Review Article

SOIL MOISTURE SENSORS IN AGRICULTURE AND THE POSSIBLEAPPLICATION OF NANOMATERIALS IN SOIL MOISTURE SENSORS FABRICATION

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ABSTRACT

In this paper, a review of soil moisture sensors and its possible preparation of them from nanomaterials ispresented. Introduction to the soil, the role of nanotechnology in agriculture, the definition of soil moisture, the need for soil moisture detection and methods of itsdetection are discussed. The works of some researchers to detect this soil parameter moisture contentis also discussed. Finally, conclusion, personal recommendations, and future outlooks will be given based on the existing work.

Keywords: *Soil Temperature Sensors, Soil Moisture Sensor, Nanotechnology, Agriculture, Nanomaterials*

1. INTRODUCTION

There are several definitions of soil depending on the discipline providing the definition:[1]
Some of them are geologic definition, traditional definition, component definition and soil taxonomy definition.
The depth of soil profile which is important for plant growth is 100-200cm[2].The maximum length of most crops is 100cm.Some crops root length is 120cm.[1].
The soil is composed of mineral matter, organic matter, air, and water[3]. These components have played a great role in the plant growth and development.
The soil has many classifications. The base of classification also varies from discipline to discipline. For example, the classification of Engineers is completely different from soil taxonomists and others.[4],[5],[6].Commonly soil can be classified based on grain size and soil consistency. There are several soil classification systems. For example Unified soil classification system(USCS)[7], American Association of State Highway and Transportation Officials (AASHTO)[8] classification system and US Department of Agriculture(USDA) [9] classification system.

The soil has many different properties and affects soil moisture distribution. Some of the properties are Soil Texture, soil structure, bulk density, soil color, thermal conductivity [10][11] and electrical conductivity.

Any component of soil that affect plant growth and development shall be tested or detected. Some of them are nutrients, water/moisture, pollutants, ph, thermal conductivity, temperature, electrical conductivity, color, texture, structure, and bulk density.

1.1. THE ROLE OF NANOTECHNOLOGY IN AGRICULTURE

Agriculture is the utilization of biological processes on farms to produce food and other productsuseful and necessary to man [12].

[13]identified and grouped the top 10 application areas of nanotechnology in developing countries. Based on their grouping one area was agriculture enhancement in developing country. They concluded that to minimize and eradicate extremepoverty in developing countries, agriculture production should be supported by nanotechnology. As a result of this, they put agricultural enhancement using nanotechnology in the second rank[14].

Nanotechnology has many applications in all stages of production, processing, storing, packaging and transport of agricultural products[15]–[18]. Nanotechnology will revolutionize agriculture and food industry by novation new techniques such as precision farming techniques and controlled environment agriculture techniques, enhancing the ability of plants to absorb nutrients, more efficient and targeted use of inputs, disease detection, and control diseases, withstand environmental pressures and effective systems for processing, storage, and packaging. The efficiency of medicine increases by use of nanoparticle in animal sciences. Silver and iron nanoparticle are used in the treatment and disinfection of livestock and poultry. Levels of environment pollution can be evaluated quickly by nano smart dust and gas sensors. Soil parameters like moisture, temperature, PH, and nutrients can be detected using nanomaterial-based sensors and then possible corrections may be taken place.

2. SOIL MOISTURE SENSORS

2.1. SOIL MOISTURE

2.1.1. SOIL MOISTURE CONTENT

People defined soil moisture content in two different terms as soil water content and soil water potential.

Soil water content is the amount of water thatcan be evaporated from a soil by heating to between 100 and 110^{o}C, but usually at 105^{o}C, until there is no further weight loss.

Soil water potential describes the energy status of the soil water and is used for water transport analysis, water storage estimates and soil-plant-water relationships. A difference in water potential between two soil locations indicates a tendency for water flow, from high to low potential[19].

In practice, it is usually a change of soil water content with the time that is of interest (e.g., seasonal changes in field soils or change in response to irrigation). Alternatively, the quantity of water retained between specific thresholds may be required (e.g., between the liquid and plastic limits or between ‘‘field capacity’’ and ‘‘wilting point’’)[20].

If moisture goes below the wilting point (wilting point (WP) is defined as the minimal point of soil moisture the plant requires not to wilt) or any lower point plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours[2].

The range of soil moisture content is from 0-100%[2][21].

2.2. THE NEED FOR SOIL MOISTURE CONTENT MEASUREMENT

Volumetric water content is an important part of the soil, influencing the many biological, physical, and chemical processes[22].

For the growing of crop three factors are most important first the soil nutrients and soil properties; second, the properties of the seeds and most important is the soil moisture level[2].

Objectives of soil moisture measurements in agriculture are: Automatic irrigation, Water saving[23], [24], Increase product or yield [2][24], Soil salinity control[25] and Soil erosion control.

2.3. FACTORS AFFECTING SOIL MOISTURE CONTENT

The factors that affect soil moisture content [26]–[29][30] are texture, structure, organic matter, the density of soil, temperature, salt content, depth of soil etc..

2.4. METHODS OF SOIL MOISTURE CONTENT MEASUREMENT

The following diagram shows the general classification of available soil moisture content measurement methods. Each method has their own advantages and disadvantages.

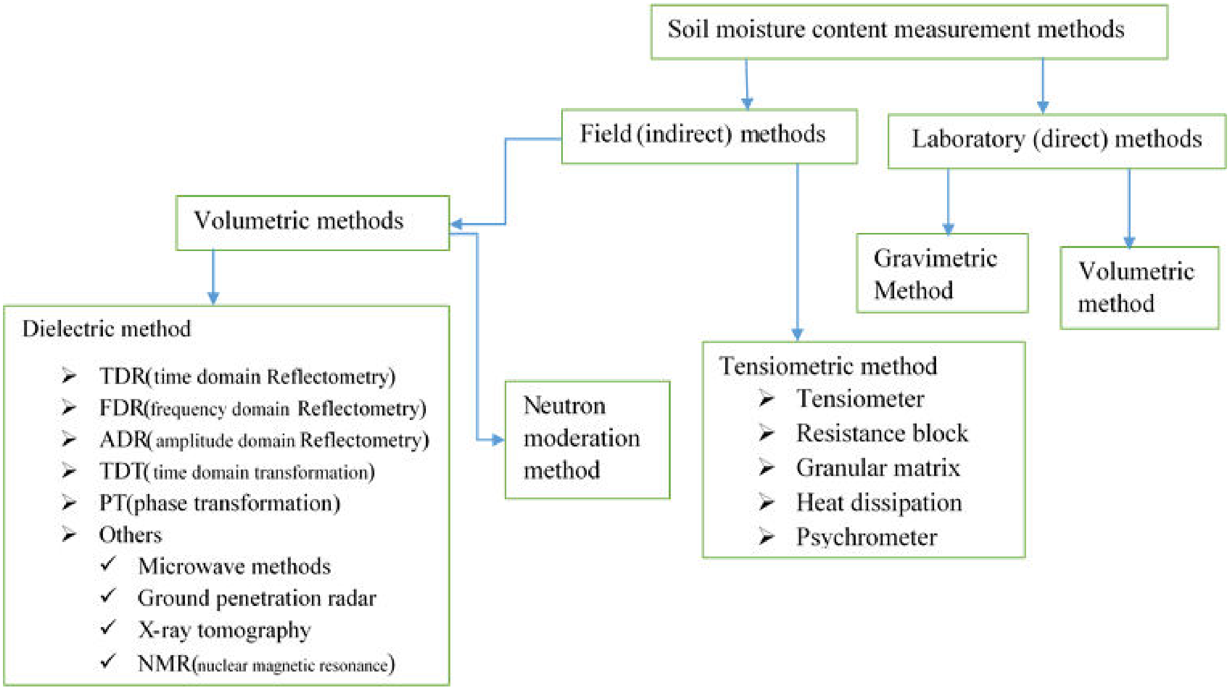

Figure 1: soil moisture content measurement methods[31][32][33]

2.4.1. GRAVIMETRIC MEASUREMENT METHOD

It is a direct laboratory method soil moisture content measurement method based on the mass of the components and defined as shown in equation 1 below [32].People use it as is the basic technique for measuring soil water content. Because this method is based on direct measurements, it is the standard with which all other methods are compared. However, gravimetric sampling is destructive, rendering and also repeat measurements on the same soil sample is impossible.

Gravimetric soil moisture content (θg) = $\frac{massofwater}{massofdrysoilormassofsamplesoil} = \frac{massofsamplesoil - massofdrysoil}{massofdrysoilormassofsamplesoil} = \frac{Mwater}{Msoil}$.. (1)

2.4.2. VOLUMETRIC SOIL MOISTURE CONTENT MEASUREMENT METHOD

Because precipitation, evapotranspiration, andsolute transport variables are commonly expressedin terms of flux, volumetric expressions for watercontent are often more useful(1).

In the laboratory the volumetric soil moisture content can be obtained as follow:

Volumetric soil moisture content (θv)= $\frac{volumeofwatercontent}{volumeofsamplesoil} = \frac{Mwater/\rho water}{Msample/\rho b} = \frac{\theta g * \rho b}{\rho water}$--------- (2)

Where ρb is the dry soil bulk density.

Because of the difficulties of accurately measuring dry soil and water volumes, volumetric water contents are not usually determined directly[20]. Due to this reason, this method is used to estimate soil moisture content indirectly. Because indirect use of volumetric soil moisture content measurement system has the same concept as direct method.

Thermal conductivity based soil moisture estimation may be constructed as either some distance separated heater and temperature sensor without porous block or contact temperature sensor and heater with the porous block.

P. C. Diaset al [34][35]prepared a novel heat dissipation soil moisture sensor with only one bipolar transistor performing as both heating and temperature sensing element. It used porous block. The input power was (VCE*IC) and (VBE α T) was used as temperature measurement or sensor. Low power consumption, small size, the minimum distance between the heater and the temperature sensor, high efficiency, low cost and high efficiency were some of the advantages of the proposed sensor. The proposed sensor presents a sensitivity that was almost 10 times higher than those found in conventional sensors with separated heating and sensing elements. For the applied energy (80 mW during 45 s) the temperature increase in the proposed sensor was about 7.5℃-9.1℃, while the conventional porous block probe presents a temperature increase of only $0.8^{o}C$-1.5℃. The sensor may not be applicable for long period of time and also takes some time until the moisture is equilibrated inside the porous block.

S. DASet al[2]proposed the design of a soil moisture meter using thermalconductivity properties of soil. Here, the heater and the temperature sensors were separated by some distance. They got a change in voltage from the IC temperature sensor output is mostly linear with the moisture content.The output voltage is increased with the increase in soil moisture and temperature. This is due to the fact that when the moisture content is increasing in the soil the void space is filled up and thermal conductivity is increasing accordingly. The system consisted of a hollow pipe made up of polyvinyl chloride (PVC), emitter-base shorted transistor as a heater, the AD590 temperature sensor, transistor biasing circuit, I-V converter and amplifier. The output of the amplifier circuit is calibrated in such a way that 1mV is equal to 1°C.The major advantages of the proposed sensor were low cost, better accuracy, and linearity.

A. Valenteet al[36]Modeled, simulated and tested a silicon soil moisture sensor based on the dualprobe heatpulse method. It was based on the application of a heat pulse during a fixed interval of time.The maximum rise in temperature (*T*M) was monitored by the measurement probe, placed at a certain distance of the heater source.A low-cost, high-performance and small CMOS transistor temperature sensor was designed and fabricated to be placed into the probe which has 0.912mm inner diameter and 20mm long.If one considered the range of water contents, the ratio of water mass to dry soil mass, in a typical agricultural soil (0.05–0.35m^3 m^{-3}), the average sensitivity of the dual probe was about 1.95°C per unit change (m^3 m^{-3}) in water content for $q = 400$ Jm^{-1}.

H. Eller[37]prepared a capacitive soil moisture sensor. The measurement quantity was the complex permittivity at a frequency of 32 MHz. It was derived by an impedance measurement with a capacitive sensor of a fork-like geometry, which was found to the best geometry for field use. The impedance is measured with a twin T-bridge which has been optimized to cover the extremely large range of permittivity of natural soils. An analysis of measured soil permittivity showed a dominant influence of liquid water content on dielectric permittivity.

A. Valenteet al [38] prepared a multi-chip-module micro-system for soil moisture measurements. A dual-probe heat-pulse technique was used (measurement of the maximum temperature rise at some distance from the heater, after applying a heat-pulse for short period of time) to determine the volumetric heat capacity and, hence, the water content of the soil.The heater was prepared from nickel-chrome resistor as resistive heating. The temperature sensors (probe and reference) were high accuracyCMOS smart temperature sensors.

V. S. Palaparthyet al[39] prepared a prototype for soil moisture content measurement using dual probe heat pulse sensors. They used T-type thermocouples for the temperature sensor and Cu coil for the heater. During installation, the heater and the temperature sensor were separated by 0.5cm distance and had 2cm length. For the heater 1.5V, DC was supplied for 120 seconds. The system consisted of the instrumentation amplifier, microcontroller ATMEGA 16 with inbuilt ADC, LCD displays,and RF XBee Pro modules for transmitting the analog value from the microcontroller to the computer which was far apart. Data processing of program was done in MATHLAB. The developed system was tested on white clay soil for different known volumetric soil moisture contents. The result showed that the rise in temperature was inversely proportional to the increase in soil moisture content. At the two extreme points the output voltage of the thermocouple changed by 85μV for 2.2% soil moisture level while it changed around 49μV for 80% soil moisture content.

The heater for soil moisture sensor can be fabricated from semiconductor metal oxides. For example, M. Gharesi and M. Ansari[40]fabricated microheater from the SnO_2 film on Aluminum substrate by homemade spray pyrolysis technique. The substrate temperature was kept at 450°C during coating. The deposited substrate annealed at 700°C for some time in the air.

Transparent heaters were spray-coated directly on a glass substrate. The coatingprocess was made in regular production conditions without the use of the clean room or high-temperature processing.Spray coating paints contained a mixture of multiwalled carbon nanotubes and graphene platelets, added as a functional phase to achieve desired electrical and optical properties[41]. Rheology of the paints was adjusted to meet conditions of spray coating process. Morphology of the layers was examined using scanning electron microscopy and profilometer. The obtained demonstrator was exterminated towards the uniform distribution of the heat and additionally subjected to accelerated aging tests. The result proved that spray coating of nanomaterials is a promising cost-effective method for fabrication of large area heated glass.

M. S. S. Varma et al[42]designed and developed a polymer coated capacitive sensor for soil moisture sensor detection.A new type of capacitive sensor coated with a polymer material, named as ”DQN-70” has been used to measure the moisture content of the soil. Three different polymers PMMA, BPDA-mPD, and DQN-70 were taken as the coating material and their impedance performance has been evaluated to select the proper coating material. Among these three materials- DQN-70 shows the repeatable and reliable output. The change in capacitance of the probe was measured at different moisture level and converted to a voltage signal. The thermo-gravimetric method was used to calibrate the sensor performance. The probe was inside the soil for more than three months and produced consistent output.

S. R. Nandurkar[43]designed a Soil Moisture Sensing Unit based on the resistance variation of the soil between the probes for Smart Irrigation Application. The experimental result showed that the change of the resistance and soil water content had inverse relationship i.e.,the resistance of the soil decreased as the water content increased. This is because water is a good conductor of electricity in the presence of ions.The probes were constructed using two metal rods tied together using an insulating tape.

C. C. António Valenteet al[44] fabricated a low-cost soil moisture sensor fromalong transparent plastic tube of a 2cm diameter that was cut into small tubes of 2-inch height each. A slanting cut was made longitudinally in each tube with a knife and then stuck with tape for easy removal. This was serving as the mold. A mixture of 1:1 ratio of Plaster of Paris and water was made and poured into the tubes without air bubbles. Galvanized nails of 1.5 inch were carefully placed inside the mold such that there was no contact between the nails and one-fourth of each nail was projected outward.These served as electrodes. The entire set up was left to set for 24 hours after which the plastic tube was removed. This was a resistance type of soil moisture sensor.

A. Panigrahyet al [45]used a nanomaterial modified probe and did a project onSoil Moisture Sensing using Arduino Uno and Interfacing with GSM Sim900. They used two electrodes of which one was Al electrode and the other wasthe polyaniline nanoparticle plated electrode. The purpose of the nanoparticle plating was to increase the probe conductivity. This sensor was a resistive type sensor.Some of the disadvantages of resistance based soil moisture measuring device are separation distance dependent, soil type dependent and low resolution.

Y. Kojima et al[46]prepared low-cost soil moisture profile probe using thin-film capacitors and a capacitive touch sensor. The soil moisture content was related to the capacitance of the capacitor. The capacitor was constructed from the electrode probes as electrode plate.The developed capacitor was low-cost soil moisture sensor using capacitors on a film substrate and a capacitive touch integrated circuit. The developed sensor captured dynamic changes in soil moisture at 10, 20, and 30 cm depth, with a period of 10–14 days required after sensor installation for the contact between capacitors and soil to settle down.

Aga Zubeda in her Ph.D. thesis work reported that nanosized $BaTiO_3$ can be used as constant temperature heater for thermal conductivity property based soil moisture content estimation [47].

On-Chip Integrated Silicon Bulk-Micromachined soil moisture sensor based on the (dual probe heat pulse) DPHPmethod was prepared.The DPHP method used a heater (Peltier effect) and a temperature probe (Seebeckeffect) to determine the volumetric heat capacity of thesoil and hence water content (θv). This is the first timethat the DPHP method is implemented in a microdeviceand the first integrated sensor for soil moisture. Thismicrodevice is more suited to measure at different soildepths in a non-destructive and automated manner[24].

3. CONCLUSIONS AND RECOMMENDATIONS

The soil is the most important resource on the earth's crust. Sometimes it is known as the life of every living creature on earth. Soil will support living things and non-living things comfortably if it becomes optimum. Optimum soil contains its components in suitable composition both in quality and quantity for living things and non-living things that contain within it. The most important soil component that affects living things especially crops on earth is soil moisture content.

Soil moisture content greatly influences the agricultural productivity of one country.Plants require optimum moisture or water for their proper development and production. Some of the advantages of soil moisture estimation are water saving, weather forecasting, reduce soil erosion, and increase productivity. Some disadvantages of improper watering of plants are soil erosion, water loss, plant wilting, and decreases plant productivity. Therefore, estimating and measuring soil moisture somewhat accurately is required. In this regard, some works were done using some methods in the past. Some of the methods are volumetric methods, gravimetric methods, and tensiometric methods. The volumetric methods include dielectric methods and the neutron moderation methods. Intern the volumetric method includes time domain Reflectometry method, the frequency domain Reflectometry method, amplitude domain Reflectometry method, time domain transformation, phase transformation and non-contact methods like microwave methods, ground penetration radar, and nuclear magnetic resonance methods. The tensiometric methods include tensiometer, the granular matrix method, the resistance block method, the heat dissipation methods and psychrometer. But still, these methods have their own limitations like high cost, low accuracy, temperature dependent, low resolution, soil dependent calibration, slow response time, poor installation, small area coverage per one sensor, the complexity of operation etc... Therefore improvement is required. For example, using advanced materials the performance of soil moisture content measurement devices can be improved.

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