Tech. Bull. Fac. Agr. Kagawa Univ., Vol. 41, No. 2 153～157, 1989

深さ平均地温の直接測定

鈴木晴雄

DIRECT MEASUREMENT OF AVERAGE TEMPERATURE AT DIFFERENT SOIL DEPTHS

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There is no standardized criterion for the measurement of soil temperature, an important environmental factor of crop rhizosphere. The ordinary measurement of soil temperature traditionally regards the value at a point of depth as the representative value. The proposed method requires the direct measurement of the average soil temperature of the ground surface down to a specific depth, the area where most of the roots are located. This value was compared with those obtained using the traditional method. The experimental results indicate that the accuracy of soil temperature measurement is greatly enhanced by the direct measurement of the average temperature of the different soil depths as compared with the average obtained from values at certain depths.

作物の根圏環境の中で重要な地温については，未だ統一された測定基準はない．本研究では，従来の地温測定がある深さ１点での値を慣習的に代表値としているのに対し，根群が多く分布するところの地表面よりある深さまでの地温平均値を直接測定することを提案し，比較実験を行った．実験結果によると，各深さの１点測定から求めた深さ平均の場合に比べて，深さ平均の直接測定によると，地温測定値の精度は大きく向上することなどが明らかになった．

1. Introduction

Although soil temperature is the most important environmental factor of crop rhizosphere, there is no definite criterion for its measurement. For example, the measurement time of soil temperature, the depth of measurement, and others differ with researchers in many cases. Especially, since soil temperature fluctuates in a wide range of depth, it is necessary to consider a standard such as air temperature at 1.25 to 2.00 m. Although the standard depth for soil temperature measurement is said to be 10 cm[1], the depth does not always depend upon the agronomical view point.

Furthermore, although in many cases of soil temperature measurement, the value obtained at a point of depth is regarded as the representative value, there are many problems with regards to accuracy in relation to the difference in laying place (in the horizontal direction) of the earth thermometer, and the accuracy of laying depth[2]. Since the distribution of crop roots is not limited only to a certain depth where the thermometer is laid, it is believed that for the measurement of soil temperature at the actual cultivation field the average of values at various depths is better than that of the ordinary measurement taken at a point. Hence, this paper deals with the comparison between direct measurement of the average temperature of the different soil depths and the indirect measurement obtained at a point, proposing the former method.

2. Materials and methods

The experiment was carried out in the field of Faculty of Agriculture, Kagawa University, from May to October, 1985. Two lines of ridge in the direction from south to north (length : 3.0 m, width : 1.0 m, height : 25 cm ; granitic clay loam) were set up, each face of the ridge was kept in bare ground. The soil temperature at each ridge was measured using thermocouple (T-type, 0.65 mm in diameter).

The direct measurement of soil temperature at 0 to 30 cm depth at a ridge was performed by laying of 10 self-manufactured earth thermometers at intervals of 30 cm (Fig. 1). By regarding 29 points of junction at each depth as the hot junctions of the thermocouples and the point at 30 cm depth as the cold junction, the average temperature of all 29 points were measured directly, and separately by measuring soil temperature at 30 cm depth the average temperature at different soil depths was directly obtained (hereafter, described as the soil temperature by the direct measurement).

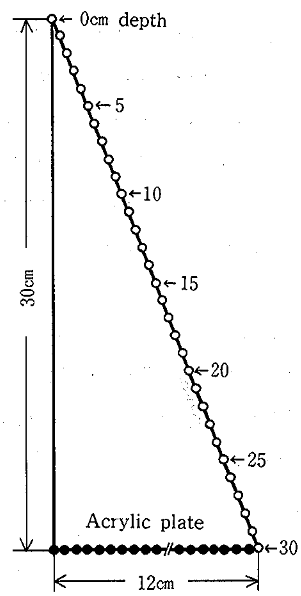

Fig. 1 Self-manufactured earth thermometer for measuring the average soil temperature at 0 to 30 cm depth. Open circles denote hot junctions of the thermocouples, Solid circles the cold junctions.

The depth of 0 to 30 cm was made as the object of measurement because generally, most roots of crops are concentrated there.

In the other ridge, the temperature at 6 points namely, the ground surface, underground 2.5, 5, 10, 20 and 30 cm deep were measured. Similarly, a total of 10 points at 30 cm interval were set up as the point of measurement. Regarding the average of 10 points as the representative soil temperature at each depth and substituting those values at 6 point of depth for spline function, the average temperature at different soil depths from the ground surface down to underground 30 cm was obtained (hereafter, described as the soil temperature by the indirect measurement).

In order to obtain the change in soil moisture which greatly affects soil temperature other than the above -mentioned, the value at about 9 a. m. every day was read using a tension meter.

3. Results and discussion

3.1 Variations during 24 hours

The direct and indirect method of measuring the average temperature at different soil depths were compared. The observation covered 24-hour period for 2 days, August 1 and October 23 (Weather, fine) and taken from ground surface down to undrerground 30 cm.

In the summer season (1, August) the average soil temperature taken at 2 hour interval for 24 hours was 35.5°C and 35.4°C using the direct and indirect measurement, respectively. In the test of difference, the t-value (degrees of freedom : 24 ; significance level : 5%) was 0.05 (<1.17) and significant differences were not found. Similarly, no significant differences (t-value : 0.22) were found in autumn (23, October).

The results of harmonic analysis for the daily change of soil temperature by the direct and indirect measurements are shown in Table 1. The difference in daily soil temperature (a_0) between the two plots by the harmonic analysis is only 0.2°C in both periods. From this finding it can be said that the soil temperatures measured using the two methods have nearly the same values. The daily temperature range (a_1) has also the same tendency as the daily mean value and it is shown that there is little difference in phase angles (ε_1).

Table 1. Harmonic coefficients for the daily cycle of the average soil temperature at 0 to 30 cm depth, measured in 1985.

	Soil temp. (Td)*			Soil temp. (Ti)*		
	a_0	a_1	ε_0	a_0	a_1	ε_0
Aug. 1	35.5	3.5	210	35.4	3.3	212
Oct. 23	20.2	3.3	213	20.4	3.2	217

a_0 : Mean value (°C), a_1 : Range of the day (°C), ε_0 : Phase angle (deg). * : Same as in Fig. 2.

Like the result of the t-test, the harmonic analysis show no differences in the soil temperature between the direct and indirect measurements during the 24 hours observation period.

3.2 Variations during 2 months

The soil temperature pattern for 2 months (May and June) using the direct and indirect measurement methods is shown in Fig. 2. The soil temperature was measured at 15 : 00 in all days. According to Fig. 2, although both soil temperatures were not entirely the same when it exceeded 30°C, the proportional relation of 1 to 1 was clear as a whole. Furthermore, the distinct difference in the change of soil moisture affecting both temperatures in the period is not found.

Since both temperatures were measured at 10

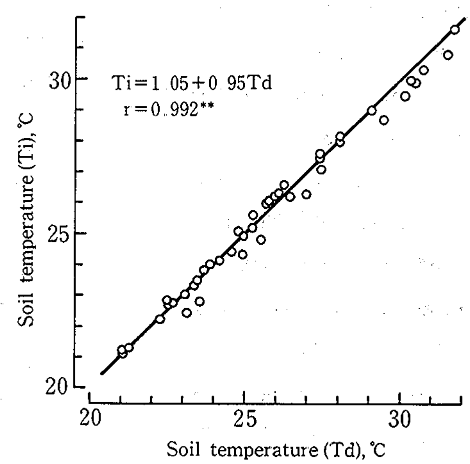

Fig. 2 Relation between soil temperature Td and soil temperature Ti. Soil temperature Td was measured by the thermometer shown in Fig. 1 from May 6 to June 27 in 1985, and soil temperature Ti the calculated one from 6 soil temperatures at 0, 2.5, 5, 10, 20, and 30 cm depth.

points, when the deviations of the soil temperatures were compared by standard deviation, the relation is shown in the following equation:

$$\sigma d = 0.14 + 0.19\,\sigma i \quad (r = 0.32*) \qquad (1)$$

where σd denotes standard deviation in the direct measurement, σi that in the indirect measurement, and * the significance level at 5%.

Since the coefficient of σi is small such as 0.19 in equation (1), in obtaining the average temperature at different soil depths, the dispersion of each value by the thermometer is small in the direct measurement in comparison with the indirect measurement and this results in an increase of accuracy in the former method. It is thought that the major reason for this is the fact that thermocouples composing the thermometer for direct measurement are fixed at the accurate depth (Fig. 1).

A comparison (t-test, singficance level: 5%) of the temperatures taken at 10 points daily for 36 days using the direct (Td) and indirect (Ti) measurement was made[2]. The relation is shown as follows; Td > Ti: 12 days, Td = Ti: 21 days and Td < Ti: 3 days. The difference between the soil temperatures was 0.2°C to 0.8°C in the case of Td > Ti, while in Td < Ti the difference became -0.2°C to-0.3°C. The difference in soil temperature was comparatively small in any case. The average soil temperatures for the entire period was 25.8°C for Td and 25.6°C for Ti, a difference of 0.2°C.

The relationship between the two temperatures measured at 15:00 is shown in Table 2. In addition, the difference in soil temperature between the 2 plots was shown in the range from the minimum value 0°C to the maximum value 1.0°C.

About half of the total 36 days showed Td > Ti where the difference between the soil temperature was 0°C. With an increase in the difference between the two temperatures the rate at which Td = Ti also increased. Thus, the rate at which Td = Ti increased from 9.1% at 0°C soil temperature difference to 63.6% at 0.3°C and reached 100% at 0.9°C. But, taking into consideration the measurement error of the thermocouple it is recognized that there is in fact no difference between the 2 plots at the level of about 0.6°C of soil temperature difference[2].

Table 2. Ratio of 3 categories ($Td-Ti > \varepsilon$, $|Td-Ti| < \varepsilon$, $Td-Ti < \varepsilon$) plotted on different values of the threshold (ε). The threshold is expressed by the differene between soil temperature Td and soil temperature Ti. Soil temperatures were measured at 3: 00 p.m. from May 6 to June 27 in 1985.

Threshold	Ratio of 3 categories		
	$Td-Ti > \varepsilon$	$\|Td-Ti\| < \varepsilon$	$Td-Ti < \varepsilon$
0 °C	54.5%	9.1%	36.4%
0.1	50.0	15.9	34.1
0.2	31.8	47.7	20.5
0.3	27.3	63.6	9.1
0.4	22.7	77.3	0
0.5	20.5	79.5	0
0.6	20.5	79.5	0
0.7	20.5	79.5	0
0.8	9.1	90.9	0
0.9	0	100.0	0
1.0	0	100.0	0

* Soil temp. Td and soil temp. Ti are the same as in Fig. 2.

In addition, since the measurement of soil temperature at a point is traditionally used, it is important to determine the exact depth at which the average temperature is found within the 0 to 30 cm depth. In this respect, the average temperature within the 0 to 30 cm depth measured directly with a thermometer exist at the 12.9 cm depth on the average (C. V. 15.3). This is comparatively near the 10 cm standard depth in the measurement of soil temperature.

As mentioned above, it is recognized that there is no difference in the average soil temperatures obtained using the direct and indirect measurement. The temperatures at 10 points, from ground surface to underground 30 cm were measured. However, it was clarified that the temperatures of 10 points taken with earth thermometers are varied more precise when the direct measurement method is used compared with the indirect measurement.

This finding shows that soil temperature in the environment of rhizosphere can be more accurately measured by the direct measurement of the average soil temperature in the way described in this paper than in case of the ordinary measurement taken at a point.

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(Received May 31, 1989)