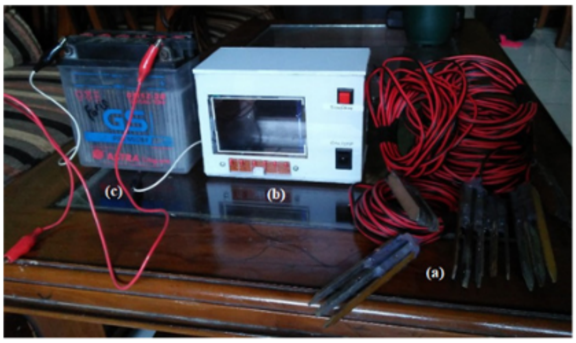

Figure 6. Measurement device of soil moisture, where a=double parallel probes, b = Arduino-based logger/controller, and c=battery as power supply

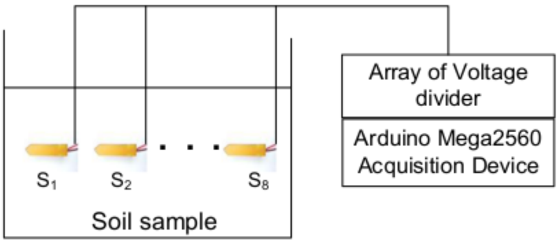

Figure 7. Measurement diagram of soil moisture

probe in a dry state (0% of SWC) and very low water content (less than 2% of SWC) was not available. The voltage output was 5 volts, the same with source voltage. It indicates there is no conduction of electron (electric current) through the soil. Electrical conduction in clean sandy soil occurs primarily in a liquid contained in the pores of soil (Jackson, 1975). Solid of the soil is usually insulators, when on the state of water contained in micro voids, it seems to be surface conduction of electrical current (Robain et al., 2003). While in state of saturation the voltage output is zero. It means no resistivity of soil, like the probe measures only the water. Therefore, the conditions of the dry state and saturated state are excluded from the correlation analysis. The steady-state time of the initial warm-up of the probe was also observed after the first installment inside the sandy soil. The responses showed that the initial response got steady at two minutes. Thus, the resistance of probe was acquired after a steady condition of probe in two minutes.

Figure 7 and Figure 8 show the responses of 3 mm and 5 mm probes to the SWC of sandy soil respectively. Generally, the responses showed a decrease in resistance in each increase in water content. That is a natural conductivity behavior of material in wet conditions. Water is conductive material to electrical current. The conduction of water contained in solid soil lies in the volume conduction phenomenon which is controlled by the electrolyte concentration in water and the geometrical structure of macro voids (Robain et al., 2003).

Figure 8 and Figure 9 reveal that the resistances of all probes are inversely proportional and nonlinear to the soil moisture. Overall the trends were similar. The experimental results obtained through laboratory tests on sandy soil samples for electrical resistance values corresponding to different moisture of sandy soil under 5V DC supply on voltage divider circuit showed that water content and electrical resistivity had a strong correlation and electrical resistivity of sandy soil was found to be decreasing with the increase of water content.

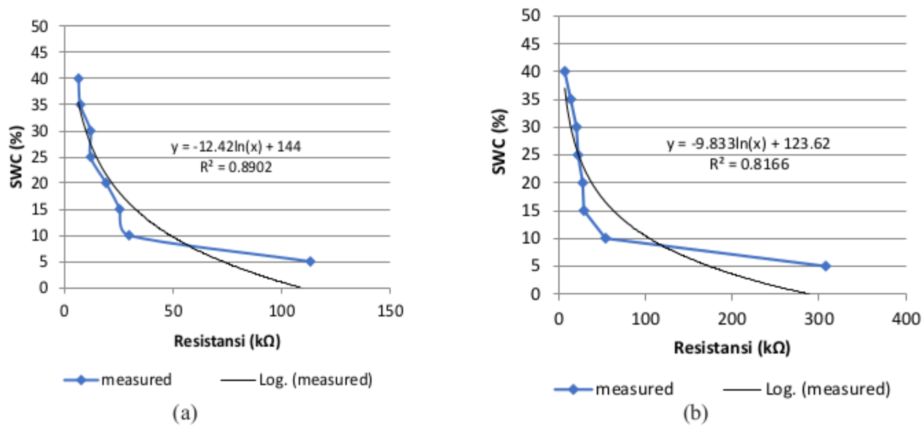

Figure 8. Response of 3 mm parallel probe to 5% to 40% of SWC, incremental in 5: (a) single probe and (b) double probe

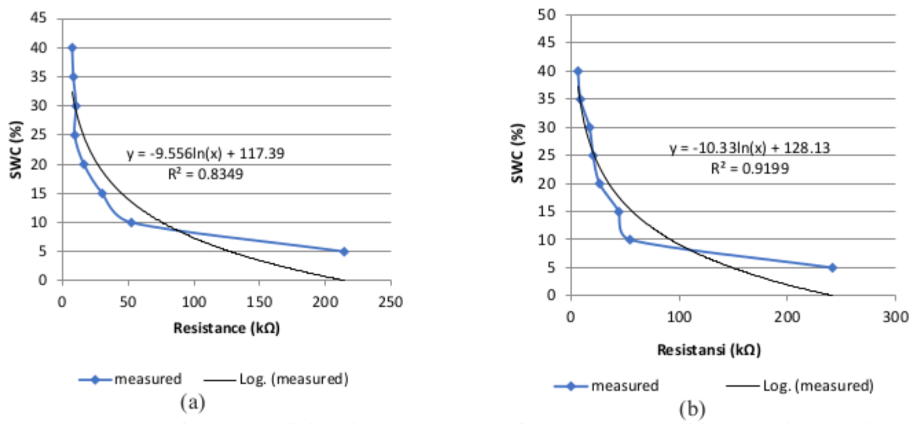

Figure 9. Response of 5 mm parallel probe to 5% to 40% of SWC, incremental in 5: (a) single probe and (b) double probe

The results of the regression analysis show that the logarithmic regression equation provides a high correlation between resistances of the probe to soil moisture content as can be seen in Table 1. This calibration outcome is closely in agreement with the result of those who applied the electrical resistivity principle to determine soil moisture level (Bhatt & Jain, 2014; Ozcep et al, 2010; Tyagi et al., 2011). Moreover, it also seems that a 5 mm probe has a better correlation than a 3 mm probe. The fittest equation is a 5 mm double parallel probe, with 62.88% of non-linearity (Figure 10).

Table 1
The equation and correlation analysis of probes to change of SWC weight base model

Probe Type	Model	R^2
3 mm Single parallel probe	y = -12.42ln(x) + 144	0.8902
3 mm Double parallel probe	y = -9.83ln(x) + 123.62	0.8166
5 mm Single parallel probe	y = -9.56ln(x) + 117.39	0.8349
5 mm Double parallel probe	y = -10.33ln(x) + 128.13	0.9199

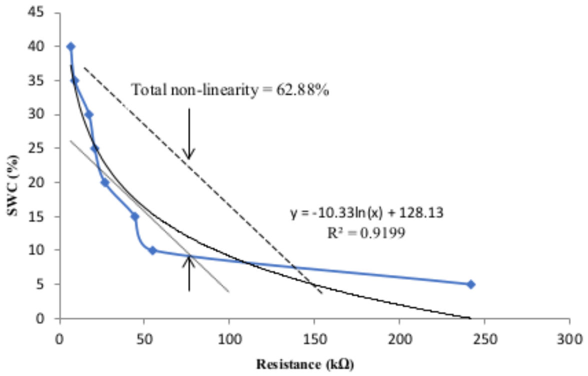

Figure 10. Non-linearity degree of 5 mm double parallel probe

CONCLUSION

A simple soil moisture sensor in parallel probe form has been successfully made from a pair of single layer PCB coated with solder wire and separated with thick acrylic. Its principle is based on the conductance properties of water contained in the soil. A simple voltage divider with 5 volt DC voltage is employed to drive the probe and a low-cost Arduino Mega2560 board is used as an acquisition device. Two types of probe (single and double) and two distances of probe (3 mm and 5 mm) were tested. The probes were tested for the sandy soil with its moisture at 0% to 40%. The results show-that the resistance of the probe is proportional inversely and nonlinear to the soil moisture. The higher moisture of soil, the lower resistance of probes. The steady conditions of the probes were in two minutes. The best fit of probe resistance (X) to the moisture of sandy soil (Y) is of the 5 mm double parallel probe, with the equation Y = -10.33 ln(X) + 128.13 (R^2 is 0.9199) and non-linearity of 62.88% of full range.

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