APPLICATION OF SOIL MOISTURE SENSORS IN AGRICULTURE: A REVIEW

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ABSTRACT

Water is a very precious resource and a driving force in irrigation. Optimal use of water is a need of the hour. Efficient irrigation watering helps in saving water, getting better plant yields, reduce dependency on fertilizers and improve crop quality. Various methods, both laboratory and field including remote sensing are available to measure soil moisture content, but the quickest and better one is with the use of soil moisture sensor electronic devices. For successful irrigation, it is necessary to monitor soil moisture content continuously in the irrigation fields. The selection of soil moisture probes is an important criterion in measuring soil moisture as different soil moisture sensors have their own advantages and disadvantages. The soil moisture sensors are used intensively at present because it gives real time readings. An attempt is made in this article to review some of the sensors available, their specifications, properties, applicability, advantages and disadvantages so that an informed decision on selection of appropriate sensor can be made for a particular application.
Keywords: *Crop, irrigation, moisture sensors, soil moisture*

1. INTRODUCTION

The world, at present is facing shortage of water which is hampering the development of agriculture and hence the food production. Judicious use of water is therefore necessary and in agriculture particularly, optimum use of water is necessary (Munoth *et al.*, 2016) as there is shortage of water in most parts of India. Soil moisture is primary information in achieving optimum water requirements for the crops (Schroder, 2006). The various levels of soil moisture content are shown below in figure 1. As the water infiltrates into the soil, the pore spaces are filled with water and water starts percolating downwards. As this process continues, the soil attains field capacity but the percolation of water continues due to capillary action and gravity. When soil water exceeds the field capacity, the excess water drains out (saturation point). Permanent wilting in this figure indicates the point at which plants have absorbed all of the available water and they wilt such that they cannot recover(Yonts *et al.*, undated). The available soil water holding capacity of soil is different for different types of soils. Peters *et al.*, 2013 have given the range of available soil water for different soil textures which clearly shows that coarse sand has least available water capacity (0.2-0.8 in/ft) whereas peat mucks has highest available water capacity (1.9-2.9 in/ft). Initially, as the soil water is depleted from field capacity (100% of available water) towards permanent wilting point (0% of available water), plant growth is not affected until the depletion reaches the point of minimum balance (also known as management allowable deficit). Depletion of soil water below this minimum balance leads to yield losses. Hence, care should be taken such that water in the crop root zone retains between minimum balance and field capacity.

There are generally two methods of measuring soil moisture, which are *Direct inspection* (Feel and appearance method, Hand-push probe, and Gravimetric method), and *Meters and Sensors* (Soil moisture blocks, TDRs, FDRs, etc.) (Evans *et al.*, 1996). The soil moisture sensors are very productive instruments in measuring soil moisture to assess crop growth (Scherer *et al.*, 2013). Soil moisture sensors measure the water content at the root zone and is useful in irrigation scheduling (Clarke *et al.*, 2008), precision agriculture and hydrology (Skierucha *et al.*, 2010), residential gardens, landscapes, rainfall monitoring, environmental testing etc. There are various types of soil moisture sensors available in the market.

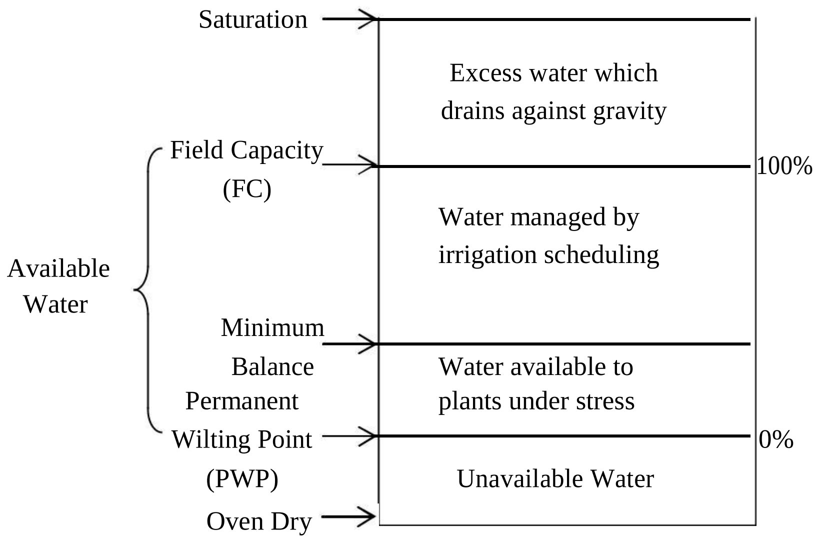

Figure 1. Various water levels in soil water content
(Source: Yonts *et al.*, undated)

However, one must take care in selecting the appropriate type of sensor by taking into account the sensor characteristics, applicability, advantages and disadvantages and most importantly cost. Effort have been made in this article to discuss some common sensors used in the field with their advantages and disadvantages so that one is able to easily identify the type of sensor required for his particular application.

2. DIFFERENT TYPES OF SENSORS

There are numerous types of sensors available today, each having variable performances (Francesca *et al.,* 2010). Some measure soil moisture content while other measure soil water potential and dielectric constant (volumetric content).
Although there are numerous techniques available for soil moisture sensing, but in this review the soil water tension based sensors (tensiometers and granular matrix sensors) and soil water content based sensors (TDR, FDR and VH400) are discussed. The nuclear scattering and gamma ray attenuation techniques have not been discussed here as they use radioactive material which may prove to be hazardous (McKim *et al.,* 1980).

2.1 Tensiometers

Tensiometers are simple soil moisture tension measuring devices used frequently in irrigation scheduling. The figure 2 shows a typical tensiometer which consists of a porous ceramic tip connected to vacuum gauge through a PVC tube. The tube consists of water which should be free from air. The porous ceramic cup is installed into the soil in such a way that soil water pressure is transmitted to the tensiometer which is read by pressure sensing devices mounted on the tensiometer. This instrument do not measure soil moisture content directly, instead it measures soil water tension (Freeman *et al.,* 2004). Generally, the response time of a tensiometer is 2 to 3 hours(Zazueta *et al.,* 1994). There are tensiometers available which can be automated with the irrigation system with the help of pressure gauge.

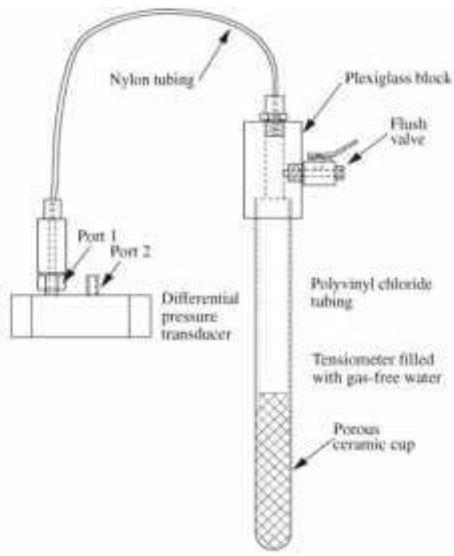

Figure 2. Soil water tensiometer
(Source: Freeman *et al.*, 2004)

Hanson *et al.*,(2002) has given values of soil moisture tension measured by tensiometer for different types of soil as shown in table 1.

Table 1. Variation in soil water tension for different types of soil

Soil Type	Soil Moisture Tension (centibars)
Sand or loamy soil	40-50
Sandy loam	50-70
Loam	60-90
Clay loam or clay	90-120

(Source: Hanson *et al.*, 2002)

Advantages

a) Tensiometers are simple, rapid, inexpensive and easy to use (Enciso-Medina *et al.*, 2007).
b) Different types of liquid like ethylene glycol solution can be used to obtain data during freezing and thawing conditions (Schmugge *et al.*, 1979).
c) A tensiometer is ideal for sandy loam or light textured soils (Alam *et al.*, 1997).

Disadvantages

a) Periodic maintenance is required as air bubbles accumulate under normal use (Hensley *et al.*, 1999).
b) It is prone to damage due to freezing temperatures (Alam *et al.*, 1997).
c) Several tensiometers are required for measurement because they measure soil water potential only in the vicinity of the tensiometer (Goodwin, 2009).
d) The usable range is only between 0-85 centibars of tension above which the gauge will malfunction (Werner, 2002).

Applicability

The tensiometers can be used in any horticulture crop under irrigation (Goodwin, 2009).

2.2 Granular Matrix Sensor (GMS)

The granular matrix sensor is made of a porous ceramic external shell with an internal matrix structure containing two electrodes as shown in figure 3. The electrodes inside the GMS are imbedded in the granular fill material above the gypsum wafer. The water conditions in the granular matrix change with variation in corresponding water conditions in the soil and these changes are continuously indicated by difference in electrical resistance between two electrodes in the sensor (Berrada *et al.*, 2014). This resistance between the electrodes is inversely related to soil water (Irmak *et al.*, 2006).

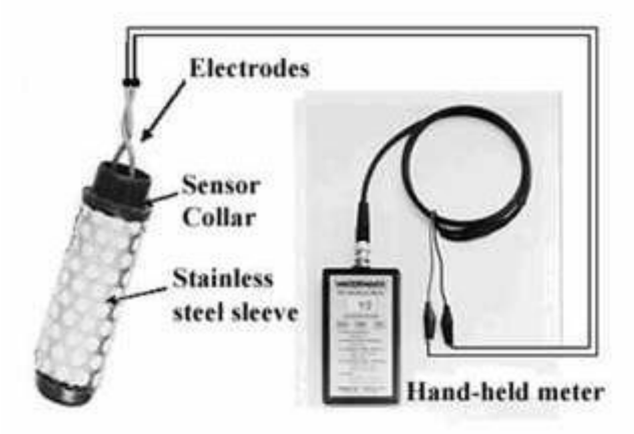

Figure 3. Granular matrix sensor (Model 200SS) (Source: Irmak *et al.*, 2006)

Advantages

a) GMS is cheaper and requires less maintenance compared to tensiometer (Shock *et al.*, 1998).
b) Automation of irrigation in fields can be achieved (Muñoz-Carpena *et al.*, 2005).
c) Negligible change in sensor performance with variation in soil temperature (Irmak*et al.*, 1990).

Disadvantages

a) It shows different response to different soil types (Enciso-Medina *et al.*, 2007).
b) Sometimes, poor contact between the soil and the sensor occurs which could cause high readings which is most likely to occur in heavy soils (Berrada *et al.*, 2014).
c) It is less responsive to small rains (<0.5 in.) (Berrada *et al.*, 2014).
d) It is low accurate in sandy soils because of their larger particle size (Zazueta *et al.*, 1994).

Applicability

The GMS is used for assessing soil moisture in crops like cotton, onion, potato, urbanized landscapes (Muñoz-Carpena *et al.*, 2005), corn (Irmak *et al.*, 2006), drip irrigated vegetable crop (Thompson *et al.*, 2005). The GMS has good accuracy in medium to fine soils because the soil particle size will be similar to that of the transmission material which has a consistency close to that of fine sand that is wrapped in porous membrane of the GMS.

2.3 Time Domain Reflectrometry (TDR)

In time domain reflectrometry, a pulse of radio frequency energy is injected into a transmission line and its velocity is measured by detecting the reflected pulse from the end of the line. This velocity depends upon the dielectric constant. It measures the moisture content by measuring how long it takes for the reflected pulse to come back (Cepuder *et al.*, 2008 and Haman *et al.*, undated). The response of a TDR is very quick (≈ 28 sec) (Zazueta *et al.*, 1994).

Figure 4. TDRunit
(Source: labmodules.soilweb.ca)

Advantages

a) TDR respond quickly to varying soil moistures (Marenghi, 2013).
b) It measures moisture quite accurately (± 2%) in any type of soil (Cepuder *et al.*, 2008).
c) Soil moisture from multiple depths can be obtained from a single probe (Pitts, 2016).
d) There is little or no disturbance to the test site during the testing process (Skierucha *et al.*, 2012)

Disadvantages

a) They need to be carefully calibrated to precisely measure the amount of time it takes for the pulse to come back (Paige *et al.*, 2008).
b) This instrument is costlier than other measuring methods (Zazueta *et al.*, 1994 and Heiniger, 2013).
c) TDR applications are limited due to high costs (Blonquist *et al.*, 2005).
d) TDR read soil moisture only in the vicinity of the sensor (Wolpert *et al.*, 2013).

Applicability

TDR is mostly used in fields having mineral crops and crops grown on organic soils. Dukes *et al.*,(2010) have listed sweet corn, green bell pepper, and the crops grown on sandy soils for which TDR can be used.

2.4 Frequency Domain Reflectrometry (FDR)

FDR sensor consists of a pair of metal rings which are formed as a capacitor and the soil sample acts as a dielectric. The electrical sensor capacitance is a direct measure of soil volumetric content. Its principle is similar to TDR sensor (Prichard, undated).

Figure 5. FDR sensor
(Source: www.experimental-hydrology.net)

Advantages

a) It is very accurate (± 1%) if calibrated properly (Muñoz-Carpena *et al.*, 2004).
b) Unlike TDR, it can be used with soil having high salinity (Muñoz-Carpena *et al.*, 2004).
c) With FDR, measurements can be made at several depths at the same location (Abouatallaha *et al.*, 2011).
d) It is expensive as compared to TDR (Maughan *et al.*, 2015).

Disadvantages

a) It requires soil specific calibration (Linmao *et al.*, 2012).
b) In FDR, good contact between soil and the sensor is to be ensured to avoid the formation of air gaps (Muñoz-Carpena *et al.*, 2004).
c) It can sense moisture content only in the vicinity of the sensor (Wolpert, 2013)

2.5 VH400 Soil Moisture Sensor

VH400 soil moisture sensor is a resistive-based soil moisture which measures dielectric constant of soil (Salih *et al.*, 2013). It helps in precise low cost monitoring of soil water content. It has rapid response time, can take reading in under one second and is much sensitive at higher volumetric water content (Ravi *et al.*, 2011). The soil moisture probe is inserted into the ground, preferably in horizontal position at the root level. This sensor is small in size, rugged, waterproof, and consumes less power. It is also insensitive to salinity of water, does not corrode over time (Zaier *et al.*, 2015), and is sensitive to even small changes in water content (Bitella *et al.*, 2014). This type of sensor is sensitive to temperature changes in wet conditions, thus temperature measurement would always be required (Bitella *et al.*, 2014). The probe is usually attached to soil moisture reading device to form a wireless sensor network, such networks are extensively used in precision agriculture and smart irrigation (Khriji *et al.*, 2014). One such device is soil moisture data logger (figure 6) which displays moisture content readings on digital screen. There are two means of communication between the system (figure 6) and the far user; first the readings are sent via Short Messaging Service (SMS) on GSM network, and second the readings can be stored in memory card which can be transferred to a computer for analysis.

Figure 6. A VH400 sensor; its Data logger The specifications of this sensor is as follows:

Table 2. Specifications of VH400 soil moisture sensor

Power Consumption	< 7 mA
Supply Voltage	3.5 to 20 V (DC)
Operational Temperature	-40°C to 85°C
Accuracy at 25 °C	±2%
Output	0 to 3V related to moisture content

(Source: http://www.vegetronix.com/Products/VH400/)

Applications

Hydrology, Agronomy, Soil physics, Irrigation and Sprinkler systems, Plant physiology, Phenotyping, Root ecology, Environmental monitoring and Rain monitoring (Ahmed, 2012 and Bitella *et al.*, 2014).

3. DISCUSSION

On the basis of the advantages and disadvantages of each of the sensor system reviewed, it can be said that selecting soil moisture sensor is not an easy task and requires detailed analysis and consideration of various factors. Cost of the sensor systems play an important role in this process apart from advantages and disadvantages of a sensor. The VH400 soil moisture sensor is easy to use and inexpensive compared to the other type of sensors mentioned in this article. The summary of sensor types along with their advantages and disadvantages in brief is discussed in Table 3, however one has to consider all the factors like location, temperature, rainfall, weather conditions, type of soil, type of crop, availability of irrigation water, etc. relevant to the particular application and use.

Hanson *et al.*,(2002) examined that the sensors placed in root zone at different points helps in determining adequacy of irrigation and actual depth of irrigation. Irrigation should be started when soil moisture content approaches the values at which irrigation should occur. Table 4 gives the soil moisture content for different types of soil at which irrigation should occur.

Linmao *et al.*, (2012) have tested successfully the functioning of capacitance sensors in high temperature, high humidity, cold situations, and in impact and vibration tests. The soil moisture sensors were used in different locations based on soil type and crop type. In this context, Dukes *et al.*, (2010) has summarized the reduction in irrigation water requirements for various type of crops in Florida region which shows that using tensiometers, the irrigation requirement of tomato crop was reduced by 40 to 50% (73% reduction of water use at 0.15 bar pressure) but they require frequent maintenance and clogging due to algae growth. The granular matrix sensor which is considered as replacement of tensiometer has not reduced water application in gravelly loam soil, however it was successfully used for irrigating onion and potato on heavy soils. An analysis by Haman *et al.*, (undated)has shown that using a TDR controlled system, one can save 60% of irrigation water and with some settings, even 80%. Overall, the capacitance probe can reduce irrigation water nearly by 50%. Maughan *et al.*, (2015) has summarised various soil moisture measuring techniques (both direct inspection and sensors) based on accuracy, quality of measurement and costs of sensors, in which they showed that FDR is the costliest but most accurate among the sensors described in this review whereas tensiometer is least expensive but it requires periodic maintenance.

Table 3. Types of soil moisture sensors and their relative advantages and disadvantages

	Sensor Type	Advantages	Disadvantages
Soil Water Tension	Tensiometers	Less expensive	Maintenance issues.
	Granular Matrix Sensors	Inexpensive	Highly variable output. Less accurate. Sensitive to temperature and soil salinity.
Soil Moisture Measurement based on Dielectric and Capacitive Techniques	Time Domain Reflectrometry	Quick and accurate response	Costly instrument
	Frequency Domain Reflectrometry	Measurement at different depths for the same location is possible	Soil -specific calibration is required
	VH400 soil moisture sensor	Rapid response time and insensitive to salinity	Data loggers used with this sensor are expensive.

The soil moisture content varies with soil texture as shown in table 4 which are the recommended values at which irrigation should occur.

Table 4. Soil moisture content for different types of soil at which irrigation should occur

Soil Texture	Soil Moisture Content (%)
Sand	7
Loamy Sand	12
Sandy Loam	15
Loam	20
Silt Loam	23
Silty Clay Loam	28
Clay Loam	27
Sandy Clay Loam	24
Sandy Clay	22
Silty Clay	30
Clay	31

(Source: Hanson *et al.*, 2002)

4. CONCLUSIONS

Water is a limited resource in the world and agriculture is a primary market. Therefore, a sustainable and economic approach is to be adopted for efficient agricultural practice and irrigation scheduling (Levido *et al.*, 2014). The use of soil moisture sensors helps growers with irrigation scheduling by providing information about when to water the crops. Selection of sensor for a particular application or on the basis of type of soil can become a tiresome exercise as there are wide level of soil moisture sensors available in the market. The advantages and disadvantages of sensors must be considered as criteria for selection because the working principle behind each type of sensor varies with its application and type of soil. The VH400 soil moisture sensor, for example is a simple and portable device that gives real time soil moisture values at rapid response time when attached to a data logger via SMS service on GSM service, bluetooth technology or even through storage memory cards, such methods are time saving and not labour intensive. The development of wireless sensor applications in agriculture makes it possible to increase efficiency, productivity and profitability of farming operations as well as the maximum crop yield with minimum use of irrigation water.

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