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Soil quality — Guidance on soil temperature measurement

Qualité du sol — Recommandations relatives au mesurage de la température du sol

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This document was prepared by Technical Committee ISO/190, *Soil quality*.

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Introduction

Soil temperature varies continuously in response to climate and meteorological changes and the interaction of soil and atmosphere. Some of the factors that affect soil temperature include diurnal and annual cycles, and irregular episodic changes in weather (i.e. radiation, cloudiness, drought, humidity, atmospheric temperature, rainfall, cold events). Landscape formation, regional differences, vegetation and soil management practices by humans also affect soil temperature. The other major influence on soil temperature variation is depth below the ground surface, with the soil temperature shifting in peaks moving deeper in the soil profile[2].

Soil temperature variations across day and year can be quite important. In boreal conditions within the year, soil temperature can pass from −15 °C to more than 15 °C at 5 cm depth. If in drylands in Mediterranean areas, the temperature can reach 40 °C at depth and more than 50 °C at the ground surface. With global warming, soil temperature tends also to increase in the same order as atmospheric temperature as demonstrated in various studies[3],[4].

Soil temperature needs to be measured being crucial for biogeochemical processes such as length of growing season, decomposition of soil organic matter, rates of mineralization and nutrient assimilation by plants as well as plant productivity. Soil temperature changes with depth influence many soil characteristics, such as microbial activity, chemical reactions, nutrient cycling, and many other processes.[2] It is known that soil organic matter is more easily decomposed by microbes activated when the temperature is raised if appropriate water content is available and temperature stays in a range favourable for microbes. Soil temperature can then be used as a proxy for the risk of carbon dioxide emission from target land.

Soil temperature is, as mentioned earlier, also a basic parameter in agricultural sciences and industries since it directly affects plant growth. Soil temperature has a strong influence on the microbial mineralization such as ammonification of nitrogen contained in organic forms to ammonium and nitrification thereof to nitrite and nitrate in agricultural soil. This contributes to growth, especially during sprouting. In agricultural businesses, using greenhouses, controlling soil temperature is a key to successfully growing vegetables for a good harvest by optimizing the growth speed and depressing the activities of worms and other soil organisms that eat vegetables. In golf courses, soil temperature is continuously monitored for proper maintenance of greens to condition the grass growth, leaf colour and green density.

In the civil engineering field for ground disaster prevention, soil temperature is used as a useful indicator suggesting groundwater flow routes. By carefully measuring soil temperature at many points in sloping ground to map the values 3-dimensionally, water streams underground can be tracked. As groundwater can be a trigger for the start of massive soil blocks sliding on a slope and an accelerator of the movement, draining groundwater therefrom reduces the risk of landslides. Thus, soil temperature is helpful in efficiently managing landslide prevention work.

The procedure for soil temperature measurement depends on the accuracy required for the given purpose for which the data are required. To know a soil temperature range in target land for climate change studies, the measurement can be done in a simple and quick way which indicates soil temperature as an approximate value. In contrast, to precisely map soil temperature distributions in the ground for slope disaster prevention, the temperature should be carefully measured to obtain not approximate but exact values. Selection of appropriate measurement methods for soil temperature should be discussed prior to site investigation.

Soil quality — Guidance on soil temperature measurement

1 Scope

This document outlines methodologies for soil temperature measurement and provides guidance on the selection of a measurement method depending on measurement purposes.

It also gives guidance on characteristics, performance and use of infrared (IR) thermometers which is now widely applied to obtain rapid measurements and thermistors which have been commonly used to obtain more accurate measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11074, *Soil quality — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
soil temperature
temperature measured at a targeted spot in the soil or at the soil surface

4 Fundamentals

4.1 Principle

Soil temperatures are measured for specific purposes. As is well known, carbon dioxide is emitted from the ground as a result of organic carbon decomposition in soil in a temperature range where microbes are active and able to decompose the organic matter. The soil temperature range, therefore, works as a good indicator of carbon emission risks. In this context, soil temperature can be measured as an approximate value, rather than as an exact value of high accuracy. For the purpose of climate change studies, quick measurement of soil temperature is thus allowable, the precision of which is not necessarily the same compared to other methods conventionally applied.

When the primary interest is in soil temperature distributions in target land, obtainable information can include indication of groundwater flow locations that directly affect soil temperature. On slopes, where groundwater streams channel the ground, they destabilize it and can cause the surface ground to move. Differences in soil temperature between spots, even if very small, can indicate spatial locations of groundwater flows. Soil temperature should thus be determined at high accuracy in order to make the differences meaningful. The higher the accuracies of obtained temperature values, the more clearly water flows can be indicated in the ground.

As described in 4.2.2, there are a variety of direct temperature measuring devices such as thermometers that can be used to measure soil temperatures. The most convenient to use are often thermistors. They typically give the value to an accuracy of 0,01 °C and have been widely used for a long time as a practical instrument when exactly determining the temperature of target objects including soil.

IR detection has been applied to check fever in humans by applying an IR thermometer at the exit of the ear canal or simply pointing the measuring device directly at the skin surface on the forehead or wrist. The measurement can be completed in less than 10 s at an accuracy of 0,1 °C at least. By applying an IR thermometer to a hole drilled in the ground, soil temperature can be similarly, easily and quickly measured. It is not necessary for an IR thermometer to be attached directly to the wall or bottom of a hole in the ground. Instead, it can be placed at the top of a hole. This operability enables remote measurement of soil temperature.

The relationship between soil temperature values measured by thermistor and IR thermometer is illustrated in Annex A, Figure A.1. No significant difference is found between the two values but the gap in the accuracy exists as mentioned above.

As described in 4.2.2 and 4.2.3, soil temperature measurement methods can be classified into two options. One is a conventional method, and the other a quick method. The former is applied for given purposes to obtain exact temperature values, even if taking time, while the latter to obtain approximate values quickly. Quick methods can be characterized as screening methods, the term of which is defined in ISO 12404:2021, 3.2.

4.2 Soil temperature measurement methods

4.2.1 General

Temperature cannot be measured directly. It can only be estimated by its influence on some properties of matter that responds to variation in the intensity of heat in an object's body where the examples of matter include mercury, bimetal strips, platinum wires, thermocouples and gas. Changes with temperature in properties such as volume, length, electric resistance, thermal electromotive force (emf) and pressure have been found most useful for practical temperature measurement. In order for all of these properties to give the same indication of the temperature of a given body, calibration techniques have been established, and certain standard references have been agreed upon. Thermometers are instruments built to take advantage of any of these properties of matter.

NOTE Mercury is no longer used as such matter due to its toxicity. However, for good understanding of temperature measuring principles, it is mentioned as matter which was typically used historically.

When estimating the temperature of a target object, matter responsive to the object's heat is brought in contact with the object. The temperature-dependent properties of matter such as volume, length and pressure are observed by applying measuring equipment to the matter. The observation is started after confirming the thermal equilibrium conditions between the target object and the matter responding to the object's heat, as well as between the matter and its properties responding to the heat of the matter. This procedure provides highly accurate estimation of a target object's temperature based on exact determination of the properties. However, it takes time for both object and matter and for both matter and properties to reach the respective equilibriums.

Target objects for temperature measurement emit heat-generated signals, the intensities of which relate directly to the temperature. One of the typical signals is IR radiation. When observing the signal intensity, no thermal equilibrium conditions need to be brought about because the signal intensity is observed without matter such as those mentioned above working as an object's proxy. This permits the IR intensity to be measured quickly. Signal intensities can be remotely observed since signals are collected without contacts with an object. IR observation, thus, provides quick and remote observation of target object temperature. However, the accuracy is not necessarily so high as achievable with direct temperature measurement due to the attenuation of the IR wave while propagating from the object to the sensor.

4.2.2 Conventional measurement

There are numerous kinds of thermometers that can be used for measuring soil temperatures. Some of commonly used types are liquid-in-glass, bimetallic, Bourdon and electrical resistance thermometers. The choice of a thermometer for a given application depends, among other things, upon availability, required accuracy, accessibility to location of sensing element and the element's physical size. These have been brought about with efforts to increase the accuracy of temperature measurement. Thus, they are used for such a purpose and the method using them is called conventional measurement.

a) Liquid-in-glass thermometers

Instruments of this kind should be checked against a standard thermometer or at a reference point, such as the ice point, once each year to adjust for any change in calibration that can result from irreversible changes in volume of the glass bulb.

b) Bimetallic thermometers

Bimetallic thermometers are made by welding together two bars of different metals and rolling the resulting compound bar into a strip. The metals generally used are invar (nickel-iron alloy) and brass or invar and steel. Because of the difference in linear expansion of the two metals, the strip bends in response to temperature changes. An arm or pointer to indicate the amount of angular deformation is attached to a helical coil of the bimetallic strip. The angular deflection is calibrated in terms of temperature. This kind of thermo-sensing element is used extensively in soils laboratories for regulating constant-temperature baths, environment chambers and constant-temperature rooms. Bimetallic thermometers are generally less precise than mercury-in-glass thermometers. The advantages responsible for their use are their lower lag, increased durability and self-recording performance.

c) Bourdon thermometers

This type of thermometer consists of a curved tube of elliptical cross section connected through a capillary to a bulb that is inserted into the soil. The system is completely filled with some organic liquid (e.g. diethyl ether, xylene, methanol). The bulb is usually long and about 10 mm in diameter. An increase in temperature causes the organic liquid to expand and increase the pressure inside the soil bulb and the curved capillary tube. This causes the curved tube to become slightly less curved, thus changing the position of the pointer attached to it. When the bulb is placed horizontally in the soil, it will give a good indication of the temperature at that depth. If vertically, an integrated or average temperature over a depth interval can be obtained.

d) Thermocouples

Thermoelectric junctions, called thermocouples, are made by joining two dissimilar metals at two different places, to form two junctions. If the entire circuit is composed of only two metals, the total electromotive force in the circuit is proportional to the difference in temperature of the two junctions. One junction is called the measuring or hot junction, and the other the reference or cold junction. For temperature measurement, the reference junction is kept at a constant temperature, for example, in melting ice. The electrical potential produced is usually measured with a potentiometer when precise measurements are desired. Also, a galvanometer or millivoltmeter can be used.

e) Electrical resistance thermometers

There are two types of resistance thermometers in general use. Simple, as described here, and thermistors as described in 4.2.2 f). One type depends upon the increase in resistance with an increase in temperature of a wire such as nickel-chromium alloy, copper, silver or platinum. The temperature coefficient of resistance of platinum wire at 0 °C is about 0,35 % per degree. Resistance changes are measured with a bridge, or in some cases a potentiometer, and are related to temperature changes. Recording bridges or potentiometers yield a continuous record of resistance and hence of temperature. However, these have been replaced with integrated circuits with amplifiers.

NOTE 1 Electrical resistance thermometers including thermistors described in f) are not necessarily designed to stick into hard materials such as tough soil and the hard ground. Thus, these thermometers are usually applied in a hole drilled at a spot and a depth targeted.

f) Thermistors

The other type of electrical resistance thermometer available is a semiconductor called a thermistor. Thermistors have a high negative temperature coefficient of resistance, of the order of 4 % per degree Celsius. This coefficient is opposite in sign to, and about 10 times larger than, that of platinum resistance thermometers. Thermistors are available in various shapes, e.g., spheres, discs and rods, all in various sizes, thus permitting great flexibility in application.

To obtain exact soil temperature values, thermistors are commonly used by placing at a target depth in a hole drilled in the ground. It normally takes time for a thermistor to reach thermal equilibrium with soil after being attached directly onto the wall or bottom of a hole. Temperature measurement is started after confirming the equilibrium conditions of the thermistor. Soil temperature can be determined in the range of −50 °C to 150 °C to an accuracy of 0,01 °C at least.

Minimizing the dead space at the interface between the device sensor and the target surface enables a thermistor to correctly measure soil temperature. However, this requirement can sometimes present difficulties, especially at locations deep in a hole.

NOTE 2 Platinum resistance thermometers, a type of thermistor, have been used which have integrated circuits in themselves.

4.2.3 Quick measurement

When requiring quick measurements of soil temperature, using IR thermometers is a practical option. IR thermometers are devices which estimate temperature from a portion of the thermal radiation or black-body radiation emitted by the object being measured. By measuring the amount of IR energy emitted by the object and its emissivity, the object temperature can be determined within a certain range of its actual temperature. A potential problem is that at near ambient temperatures, readings can be subject to error due to the reflection of radiation from a hotter body, such as the person holding the instrument, rather than radiated by the object being measured, and then to an incorrectly assumed emissivity.

The design consists of a lens to focus the IR thermal radiation on to a detector, which converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This permits temperature measurement from a distance without contact with the object to be measured. Thus, IR thermometers are called non-contact thermometers, to describe the device's ability to measure temperature from a distance, and are useful for practically measuring temperature under circumstances where thermocouples, thermistors or other probe-type sensors normally used for conventional measurement cannot be applied or when being forced to give up obtaining accurate data by conventional measurement for a variety of reasons.

IR sensors are commercially available as thermometers for fever in humans. These are designed to detect IR waves emitted from the drum to the exit of the ear or from the skin surface (e.g. forehead, wrist). Thus, when needed to quickly measure soil temperature, an IR sensor can be held close to a target spot in a hole drilled in the ground or placed at the top of the hole together with an optical lens to focus the IR waves on the sensor. This advantageous procedure permits soil temperature measurement to be at any depth in a hole at a site, by carefully applying the lens, even if the measurement target spot is deep in a hole.