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Multi-point temperature measuring equipment for crop environment, with some results on horizontal homogeneity in a maize crop. 2. Equipment used.

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Summary

This paper reports on details regarding equipment used in obtaining field data on crop environment temperatures published earlier. Platinum resistances mounting and error analysis, calibration of these resistances and data logger requirements and modifications are dealth with. Finally equipment details regarding the actual collection of accurately scanned field temperatures are discussed.

Introduction

In an earlier paper (Stigter et al., 1976a) we have explained the choice of the sensor in our case of multi-point temperature measurements within a crop. The accuracy we needed, in view of the use of the data concerned (Stigter et al, 1976a, 1977; Stigter, 1977) and in relation to other sources of error (Stigter et al., 1976b), forced us to pay more than routine attention to data collection problems. In this second paper we discuss separately some details regarding errors and calibration of the sensors and regarding modification and field performance of the datalogger.

Sensor mounting and error analysis

In a section on thermometers used (Stigter et al., 1976a) we explained our choice of platinum resistance Degussa P4 thermometers in a waterproof protection and also protected from radiation but freely accessible to horizontal air movements at the height concerned. This protection against humidity and moisture together with a prevention of mechanical dammage of the glass holding the resistance wires, but

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without introducing large thermal contact resistances, was obtained by using a copper tube with silicon heat sink compound (Dow Corning 340) as embedding material. To ensure a constant long-wave emissivity during experiments regarding radiation errors, the copper tube got an opaque plastic sleeve. The sleeve was white to give a good protection against solar radiation (including reflected solar radiation from outside the partly open radiation protection during actual measurements (Stigter et al., 1976a)). After a few years of use some of these resistances became unstable due to large thermoelectric effects within the sensor. These glass resistances were replaced by Degussa with the ceramic type W60/2θ.

Points that are of importance in indoor error analysis of platinum resistances are listed by Werner (1962). Measuring methods may be classified as bridge type or potentiometric methods (e.g. Dauphinee, 1962; Tanner, 1963; Bolk, 1976). We have chosen for a four-wire measurement type to be classified as potentiometric. Fig. 1a shows the measuring principle near the sensor resistance.

This choice permitted a direct measurement, minimizing influences of lead wires and variable switch connection resistances. Our sensor leads were each connected to a pair of gold-plated contact pins, mounted in a plastic holder. These pins could be plugged into a sensor arm holding the connection with data collecting equipment. No problems were expected regarding sensor stability in time (e.g. Berry, 1962). For our case of a measuring current of 1 mA, self-heating is estimated under our measuring conditions to be about 4 mK. As we apply the current only intermittently, self-heating may be fully neglected in our applicaion. Calibration errors are discussed below.

Calibration of the sensor

The general equation relating temperature and resistance in our range of temperatures is

$$R_T = R_0 (1 + A \cdot T + B \cdot T^2) \qquad (1)$$

with

R_T, resistance at T °C
R_0, resistance at 0 °C
T, temperature in °C
A, constant (3.908×10^{-3} K^{-1} in standard DIN 43760)
B, constant (-5.784×10^{-7} K^{-2} in standard DIN 43760)

Within an overall field measuring accuracy of 0.05 °C we aimed at a basic thermometer calibration accuracy of 0.01 °C. This is more accurate than may be expected from the manufacturers' specifications, being one-third of DIN 43760 in our case (cf., for example, Collins, 1963; Bolk, 1976). Therefore all sensors used were individually calibrated.

It appears that $R_0 \cdot B \cdot T^2$ in Eq. 1 is a correction for non-linear response and B can be taken constant for all sensors. Omission of this term gives an inaccuracy of 0.1 °C at 25 °C if the temperature is calculated from $T = (R_T - R_0)/A \cdot R_0$. So an

Fig. 1. Diagram of the four-wire resistance measuring method and the modified form with a compensating voltage.

I = measuring current (1 mA).
R_T = Pt resistance ($\simeq$ 108 Ω at 20 °C).
E_a = potential to be measured (108 mV ± 4 μV).
E_b = potential to be measured (3 mV ± 4 μV).
E_{comp} = compensating potential (105 mV).

inaccuracy of 1 % in the estimation of R_0 and B is quite acceptable in this respect. Knowing the temperature T from the calibration and taking $R_0 = 100\ \Omega$, the correction term can be calculated which gives a linear relationship between R^*_T and T:

$$R^*_T = R_T - R_0 \cdot B \cdot T^2 = R_0 + R_0 \cdot A \cdot T \qquad (2)$$

R_0 and $A \cdot R_0$ can then be calculated with the linear regression method.

Comparing measured values and values calculated from Eq. 2 at the temperatures used for calibration, one obtains a measure of the calibration accuracy. Average discrepancies were of the order of 2 mΩ (0.005 °C) and maximum discrepancies were of the order of 8 mΩ (0.02 °).

Measurements were performed in a Colora Ultra thermostated bath, with shellflex 80 as the bath liquid. Fluctuations around the temperature values set were ± 0.015 °C. Measurements were made near 15, 20, 25 and 30 °C. Some checks with lines from seven temperature points did not give any improvements. Reference temperatures were measured with a Hewlett and Packard Quartz thermometer (± 0.01 °C) and as a reference calibration resistance we used a standard resistance from General Resistance which is calibrated annually within 0.5 mΩ at a standard bureau. Resistance determinations during calibration performances indoors were made with the same data logger as used in the field. This equipment is described below.

Data logger requirements and modifications

Using a measuring current of 1 mA, the sensitivity of the circuit of which Fig. 1a forms a part is about 0.4 mV/°C. To be able to measure and check the wanted overall accuracy of ± 0.05 °C, the resolution should be 0.01 °C. This means a resolution of 4 μV on a total drop of 100 μV over the resistances concerned, requiring a digital volt meter (DVM) of 5½ digits. In our case the DVM had 4 digits. Therefore a compensating potential had to be used (Fig. 1b).

The data logger, a Modulog from Intercole Systems, has the following relevant specifications:
— true differential input with an input impedance of 100 MΩ;
— interchannel drift correction with guaranteed 1 μV stability;
— integrating DVM with a scale length of 0–9999 and a maximum resolution of 1 μV;
— the commutating unit, with the preamplifier, can be separated from the main unit with the DVM, allowing the commutating unit to be placed near the sensors at a maximum distance of 300 m from the main unit;
— channel selection with a 3 pole reed relay;
— skip facility for groups of 10 sensors.

In order to measure temperatures as mentioned, the commutating unit was modified (Fig. 2 and 3). The modification consists of: (1) the facility to connect the Pt 100 sensors sequentially to a constant current source; (2) the insertion of a compensation voltage in the high input of the input amplifier. For the first purpose the guard of the input amplifier is no longer switched with the input signals but is permanently connected to the common connection of the temperature sensors. The guard relay is now available to switch the current source to the sensors. To keep things simple for the second purpose a resolution of 1 μV was chosen. The DVM than has a span of 10 mV, with one polarity, which corresponds with a temperature span of 25 °C. With a compensating potential of 105 mW temperatures between 12 and 37 °C could be measured with a resolution better than 0.01 °C. This potential was obtained from a current of 1.05 mA flowing through a resistor of 100 Ω in the high input line of the amplifier (Fig. 3). The current sources, Knick JB 98, and the resistor of 100 Ω must have a high overall stability, in the order of 10^{-5}. They were therefore placed in an oven with a constant temperature of 50 ± 1 °C. Another resistor of 110 Ω with a stability of 10^{-6} was also placed in the oven. In each scan this resistor was measured. Thus it was possible to determine the overall instability of the datalogger, excluding the scan relays, and compensate for it. This instability was in the order of 5 μV maximum.

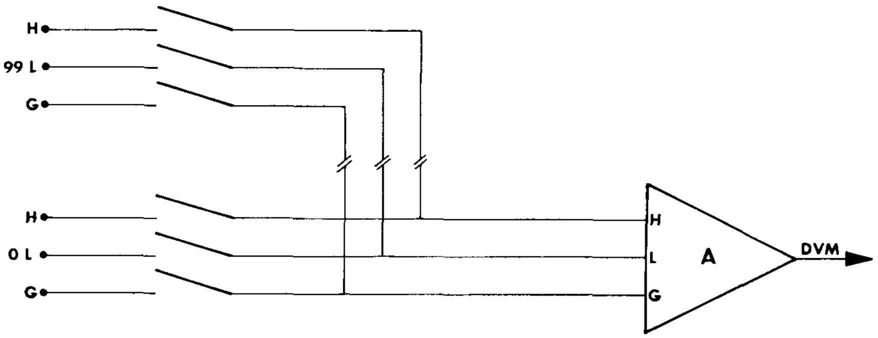

Fig. 2. Original input configuration of the datalogger for 100 sensors. H = high input; L = low input; G = guard; A = preamplifier.

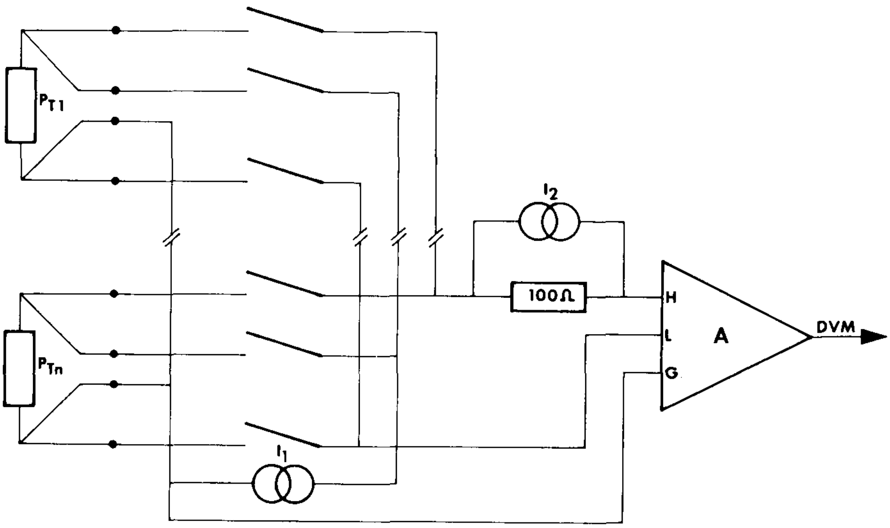

Fig. 3. Modified input configuration. H, G, L and A as in Fig. 2.
I_1 = measuring current (1 mA).
I_2 = current for compensating potentials (1.05 mA).

Discussion on the collection of crop environment temperatures

For the measurements of the crop environment temperatures, the scanning unit with the preamplifier was placed in the field near the sensors. In this way a minimum of sensor cable was needed, and a simple unshielded type could be used without affecting the accuracy.

The scanning unit was placed in a naturally ventilated hut, placed off-wind from the sensor area. During the periods the equipment was not used, condensation of moisture was prevented by electrical heating and forced ventilation within the hut.

Only ambient temperature changes affected stability, mainly because they caused temperature gradients across the reed-relays, resulting in thermal electromotive forces (emf's) in the order of 2 to 3 μV, with a maximum of 10 μV. Between experiments these thermal emf's could easily be determined by disconnecting the current sources.

The crop environment temperature measurements were part of a bigger research project (Stigter et al., 1977) in which different kinds of sensors were connected to the data logger.

The data were punched on paper tape, for further computer treatment, and simultaneously printed for checking on the spot. This checking proved to be very helpful in regard to immediate information on data collection and equipment performance. In order to reduce the amount of collected data without affecting the accuracy, the sample rates of different types of sensors were matched with their worst case time constants (Stigter et al., 1976b). For this purpose we used among other things a facility to skip the slower sensors during several scans.

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