An overview of soil moisture measurement methods

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Keywords: Soil moisture; Drying method; Tensile method; Neutron ray method; Infrared ray method; TDR method; Dew point microvoltmeter method

Abstract: This paper introduces the importance of soil moisture to plant growth, the composition of soil moisture and the expression of soil moisture. Soil moisture measurement techniques are classified according to sampling method. The principle and test method of six typical soil moisture measurement methods, including drying method, tensile method, neutron emission method, infrared ray method, dielectric method and dew point microvoltmeter method, were analyzed in detail, and their advantages and disadvantages were summarized. It can be used for reference in the future research, application and deep multi-disciplinary integration of soil testing technology.

1. Introduction

Soil moisture plays an irreplaceable role in the whole growth cycle of crops . The root system of crops absorbs dissolved nutrients and mineral ions in water, providing all the nutrients needed for the growth of crops [1]. The moisture content of the soil determines the dissolved nutrients and mineral ions. The rapid and accurate determination of soil moisture content plays an important role in the law of water demand during the growth period, scientific management of agricultural water resources and the monitoring of the material composition of water[2].

2. Soil moisture measurement methods

Soil moisture can be divided into free water, chemically bound water and hygroscopic water . Free water can move freely between soil and vegetation without adsorbing macromolecules [3]. Chemically bound water is water that is surrounded by a solute or bound to a solute by a chemical bond. Hygroscopic water refers to the extremely thin water film on the surface of soil particles, whose source is the water molecules in the gaps adsorbed by soil particles [4].

At present, generally soil moisture measurement methods are two categories. One is location measurement, the other is direct sampling[5].Direct sampling of soil moisture can be divided into chemical and physical methods [6]. Drying method, specific gravity method, centrifugal method and ultrasonic method belong to physical methods [7]. The calcium carbide concentrated sulfuric acid method belongs to the chemical method. The location measurement method is divided into non-radioactive method and radioactive method.Electric measurement method, remote sensing method and tension meter method belong to non-radioactive method . Neutron and gamma methods are radioactive methods[8].

3. Several typical measurement methods

There are many methods to measure soil moisture. Each method has its unique technical means and relative advantages. The following are some typical methods.

3.1 Drying method

At present, drying method is most commonly used method for measuring soil moisture, and it is

  DOI: 10.25236/isrme.2019.075

the calibration of the measured standard value of soil weight and moisture content [9]. It is 100 ℃ using water at atmospheric pressure to the principle of gas volatilization, the soil samples under 105 ℃ drying to constant weight. The free water and hygroscopic water in the soil will evaporate through transpiration. The ratio of soil water loss mass and drying soil mass can be calculated to obtain the mass water content of soil moisture.

1). Weigh the sample about 10 grams and place it in the weighing dish;

2). The sample into the oven at 105 ℃ to 110 ℃ approximation under the condition of constant temperature drying 8 ~ 10 hours to constant weight;

3). Put the dried samples in the dryer to cool for about 20 minutes, and use a precision balance to weigh them immediately;

4). Repeat the steps of 2 and 3, take out and cool in the dryer, and immediately weigh again (the difference of secondary weight shall not exceed 3 mg);

5). The weight water content of soil can be obtained by calculating the ratio between the mass difference before and after drying and the soil weight before drying.

The soil water content measured by drying method is the weight water content of soil. Advantages of drying method: simple measurement method, easy to operate, intuitive test results, high measurement accuracy, wide range of measurement. Disadvantages of drying method: it is unable to realize the online rapid measurement of soil moisture, the measurement cycle is long, and the water loss in the sampling and transportation process will produce errors. It cannot meet the requirements of real-time and rapid measurement, and can only be used as a reference for the calibration process.

3.2 Tensiometer

The tensiometer method is a read-only instrument for measuring soil water tension, and its structure is shown in figure 1. The tension meter has a simple component. The upper end of the water filling pipe is sealed with rubber plug, and the other end of the water filling pipe is a hollow and breathable ceramic head. The upper end of the water-filled pipeline is equipped with a vacuum instrument. During the measurement, the tension gauge ceramic head is buried in the soil. The ceramic head is in close contact with the soil. When the soil is dry, the soil in contact with the ceramic head will suck the moisture out of the filling pipe due to the gravitation trend, forming a local vacuum at the top of the filling pipe. After the soil is hygroscopic, the water flows back to the ceramic head and the vacuum in the filling pipe decreases. The numerical variation of the vacuum gauge reflects the change of soil water tension, so as to determine the soil water content [10].

The advantages of Tension meter method: low cost, can set up multiple testing point, high intensity, long service life, easy to replace supplement, direct reading meter reading fast and exact,pipe length test range, continuous real-time online measurement. Disadvantages of the tensiometer method: Tension into water content is a nonlinear energy relationship, the calculation is complex; Affected by soil physical and chemical properties, the error is large. There are hysteresis and loop phenomenon in the measuring process, period is long.

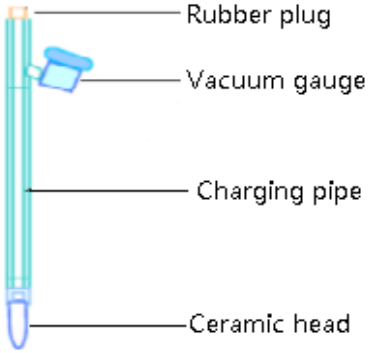

Fig. 1 schematic diagram of tension meter

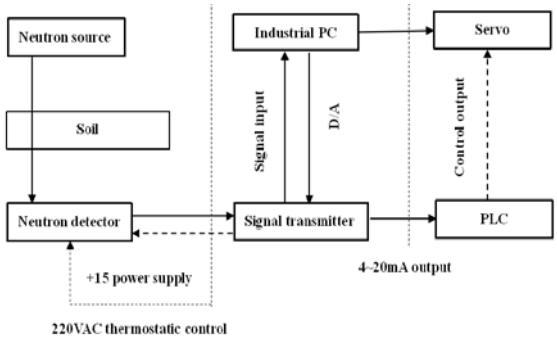

Fig. 2 Working principle of neutron moisture meter

3.3 Neutron ray method

Neutron ray method is one of the ray methods. Neutron ray method is based on the fact that other

elements do not have the characteristic of hydrogen element, which can slow down neutrons[11].The principle of measurement is as follows: the neutron source is buried in the soil to be measured, and the neutron source emits high-speed fast neutrons through fission reaction, and the fast neutrons have irregular collisions with the atoms and ions of soil components.The fast neutrons lose energy, and their speed decreases and become slow neutrons . The hydrogen content is proportional to the density of the slow neutrons formed by the fast neutrons losing energy. According to the density of slow neutrons near the neutron source and the functional relationship between slow neutrons and water molecules, the soil water content can be obtained.

The working process of the neutron moisture meter is shown in figure 2. The neutron ray emitted by the neutron source is transmitted through the soil and moderated by the soil. The neutron detector receives the neutron rays which are slowed down and converted into pulse signals, the pulse signal transmitted to the signal transmitter, the signal transmitter to the pulse signal transmitted to the computer machine and PLC control system, computers to manipulate the corresponding calculation to get the moisture value.

The advantages of neutron method in measuring soil moisture are as follows: continuous fixed-point monitoring, no damage to soil structure, fast measurement speed, small measurement deviation and large measurement range. Shortcomings of neutron method: it is greatly affected by the difference in physical properties of soil, difficult surface measurement, environmental pollution by radioactive sources, and harmful to human body.

3.4 Infrared method

Infrared ray method is a non-contact moisture measurement method. Its principle is the moisture of the substructure hydroxyl (OH) of vibration absorption of infrared light[12].When irradiating the soil with infrared light of a specific wavelength, the energy of part of the infrared light will be absorbed by the water contained in the soil, and the more water there is, the more energy will be absorbed .Generally, two wavelengths that are not strongly absorbed by water are used as the reference wavelength and one that is strongly absorbed by water is used as the measurement wavelength. The method combining the three wavelengths is used to detect and calculate the reflected light energy ratio of the reference wavelength and the measurement wavelength.

When the infrared light is transmitted or reflected from the soil and absorbed by water molecules as part of the energy, the soil moisture content can be calculated through the attenuation of the infrared light energy. Use beal's formula for calculation $I_m = I_0 e^{-\alpha W}$.

Working principle of infrared moisture meter is of high precision infrared filter is installed on the wheel, take turns by measuring the wavelength of the light filter and reference wavelength light, through the filter of beam focusing on soil samples.The photodetector receives the reflected light and transmits it to the computer with an electrical signal.The water content of the soil can be calculated from the proportional relationship between the measured wave and the reflected electric signal of the reflected wave.When measuring soil moisture, the commonly used measurement wavelength is 1.94 μm. This wavelength of infrared light can be strongly absorbed by water molecules.

Advantages of using near infrared ray to test soil moisture: non-contact measurement, non-destructive, not affected by soil thickness and solid phase composition, quick response, high measurement accuracy, remote measurement and real-time analysis can be realized. Disadvantages: affected by soil surface water porosity and surface roughness, it can only measure soil surface water content.

3.5 Dielectric method

The dielectric constant of solid materials (dry soil, sand, gravel, etc.) is generally no more than 5, the dielectric constant of soil air is 1, and the dielectric constant of soil is about 80 [13]. So the soil moisture content determines the soil dielectric constant. It is proved that it is an effective method to measure soil moisture content by measuring soil dielectric properties.Taking TDR as an example, the dielectric measurement method is introduced.

The principle of TDR measurement is that the propagation speed of electromagnetic wave is

closely related to the transmission medium. When electromagnetic pulse of propagates on the transmission line and encounters different media, reflection phenomenon will occur due to impedance discontinuity. According to the length of the probe and the velocity of electromagnetic wave propagation, the time of reflection electromagnetic wave was determined, and the dielectric constant of the substance was calculated. The dielectric constant changes greatly when the soil water content is different, so the water content of soil can be determined by the propagation speed of electromagnetic pulse.

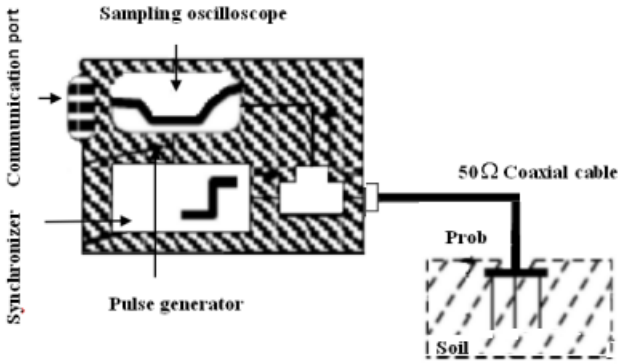

Fig.3 TDR structure diagram

TDR soil moisture velocimeter is composed of probe, transmission line, sampling oscilloscope and high frequency pulse signal generator. The structure diagram is shown in figure 3. TDR transmits electromagnetic waves with a frequency of 1MHz ~ 1GHz through the pulse signal transmitter and transmits them into the medium through the coaxial cable. By measuring the reflection time of electromagnetic waves at the end of the medium and obtaining the dielectric constant, the soil moisture content can be further calculated. The propagation of electromagnetic wave in medium can be expressed as:

$$K_a = (c/v)^2 = (ct/2L)^2$$

K_a - dielectric constant of soil; c - electromagnetic wave propagation velocity in vacuum; v - transmission speed of electromagnetic wave; t - transmission time; L - probe length

TDR method and drying method are regarded as the calibration of moisture measuring instrument, which is generally accepted at present to accurately measure soil moisture content. Its advantages are: continuous in situ rapid and accurate measurement, no damage to the soil matrix, good portability, long time location monitoring. Disadvantages are: expensive instrument, complex circuit design difficulty, cannot measure the shallow soil, step voltage will damage the device, sampling oscilloscope jitter error.

3.6 Dew point microvoltmeter method

Dew point microvoltmeter measures water potential by dew point method or hygrometer method [14]. The process of dew point microvolt method: first, apply a reverse current to the thermocouple to cool the thermocouple node below the dew point temperature, and the water vapor is in a state of oversaturation, and the water vapor condenses into dew on the surface of the thermocouple; Cut with reverse current at this time, thermocouple nodes quickly rising, reaches the dew point temperature thermocouple surface evaporation absorbs heat, thermocouple and cooled, its temperature maintain near the dew point temperature, the surface of the node is after the water evaporates, the temperature will rise again to the original temperature balance. The dew point temperature in the equilibrium state is recorded and converted into the water potential of the soil to be measured by the corresponding function.

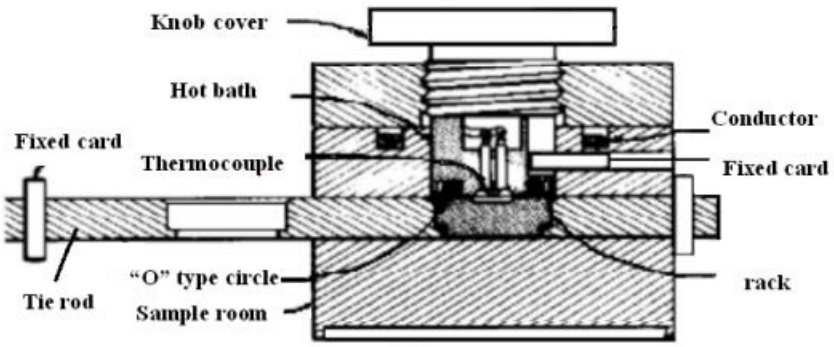

Fig. 4 Dew-point meter structure

4. Conclusion

This paper introduces several typical soil moisture measurement methods, a more detailed introduction of their measurement principles, measurement process, as well as advantages and disadvantages. Soil moisture measurement technology is involving multiple disciplines such as automatic control and engineering thermophysics. This reflects the broader development direction of soil testing technology, and also puts forward requirements of multidisciplinary collaborative innovation for the research and development team of this technology.

References

[1] Manzoni S, Vico G, Palmroth S, Porporato A, Katul G. Optimization of stomatal conductance for maximum carbon gain under dynamic soil moisture. Advances in Water Resources,2013,62:90-105.

[2] Choler P, Sea W, Briggs P, Raupach M, Leuning R. A simple ecohydrological model captures essentials of seasonal leaf dynamics in semi-arid tropical grasslands[J]. Biogeosciences, 2010,7(3):907-920.

[3] Eran S, Tammar K, Yechezkel M, et al. Microsensing of water dynamics and root distributions in sandy soils[J], Vadose zone Journal,2008,7:1018-1026.

[4] Carlos M P V, Jan W H, Alvaro M, et al. Soil water retention measurements using a combined tensiometer-coiled time domain reflectometry probe[J]. Soil Science Society of American January,2002,66:1752-1759.

[5] Peng Li, Remote sensing inversion and change monitoring of ecological water information index parameters in the upper reaches of minjiang river[D], Chengdu university of technology, 2016:12.

[6] Dickinsona C, Siqueiraa P, Clewleyb D, et al.2013. Classification of Forest Composition Using Polarimetric Decomposition in Multiple Landscapes[J]. Remote Sensing of Environment, 131:206-214.

[7] Dietz AJ, Kuenzer C, Gessner U, et al. 2012. Remote sensing of snow -a review of available methods [J]. International Journal of Remote Sensing, 33(13):4094-4134.

[8] Du Y. 2008. A new bistatic model for electromagnetic scattering from randomly rough surfaces [J]. Waves in Random and Complex Media, 18(1):109-128.

[9] Li Xiujuan, Research on water-saving irrigation control system of modern agricultural facilities[D], Hefei university of technology, 2007:23.

[10] Wu Tao, Research on online detection method of soil surface water content based on digital image processing[D], Jiangsu university, 2007.35.

[11] Guo Tao, Yu Hongbo, Review on determination methods of soil moisture content [J]. Inner Mongolia science & technology & economy. 2008,3(397):66-67.

[12] Xu chunyan, Review of studies on dynamic changes of soil moisture in jinghui canal irrigation

area, groundwater, 2012,34 (2):6-8.

[13] Cichota R, Hurtado A L B, Lier Q J. Performance of a multi-level TDR system exposed to tropical field conditions-A time-space comparison with tensiometry[J]. Journal of hydrology, 2008, 352:181-190.

[14] He Qihua, He Yonghua, Bao weikai, Dynamic changes of soil moisture in arid and semi-arid regions [J]. Acta hilly sinica,2003.21(2):149-156.