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EXPERIENCES WITH THE USE OF A NEW MEASURING METHOD TO DETERMINE THE FREE WATER CONTENT IN SOIL

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Abstract. New method for the determination of the water content of the soil based on the thermo-pulse method of Collins and Lhotzky was developed.

Keywords: free water in soil, new measuring method

INTRODUCTION

Usually, the agricultural industry judges the necessary water supply to plants subjectively. Colour and consistence of the soil and, if appropriate, wilting symptoms of the plants are consulted. It is not surprising that the correct quantity of water is hardly ever met which the plant requires for its well-being.

Too much or a lack of water have a negative effect on the matabolism of the plant. Water, nutrition and energy requirements are impaired. Yield and quality suffer accordingly.

It is therefore important to keep the fluctuations of the moisture content of the soil within narrow limits. Information on the moisture content at particular places, as for instance near the roots of the plant are a pre-requisite for being able to control the water supply.

Hence a measuring method is required for the determination of the water content of the soil and which can be used to control the subsequent water supply.

Such a method has now been developed at the Institute of Agri- and Fruit-culture in collaboration with the RWTH Aachen. It is based on the thermo-pulse method of Collins and Lhotzky [1] and makes it possible to follow the development of the water content of the soil at selected places without destructive interference.

It is the purpose of this paper to describe this new method.

MEASURING METHOD AND APPARATUS

Measuring method

The thermo-electric method to determine the moisture content in materials makes use of the fact that the thermal penetrativity $b = \sqrt{\lambda c_p \rho)}$, i.e. the root of the heat conductivity λ and the heat capacity per unit volume ($c_p \rho$) increases with increasing water content for all materials examined so far.

To determine the thermal penetrativity, a thin wire is embedded reproducably in the medium at the place where the moisture content is to be determined. It then receives a defined quantity of heat by passing an electric current through the wire for a defined time interval of a few seconds at a potential difference which is being measured. From the change of the resistance of the wire, its temperature is being determined at the same time. The larger the penetrativity of the medium, the smaller is the recorded

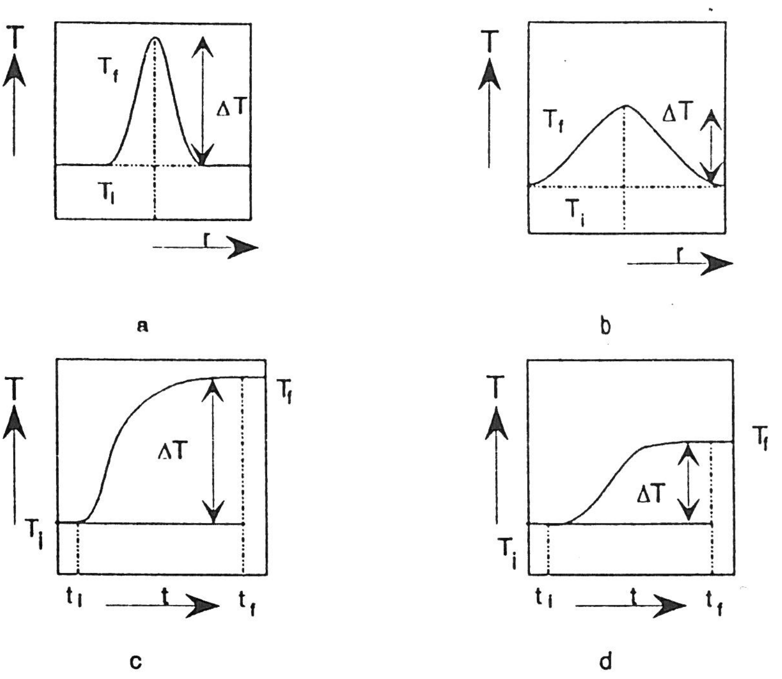

Fig. 1. Temperature of the sensor and surroundings during a heat pulse as function of distance from the wire for a small (a) and large (b) thermal penetrativity and as function of time for a small (c) and large (d) penetrativity. Initial temperature T_i - broken line, final temperature T_f - continuous line.

temperature rise during the duration of the heat pulse, as shown in Fig. 1a and 1b. At the higher penetrativity the temperature rise extends further into the medium during that time interval. Figure 1c and 1d shows how the temperature in the wire rises with time. The higher temperature at a low penetrativity is reached at about the same time as the lower temperature of the wire in case of a lower penetrativity of the material.

The short heating pulse influences only an area of a few millimeters in depth around the wire which decays very quickly and hence permits well-defined local measurements in selected regions of the medium at very short time intervals.

Because the heat input is kept constant for any given material - although it can be adjusted to suit the nature of the material - the penetrativity is inversely proportional to the temperature rise in the wire, i.e., the temperature difference $\Delta T = T(t_f) - T(t_i)$ before and after applying the heat pulse. Only these two characteristic values are necessary for the determination of the water content of a material. The inverse of the temperature difference $B = 1/\Delta T$ as function of time and temperature rises monotonously with the water content of the material.

To obtain a quantitative measure of the water content, the system has to be calibrated.

Instrumentation

Figure 2 shows a diagrammatic sketch of the measuring system for the electrothermal surveillance of a drying process.

The sensors are thin wires with a diameter of 0.25 mm and usually a length of 150 mm. They are connected to the evaluation unit via wires and insulating screw joints. Up to eight sensors can be connected to one measuring unit. An extension to accomodate more sensors is possible. The recorded signals are saved on a hard disk and can be fed into a computer via an intergrated serial port for

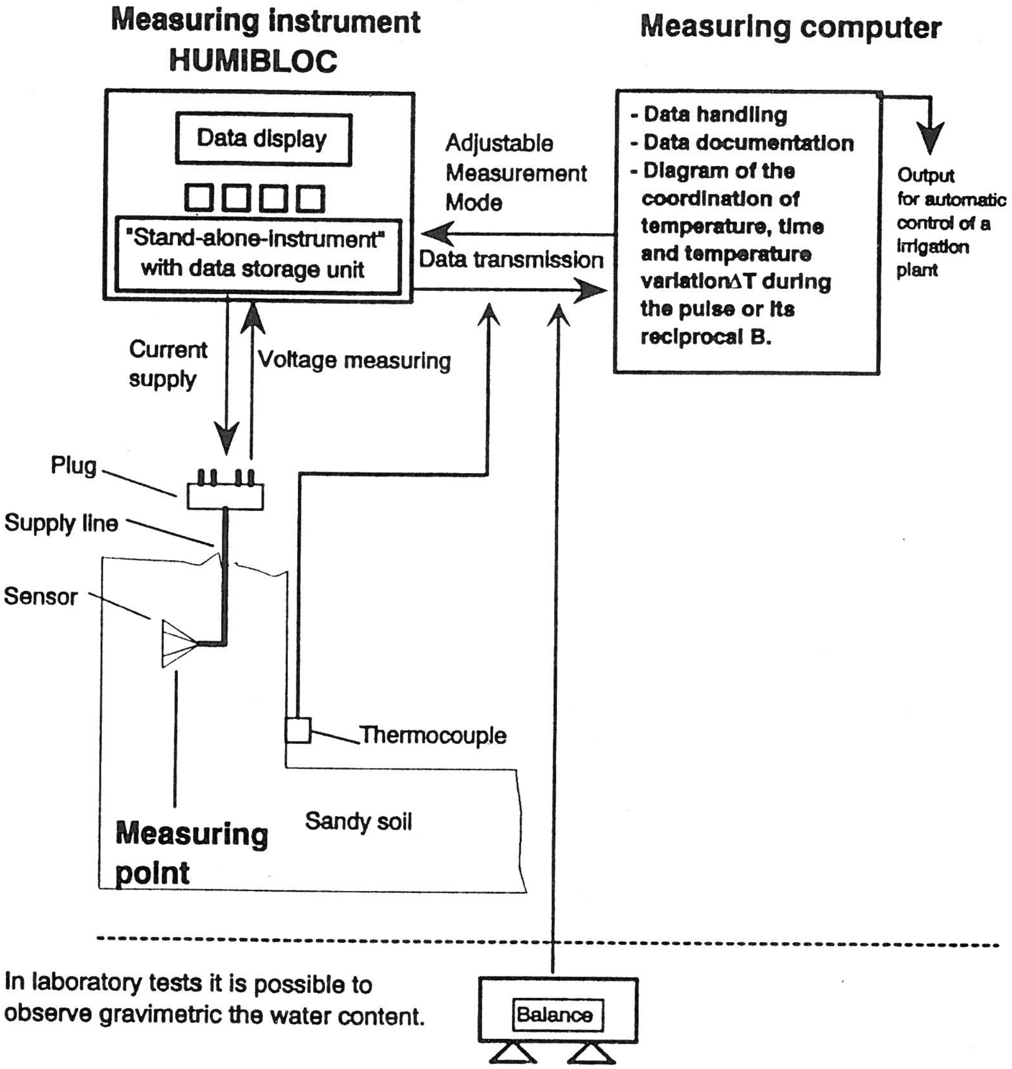

Fig. 2. Diagrammatic sketch of the measuring system for the electro-thermal surveillance of a drying process.

further evaluation.

Several graphic presentations can be used to display the data on the screen: (i) the temperature T *vs* time, (ii) the temperature difference ΔT *vs* time, (iii) the inverse of the temperature difference $B = 1/\Delta T$ *vs* time.

At the same time temperature signals from thermocouples and signals from a weighing balance can be recorded, documented and graphically displayed.

The graphic presention of the results permits a particularly simple and lucid view of the development of the moisture content of a system.

CALIBRATION FOR THE DETERMINATION OF THE ABSOLUTE MOISTURE CONTENT IN SANDY SOILS

For the calibration of the measuring signal to the moisture content homogenized soil with a known average moisture content is usually used. However, this method has some disadvantages. Different samples with different moisture content have to be prepared. The sensors have to be placed accurately always in the same way, a method which is time consuming and subject to errors. This is avoided by using a drying method in which the wire has only to be placed once into one sample. During the drying process the loss of water is determined continuously by weighing. Hence, a calibration over a wide range of moisture content is obtained from a single experiment. At the end of the drying process, the thermal contact of the sensor can be checked and corrective adjustments can be applied, if needed.

Initially, tests were carried out using larger samples of 2.5 kg sand to which 500 g water were added. After mixing for several minutes the sample was sealed in a plastic bag and left for several days in order to ensure a homogenized mosture distribution. After that the mixture was filled into a flat tray measuring 200x300x40 mm. Several sensors were placed at different levels into the soil. During the drying process, the signals began to diverge, indicating that the drying process did not proceed reasonably uniformly over the thickness of the sample. In order to achieve a reliable calibration the test bodies have to be thin enough for the drying process to proceed reasonably uniformly over the whole thickness so that local differences become small and can be neglected.

For the final calibration test bodies with a height of only 10 mm were used, made up of 200 g of dry sand into which 20, 15, and 0 % water was mixed. Again the samples were stored for several days in a sealed plastic bag. After that the mixture was placed in a dish. The 150 mm wire was placed at a depth of 5 mm. When weighing the dish the current supply was disconnected from the sensor wire. Figure 3 shows the change of the total moisture content with time for test samples containing 15 and 20 % of water.

The rate of drying was the same for the different test samples, namely 1.6 g/h, indicating that the sample thickness was sufficiently small to ensure a uniform moisture distribution right across the sample for the whole duration of the experiment. Figure 4 shows the measuring signal obtained from the three sand test bodies with time.

The initial values for ΔT lie between 5 and 58 K. The measuring signal for the dry test body remains nearly constant over the whole measuring period whilst the signals for the 15 % and 20 % moisture approach steadily a final value of 57 K, close to the signal of the dry sample.

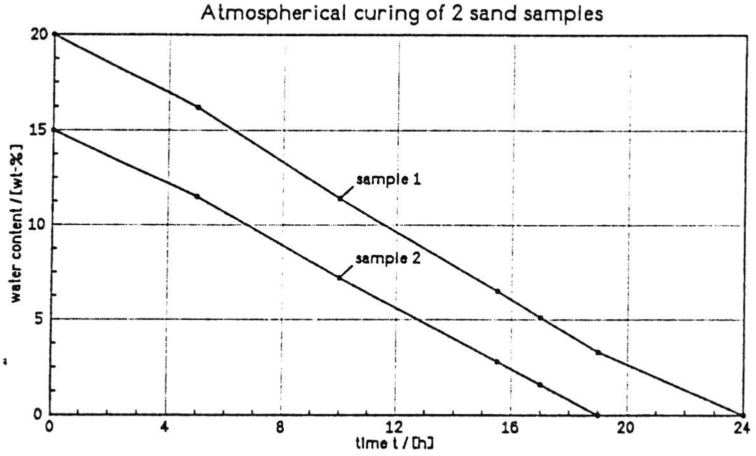

Fig. 3. The change of moisture content of sand with drying time.

For the calibration the temperature rise corresponding to a given moisture is plotted versus the moisture content of the soil. Figure 5 shows such a plot for the test body with an initial moisture content of 20 %.

The curve for the measuring signal as function of moisture content can be approximated to three straight line regions:

$\Delta T = 50$ K/wt−% φ for $0 < \varphi < 4$ wt−%
$\Delta T = 30$ K/wt−% φ for $4 < \varphi < 12$ wt−%
$\Delta T = 22$ K/wt−% φ for $12 < \varphi < 20$ wt−%

where ΔT stands for the temperature rise at the sensor during one heat pulse and φ for the percentage water content of the soil. The resolution is largest between 0 and 4 %. Hence it is largest at the critical water content just before the soil is drying out. Since the penetration depth does not only depend on the moisture content but also on the temperature of the soil, separate calibration experiments have to be carried out for temperture regions which deviate greatly from normal soil temperatures.

The results on thin samples have confirmed that the new measuring method

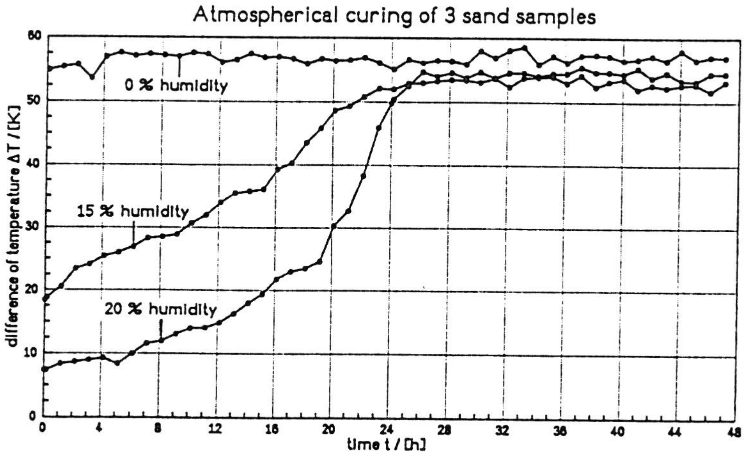

Fig. 4. The temperature rise ΔT caused by a heat pulse as function of drying time for the three callibration test bodies of sand with different water content.

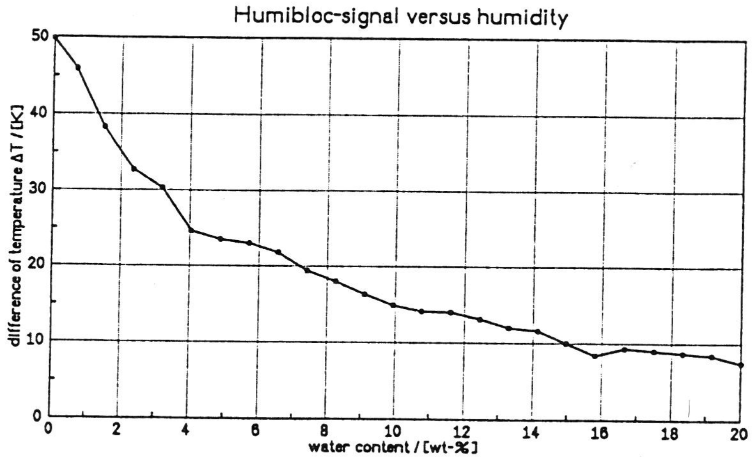

Fig. 5. The temperature rise ΔT caused by a heat pulse as function of the moisture content of a sandy soil.

records the local moisture content reliably if the sensors are placed correctly. If Humibloc measuring signals are recorded from several levels the course of the moisture content for the whole material can be determined. The new system gives therefore more information which cannot be received with the Lysiometer method, for example. Even so, it appeared sensible to carry out also comparative measurements with a Lysiometer. For this purpose two sensors were placed into several types of soil in a Lysiometer which was closed at the bottom. During the experiments the container was left open for one day to obtain a loss of water by evaporation. The following day the container was covered in order to obtain an equalisation of the water throughout the container. After this period a nearly uniform moisture content was achieved over the whole container, as was ascertained by drying samples taken from a Lysiometer which was run in a similar way.

When considering the resolution of the instrument for the determination of the moisture content it is useful to recall that the capacity of taking up water in sandy soil lies by a volume fraction of about 30 %. Beyond this value, which corresponds to a 20 % water content of the soil, water begins to appear as wetness. The volume fraction of water in agriculturally used soils usually lies between 5 and 25 %. For an optimal supply to the plants the limits are narrower. When changing the moisture content from 25 to 5 % the signal of the measuring instrument doubles, rising steadily over the interval. If only a small fluctuation of the signals is to be expected, the circuit is adjusted in such a way that a high resolution is obtained over the region. If a broad region is expected it may be useful to linearize the characteristic of the sensor in order to improve the resolution and simplify the evaluation of the results.

SURVEILLANCE OF THE IRRIGATION OF AN APPLE TREE IN SANDY SOIL

The new method was used for the first time to survey the moisture content of apple trees which were planted into cylindrical containers with a diameter of 350 mm and a depth of 600 mm. Watering was achieved by a water container with connecting pipes by rising for a short time in order to flush water from the bottom upwards to the pot of the plant. Once the pot was soaked, the container was lowered again to drain any surplus water. Sensors were placed at depths of 50, 150 and 400 mm in the area of the plant roots. The changes of the water content of the soil in the pot was followed for three days. During this time the environmental temperature varied between 12 and 21 °C. Figure 6 shows the results. The times of flushing are shown by arrows. The measuring signals show values ranging between 3 and 40 K.

With reference to the calibration measurements the following conclusions may be drawn. The sandy soil reached a moisture content after irrigation of about 20 %. After 14 h of drying at about 15 °C between 4-6 % moisture are reached in the upper level of the soil, 9-10 % in the middle region and about 15 % in the lower region. Since the moisture content never falls below 4 % it would probably be better to reduce the number of flushings to three times a day and avoid in this way soaking the soil too often and washing out too many nutrients.

COMPARISON OF THE NEW METHOD WITH THE THERMO-PULSE AND THE HOT WIRE SYSTEMS

The new thermo-electric pulse system offers a number of advantages over the thermo-pulse system used most commonly at present [1]. This system, as does the new one, uses a single wire as sensor. However,

- the thermo-pulse system uses the time which it takes to discharge a condensor as its primary measuring signal. It gives an indirect information of the temperature of the wire integrated over its length and the duration of the pulse whereas with the new system the duration of the temperature is only averaged over the

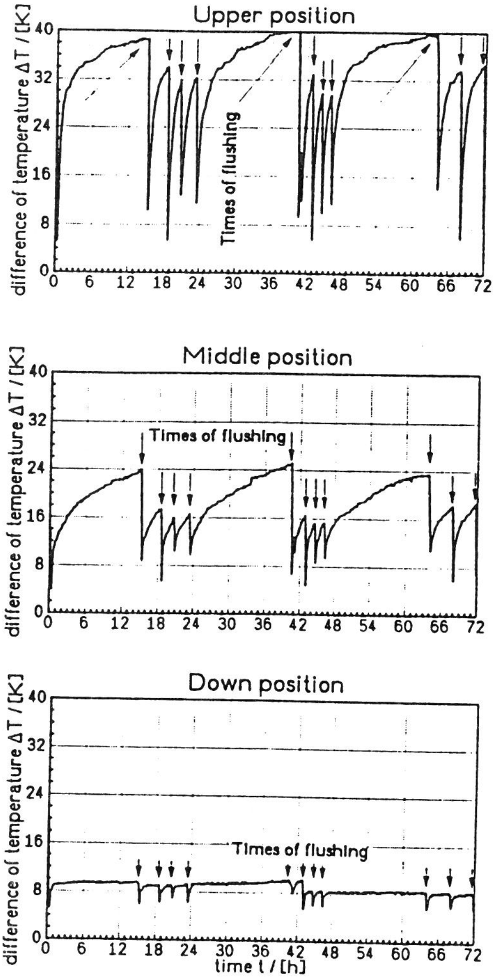

Fig. 6. The temperature rise ΔT during a heat pulse at a flushing irrigation of the plant pot of an apple tree as function of time.

ture of the wire integrated over its length and the duration of the pulse whereas with the new system the duration of the temperature is only averaged over the length of the wire. During the duration of the pulse the temperature is recorded continuously;

- the time of discharge depends on the initial temperature of the wire whilst the temperature rise used in the new system is to a first approximation independent of the temperature;
- the tolerances of the condensors used in the thermo-pulse system and the temperature dependent loss resistances are additional sources of error which do not occur in the new system, since the current and the potential difference across the wire are recorded continuously. From these data the resistance of the wire and hence its temperature are calculated;
- since in the thermo-pulse method the resistance of the supply wires are connected in series with the sensor wire, temperature and length of the supply wires influence the discharge time of the condensor. This effect is the larger the longer the distance between condensor and sensor is. With the new method the potential difference across the sensor is measured according to the four-point-method with a high resistance and hence neither cable nor contact resistances can falsify the measuring signal.

Advantages are also obtained in comparison with the hot wire method (D1):

- whilst with the thermo-electric pulse method only a low priced sensor wire is embedded into the material, the hot wire method requires a platinum wire and two thermo couples which are lost in each experiment;
- the hot wire method assumes a uniform initial temperature distribution;
- the time required per measurement is much shorter for the new method.

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