**Application of Soil Testing Sensors in Agriculture**

Mudigiri Chandana1\* (Ph.D scholar), K. Navya1 (Ph.D scholar), K. Bhavitha2 (Ph.D scholar), G.Harshitha2 (Ph.D scholar) and Y. Chaitanya2 (Ph.D scholar), B. Kranthi Kumar 3

1.Ph D scholar, Dept of soil Science, PJTSAU, Hyderabad.

2. Ph D scholar, Dept ofAgronomy, PJTSAU, Hyderabad.

3. Subject Matter Specalist, Dept of soil Science, Krishi vigyan Kendra, Malyal, Mahabuababd.

**ABSTRACT**

The soil whose main role is to provide nutrients in the process of plant growth is the foundation and an important part of agriculture. Soil testing is an important step for increasing agricultural production and raising farm income. Traditional soil testing methods are based on chemical methods carried out under laboratory conditions. An important application of sensors in agriculture is in the direct measurement of soil chemistry through tests such as pH, moisture, nutrient content, Humidity, temperature. Soil testing results are important to obtain to get high yield with good quality. ISE (Ion Selective Electrode) and ISEFT (ion-sensitive field effect transistor) sensors have also been used to monitor the uptake of ions by plants.

Key boards : pH, moisture content, nutrient content, ISE, ISEFT

**INTRODUCTION**

The soil, whose main role is to provide nutrients in the process of plant growth is the foundation and an important part of agriculture. Macro and micro nutrients in farmland are important factors affecting crop growth. Soil testing results are important inputs to the profitable application of fertilizer, lime, and other soil amendments. When soil test results are combined with information about the nutrients that are available to the various crops, a reliable basis for planning the fertility program can be established (Hoeft *et al*., 1996). A standard test usually includes determination of available Nitrogen (N), phosphorus (P), exchangeable potassium (K), calcium (Ca) and magnesium (Mg), their saturation percentages, the cation exchange capacity (CEC), pH, and lime requirement. Some laboratories may also test for organic matter (OM) content, salinity, nitrate, sulfate, certain micronutrients, and heavy metals (Foth and Ellis, 1988). In addition, the crop growth environment is affected by soil texture (sand, silt and clay content), level of soil compaction, moisture content, and other mechanical and physical soil properties.

**Soil Testing in India**

Soil testing is an important step for increasing agricultural production and raising farm income. Traditional soil testing methods are based on chemical methods carried out under laboratory conditions. These methods are generally time consuming, tedious, and involve laborate sample preparation steps. On the other hand, the number of soil samples needed to be analyzed is large because of the small size of the land holdings in many parts of India. Consequently, even if soil samples are collected from different agricultural fields, timely testing of these samples is generally not possible and the test results often fail to reach farmers in a timely manner. Currently, there are about 1049 soil testing labs operating in the country with an annual analyzing capacity of only 10.7 million samples. Analyzing capacity of soil testing labs simply lags far behind the requirement. There is a need to repeat soil testing from time to time depending on soil types and crops. Hence, new technology has to be introduced to make soil testing-based nutrient management a reality.

**Application of sensors**

An important application of sensors in agriculture is in the direct measurement of soil chemistry through tests such as pH, moisture, nutrient content, Humidity, temperature. Soil testing results are important to obtain to get high yield with good quality. ISE (Ion Selective Electrode) and ISEFT (ion-sensitive fieldeffect transistor) sensors have also been used to monitor the uptake of ions by plants. The rate of nutrient uptake is determined by the demand of the plant, which is dependent on the growth rate and on the status of the plant’s nutrient content. Ion-selective sensors have been developed to detect a variety of ions. ISE sensors have been developed to monitor nitrogen ions in the soil and crops. Hi-tech systems are in demand to help grow high-performance crops. Researchers are using sensors to match the crops to different soils and weather conditions.

**ELECTROCHEMICAL SENSORS FOR SOIL NUTRIENT DETECTION**

Ion Selective Electrode (ISE) and Ion Selective Field Effect Transistor (ISFET) are two types of commonly used potentiometric electrochemical sensors for soil nutrient detection.

**Ion Selective Electrode (ISE)**

The response mechanism of ISE method can briefly described by the Nernst equation as a change of an ISE’s potential, compared with a reference electrode, is linear to the change of the ionic activity (in logarithmic units) of the target ion.

ISEs were reported to detect soil nitrate, ammonium and potassium. To date, no promising ISE for phosphorus detection was reported, but several literatures presented that the PVC-based membrane ISEs could be used to measure phosphate content in biological samples.

ISEs were used for soil nutrient detection in two directions: (1) Flow Jianhan *et al.* chemical analysis. To date, soil sampling is manually carried out in a field general, visible/ultraviolet spectrometry is employed for detecting nitrogen variability of soil nutrients in a field or fields. Therefore, novel soil nutrient 1350 Injection Analysis (FIA) systems and (2) vehicle-based soil sensing systems

**Limitation:**

ISEs might not have been ready for real-time sensing applications because of their response delay (several minutes).

**Ion Selective Field Effect Transistor (ISFET)**

ISFET is the integration of an ISE and a field effect transistor (FET). The ion selective membrane is placed on the top of the insulator layer of the FET structure, so the threshold voltage of the ISFET can be chemically modulated and the measured voltage is related with the concentrations of a dimensions, low output impedance, high signal-to-noise ratio, fast response and the ability to integrate mulit-ISFETs on one chip.

ISFETs were reported to detect soil ammonium, nitrate and potassium. A successful automated system for soil pH mapping was reported to be tested under field conditions.

**Limitation**

However, ISFET’s high cost and inconsistent repeatability limited their wide extension use in practical systems.

Both ISEs and ISFETs respond selectively to a particular ion in solution according to a logarithmic relationship between the ionic activity and electric potential. The ISEs and ISFETs require recognition elements, *i.e.,* ion selective membranes, which are integrated with a reference electrode and enable the chemical response (ion concentration) to be converted into a signal (electric potential). Due to an increased demand for the measurement of new ions, and tremendous advances in the electronic technology required for producing multiple channel ISFETs, numerous ion-selective membranes have been developed in many areas of applied analytical chemistry.

**Soil NPK estimation by optical measurements**

The optical soil measurement methods in this paper can be classified into six types. Visible–infrared (*Vis* – IR) spectroscopy, inductively coupled plasma spectroscopy, fluorescence spectroscopy; and colorimeters are used for measuring soil nutrients.

***Vis*–IR spectroscopy**

*Vis*–IR spectroscopy is a physical nondestructive, rapid, reproducible and low-cost technique that characterizes materials according to the energy absorbed by the material in the wavelength range 700 nm - 1 nm. Each soil nutrient has its own and unique spectral feature which helps in its quantification and identification. It is a type of non liquid nutrient testing method which makes it a cutting - edge technique for soil analysis. The procedure is very convenient and truly portable in the sense that, it requires almost no sample preparation. To extract quantitative information out of the IR spectra it is required to use calibration curve obtained from multivariate techniques. The calibration curve is used to find unknown concentration of a solution by using the graph of intensity of spectrum versus known concentration. Thus, over the other methods, spectroscopic methods for soil analysis are advantageous and easy. The only limitation of the method is the soil mapping and generation of appropriate database. The application of IR spectroscopy to soil is being studied from 1960 and is used extensively for determining soil Carbon and Nitrogen content. *Vis*–IR spectroscopy is now being studied for its use in determining soil Phosphorus and Potassium content.

**Reflectance spectroscopy**

Reflectance spectra are of three types: internal reflectance, diffuse reflectance and specular reflectance. Most of the soil nutrient detection is done using diffuse reflectance spectroscopy. Based on the near-infrared reflection spectroscopy, Du *et al.* (2019) published a set of detailed instructions and research on diffuse reflectance technique for soil nitrogen detection. They developed a portable nitrogen detector. They used a small, compact Fourier transform infrared (FTIR) coupled spectroscope with a supporting software for data acquisition and spectral analysis. They identified wavelengths for soil nitrogen as 1500- 1850 and 2000 - 2400 nm for nitrogen containing groups. Hu *et al.* (2016) studied the effect of using a small region of wavelength 1100–2450 nm for sensing soil phosphorus and potassium and found that narrower sensing range is beneficial in making sensors. Mukherjee and Laskar (2019) developed a *Vis*–NIR diffuse reflectance spectroscopy - based sensor for measurement of NPK in soil extracts.

**Raman spectroscopy**

Raman spectroscopy is a rapid soil nutrient testing tool. It uses a strong beam of visible or ultraviolet light to illuminate the sample and collect the scattered Raman spectra. Based on vibrations and rotations of radiation excited molecules, Raman spectra signature can provide structural information which serves as a key for sample identification. The sensor is capable of remote detection and quantification of soil nutrients like phosphorus, nitrogen and potassium. Larar *et al*. (2012) studied soil phosphorus concentration using Raman spectroscopy.

**Colorimetric**

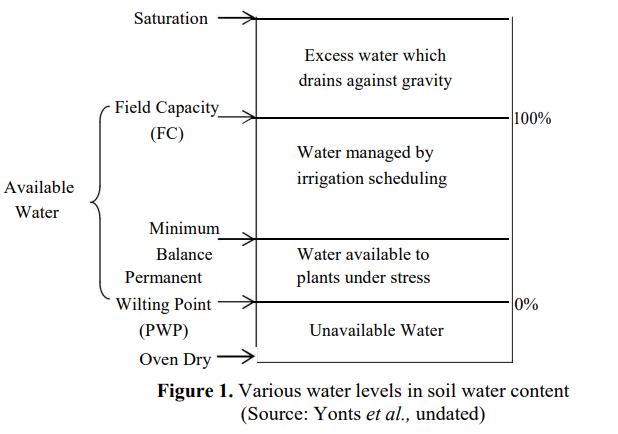
Soil testing kits perform a quick, on-the-spot, and approximate measurement of nutrients present in the soil (McCoy and Donohue 1979). These kits use the principle of colorimetric technique for analyzing the soil nutrients. The colorimetric method compares the color change of the solution with calibrated reference color charts. The shade of the color on the color chart indicates a range of concentration. By relating color of the solution to concentration of nutrients, colorimetric method measures the fertility level of nutrients (NPK) in the soil.

**Optical imaging**

Chen *et al*. (2019) reported a unique technique for determining the nutrient status in plants. According to them analyzing images of plant leaves could help predict potassium deficiency in plants. Matrix laboratory (MATLAB) software and support-vector machines (SVM) calibration model were used together to analyze leaf image and derive potassium level from the given information. Li, Jia, and Le (2019) used 900 - 1700 nm wavelength for detecting total soil nitrogen content using a hyperspectral imaging system.

**Soil moisture Sensors**

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. 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.

****

**DIFFERENT TYPES OF SENSORS**

**Tensiometers**

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.

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

|  |  |
| --- | --- |
| **Soil Type** | **Soil moisture tension (centibars)** |
| Sandy or loamy soils | 40-50 |
| Sandy loam | 50-70 |
| Loam | 60-90 |
| Clay loam | 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.

**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.

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).

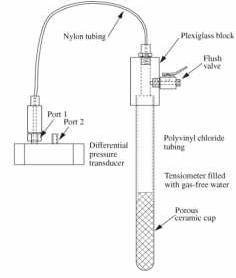


Figure 2. Soil water tensiometer (Source: Freeman *et al.,* 2004)

**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 This resistance between the electrodes is inversely related to soil water

**Advantages**

a) GMS is cheaper and requires less maintenance compared to tensiometer.

b) Automation of irrigation in fields can be achieved.

c) Negligible change in sensor performance with variation in soil temperature.

**Disadvantages**

a) It shows different response to different soil types.

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.

c) It is less responsive to small rains.

d) It is low accurate in sandy soils because of their larger particle size.

**Applicability**

The GMS is used for assessing soil moisture in crops like cotton, onion, potato, urbanized landscapes, corn 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.

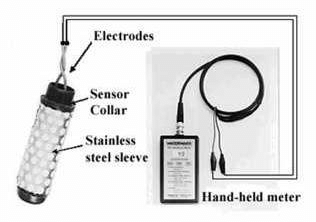


Figure 3. Granular matrix sensor (Model 200SS) (Source: Irmak *et al.,* 2006)

**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).

**Advantages**

a) TDR respond quickly to varying soil moistures.

b) It measures moisture quite accurately (± 2%) in any type of soil.

c) Soil moisture from multiple depths can be obtained from a single probe.

d) There is little or no disturbance to the test site during the testing process.

**Disadvantages**

a) They need to be carefully calibrated to precisely measure the amount of time it takes for the pulse to come back.

b) This instrument is costlier than other measuring methods

c) TDR applications are limited due to high costs.

d) TDR read soil moisture only in the vicinity of the sensor.

**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.

****

**Figure 4. TDR unit (Source: labmodules.soilweb.ca)**

**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).

**Advantages**

a) It is very accurate (± 1%) if calibrated properly.

b) Unlike TDR, it can be used with soil having high salinity.

c) With FDR, measurements can be made at several depths at the same location.

d) It is expensive as compared to TDR.

**Disadvantages**

a) It requires soil specific calibration.

b) In FDR, good contact between soil and the sensor is to be ensured to avoid the formation of air gaps.

c) It can sense moisture content only in the vicinity of the sensor.



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

**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, and is sensitive to even small changes in water content. 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 which displays moisture content readings on digital screen. There are two means of communication between the system 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 logger The specifications of this sensor is as follows:

****

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

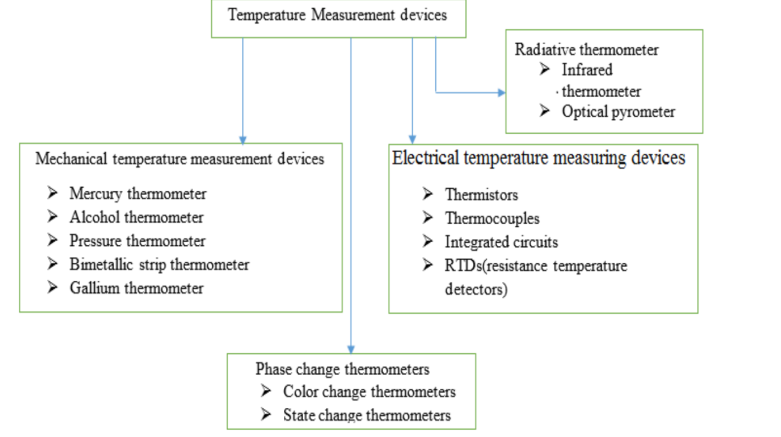
|  |  |
| --- | --- |
| Power consumption | < 7 Ma |
| Supply voltage | 3.5 to 20 V (DC) |
| Operational Temperature | -40⸰C to 85 ⸰ C |
| Accuracy at 25⸰ C | ± 2% |
| Out put | 0 to 3 V related to moisture content |

**Applications**

Hydrology, Agronomy, Soil physics, Irrigation and Sprinkler systems, Plant physiology, Phenotyping, Root ecology, Environmental monitoring and Rain monitoring.

**SOIL TEMPERATURE SENSORS**

In the case of soil temperature sensor, there is no much work. For example a bent-stem soil thermometer is used to measure soil temperature between the ground surface and a depth of 20 cm underground, and has a bend between the bulb and the scale (WMO 2010). But this thermometer has many problems. Some of the 366 Almaw Ayele Aniley,et al problems of this thermometer is: it is exposed to external factors like sunlight, cold etc.., it requires removal of it from the installed place during harsh season. The following figure shows the different types of temperature sensors (Kedzierski 1993).



**Figure 7. classification of temperature sensors**

Except for IC sensors, all the temperature sensors have nonlinear transfer functions, *i.e.* the temperature dependence of the physical parameter under scrutiny (e.g. resistance, voltage output, etc.) is nonlinear (Feteira 2009).

**Conclusion**

Detection of soil nutrients depends on variations in soil and environmental factors resulting in poor detection accuracy. This problem can be solved by applying pretreatment methods and different calibration methods. The only concern with spectroscopic methods is that typical spectrometers are bulky and expensive, and requirement of site-specific calibration. colorimetric methods can be used to develop a portable, cost effective optical sensor for soil macronutrient detection. In general, the colorimetric technique doesn’t need expensive equipment and perfect measurement conditions or good database or sophisticated analysis techniques. Further research on colorimeter-based soil nutrient detection can be carried out for developing a cost-effective portable sensor. Research findings suggest that the solution-based soil extractant can be replaced by ion-selective membranes to make the colorimeter-based sensor more compact and convenient. The latest trend in the field of nutrient testing is the use of imaging techniques. Although much research has happened in the optical sensing field, a cost-effective portable soil NPK sensor still does not exist in the Indian market. 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.

**References:**

Hoeft, R.G., Peck, T.R., Boone, L.V., 1996. Soil testing and fertility. In: Illinois Agronomy Handbook 1995–1996, Circular 1333, Cooperative Extension Service, College of Agriculture, University of Illinois at Urbana-Champaign, Chapter 11, pp. 70–101.

Foth, H.D., Ellis, B.G., 1988. Soil fertility. Wiley, New York, New York.

Munoth P, Goyal R, Tiwari K (2016) Sensor based irrigation system: A review. International Journal of Engineering Research & Technology (IJERT), NCACE-2016 Conference Proceedings, 4 (23):86-90.

Schroder HJ (2006) Soil moisture-based irrigation for efficient use of water and nutrients and sustainability of vegetables cropped on coarse soils. A thesis presented to the Graduate School of the University of Florida.

Evans R, Cassel KD, Sneed ER (1996) Measuring soil water for irrigation scheduling: monitoring methods and devices. Publication no.AG 452-2.North Carolina Cooperative Extension Service.https://www.bae.ncsu.edu/programs/extension/evans/ag452-2.html.

Scherer FT, Franzen D, Cihacek L (2013) Soil, water and plant characteristicsimportant to irrigation. Extension Service, North Carolina State University, AE 1675 (Revised).

Clarke M, Acomb G, Philpot B (2008) Florida field guide to low impact development. Program for resource efficient communities, University of Florida.

Skierucha W, Wilczek A (2010) A FDR sensor for measuring complex soil dielectric permittivity in the 10–500 MHz frequency range. Sensors, 10: 3314-3329.

Freeman AL, Carpenter CM, Rosenberry OD, Rousseau PJ, Unger R, McLean SJ (2004) Use of submersible pressure transducers in water-resources investigations. 40- 43.

Zazueta SF, Xin J (1994) Soil moisture sensors. Bulletin 292, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida [www.experimental-hydrology.net/wiki/index.php?title=Soil](http://www.experimental-hydrology.net/wiki/index.php?title=Soil) moisture FDR\_(profile\_probe).

Enciso MJ, Porter D, Périès X (2007) Irrigation monitoring with soil water sensors. Cooperative Extension, B-6194, The Texas A&M University System.

Schmugge TJ, Jackson TJ, McKim HL(1979)Survey of methods for soil moisture determination. NASA Technical memorandum.

Hensley D, Deputy J (1999) Using tensiometers for measuring soil water and scheduling irrigation. Coopertive Extensive Service.Department of horticulture, College of tropical agriculture & human resources, University of Hawaii at Manoa. Landscape L-10.

Goodwin I (2009) How to use tensiometers?.Department of environment and primary industries, Agriculture Victoria: ISSN 1329-8062.

Feteira, A., 2009. Negative Temperature Coefficient Resistance (NTCR)Ceramic Thermistors: An Industrial Perspective. , 983.

Werner H (2002) Measuring soil moisture for irrigation water management. Cooperative Extension Services, College of Agriculture and Biological Sciences, South Dakota State.

Thompson RB, Gallardo M, Agüera T, Valdez LC, Fernández MD (2005) Evaluation of the Watermark sensor for use with drip irrigated vegetable crops. Irrig Sci (2005). DOI: 10.1007/s00271- 005-0009-5.

Du, X., J. Wang, D. Dong, and X. Zhao. 2019. Development and testing of a portable soil nitrogen detector based on near-infrared spectroscopy. In 2019 IEEE 8th joint international information technology and artificial intelligence conference (ITAIC), 822.

Hu, G., K. A. Sudduth, D. He, D. B. Myers, and M. V. Nathan. 2016. Soil phosphorus and potassium estimation by reflectance spectroscopy. Transactions of the American Society of Agricultural and Biological Engineers (ASABE) 59 (1):97–105.

Mukherjee, S., and S. Laskar. 2019. Vis–NIR-based optical sensor system for estimation of primary nutrients in soil. Journal of Optics 48 (1):87–103. doi: 10.1007/s12596-019-00517-1.

McCoy, D. E., and S. J. Donohue. 1979. Evaluation of commercial soil test kits for field use. Communications in Soil Science and Plant Analysis 10 (4):631–52. doi: 10.1080/00103627909366925.

Chen, L., S. Huang, Y. Sun, E. Zhu, and K. Wang. 2019. Rapid identification of potassium nutrition stress in rice based on machine vision and object-oriented segmentation. Journal of Spectroscopy 2019:1–8. doi: 10.1155/2019/ 4623545.

Dukes DM, Zotarelli L, Morgan TK (2010)Use of irrigation technologies for vegetable crops in Florida. Workshop, Horttechnology, ASHS Publications, 20(1).

Prichard L Terry (undated) Soil moisture measurement technology.University of California Davis. <http://cecentralsierra.ucanr.org/files/96233.pdf>.

Salih Md. EJ, Adom HA, Shakaff Md. YA, Shuib AM (2013) Real time wireless agricultural ecosystem monitoring for cucumus melon Cultivation in natural ventilated greenhouse. International Journal of Scientific and Research Publications, 3(11).

Ravi SK, Tapaswi K, Lokesh B, Krishna SG (2011) Smart sensor for agricultural chronology. (IJCSIT) International Journal of Computer Science and Information Technologies, 2(6):2650-2658.

Bitella G, Rossi R, Bochichhio R, Perniola M, Amato M (2014) A novel low-cost open- hardware platform for monitoring soil water content and multiple soil-air-vegetation parameters. Sensors, 14:19639-19659. DOI: 10.3390/s141019639.

Khriji S, Houssaini ElD, Jmal WM, Viehweger C, Abid M, Kanoun O (2014) Precision irrigation based on wireless sensor network. IET Science, Measurement and Technology. DOI: 10.1049/ietsmt. 2013.0137.

Kedzierski,M.a.,1993. Principles and methods of temperature measurement. Experimental Thermal and Fluid Science, 6(1), p.106.