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Soil temperature in a sugar-cane crop as a function of the management system

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Abstract

Air and soil temperatures are, by far, the most important state variables of agroecosystems. In the case of sugar-cane (*Saccharum officinarum* L.) they affect plant development, maturation and a series of biological and physical-chemical soil processes. This paper presents a comparative study of three management practices, applied to the first ratoon of a sugar-cane crop established on a Rhodic Kandiudox (Terra Roxa Estruturada) of Piracicaba, SP, Brazil. The management practices are: (i) interrow with bare soil; (ii) trash mulching, maintaining harvest residues (straw+tips) on the soil; (iii) soil with residues from burning the prior crop. Soil temperature was measured with digital stick thermometers driven into the soil down to the depths of 0.03, 0.06 and 0.09 m, meter by meter, close to the crop row, along an 84-point transect that covered all treatments and borders. The measurements were performed from November 1998 (right after the first harvest of the planted cane) to June 1999. The effects of the treatments on soil temperature were, evidently, more prominent in the period November/February when the plants had a smaller height, not closing interrows. Data that were collected on typical days, chosen along the development cycle of the crop, always from 11:00 to 12:00 a.m., show significant differences, mainly between mulched and non mulched treatments, reaching values as high as 7 °C for the average of the three depths. A comparative analysis is made between treatments and their effects are discussed in relation to the sugar-cane crop.

Introduction

Air and soil temperatures are the most important state variables of agroecosystems. These variables are important in many phases of sugar-cane development, and with the introduction of a new harvest practice, which leaves a considerable amount of trash on the field, soil temperatures will be severely affected. This new management practice, which also induces soil compaction problems (Oliveira et al., 1998), is designed to replace the traditional harvesting practice which involves the burning of the dry straw before harvest to facilitate the manual cutting of the canes. The new practice involves machine harvesting with all residues (straw+tips=trash) being chopped and left on the soil surface. This soil cover is of fundamental importance to the development of the crop, since it affects the radiation balance due to modifications in thermal conductivities and reflection coefficients and, as a consequence, interferes in all other energy balance components. Soil temperature, being controlled by this balance (Pezzopane et al., 1996), can present significant changes in relation to traditional harvest practices which leave the soil surface exposed to sunlight.

The effect of mulching on soil temperature regimes has been extensively studied. Bragagnolo and Mielniczuk (1990) detected a reduction of 8.5 °C in surface soil temperatures, when using wheat straw

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mulch. Derpsch et al. (1985) found summer temperatures higher than 50 °C at the 0.03-m depth in uncovered soil, which in many situations can cause effects. Similar changes were also reported by Lal (1974), Derpsch et al. (1983), Sidiras and Vieira (1984) and Morote et al. (1990), the last authors studying the effect of mulching in irrigated soybean fields. They observed large differences in soil temperatures between dry non-irrigated and wet irrigated plots on hot days. Sidiras and Pavan (1986) observed higher temperatures at the 0.03-m depth for soils prepared conventionally, in relation to minimum tillage and permanent soil cover. Other relevant reports related to soil temperature regimes are those of Diniz and Bastos (1980) comparing forest soils with deforested areas; Vieira et al. (1991) and Salton and Mielniczuk (1995) also compared minimum tillage with conventional soil preparation practices; Nye and Tinker (1977) and Olasantan (1999) studied the effects of soil temperature on seed emergence and root growth and development; and Caldeira et al. (1997) and Parr (1975) reported organic compost degradation effects.

For the sugar-cane crop in Australia, Whitman et al. (1963) studied the effects of light, temperature and water on the sprouting of planted cane stalks. They emphasized that the optimum temperature was around 30 °C, that a significant reduction occurred below 22 °C, and was nil for temperatures between 16 and 10 °C. In Florida, Gascho et al. (1973) observed that the minimum temperature for cane emergence is about 12 °C, and that temperature had a marked effect on the number of stalks, growth and sugar yield. All of these crop development parameters were higher for temperatures around 30 °C. Chen and Yang (1978) and Yang and Chen (1979) in Taiwan also evaluated sugar-cane growth in pot and field experiments, confirming the results of the aforementioned reports from Australia and Florida.

In Brazil there is no specific research on soil temperature for sugar-cane. Several authors, e.g. Moreira (1995), reported temperature effects in an indirect form, their main objectives always being related to other aspects of the crop. In the experiment presented here, many other aspects of the sugar-cane crop are also studied, mainly N fertilizer use efficiency, fate of organic matter, and water balance, to be published elsewhere. Since soil temperatures are related to all these processes, this study presents data collected during the spring-summer period, when sugar-cane plants are young and the soil surface is more intensively exposed to sunlight.

Table 1. Some soil (Rhodic Kandiudox) characteristics of the 0–0.15 m layer

Characteristic	Mean value (84 points)
pH in $CaCl_2$	5.0
Organic matter (kg m^{-3})	25.0
Calcium (mol_c m^{-3})	64.0
Magnesium (mol_c m^{-3})	18.0
Potassium (mol_c m^{-3})	4.3
Bulk density (Mg m^{-3})	1.349
Sand (g kg^{-1})	290.0
Silt (g kg^{-1})	160.0
Clay (g kg^{-1})	550.0

Material and methods

The field study was conducted at Piracicaba, SP, Brazil (22° 42′ 30″ S and 47° 38′ W) on an area mapped as ‘Terra Roxa Estruturada’ (Rhodic Kandiudox), a soil frequently used to produce sugar-cane. Table 1 presents some relevant characteristics of this soil. The field was planted to sugar-cane (*Saccharum officinarum* L.) in October 1997 and harvested in October 1998 after which the soil temperature study began using the first ratoon crop. Three management treatments were compared: (i) mulching with trash (cane tips and straw from the last harvest) (T_1 and T_2); (ii) bare soil between rows (T_3); and (iii) soil surface with the residues left by the traditional practice of straw burning before harvest (T_4). The treatments T_1 and T_2 are similar in respect to the mulching with trash, and are therefore replicates in terms of this soil temperature study being different only in terms of ^{15}N label which was used in an additional organic matter residue study.

The total experimental sugar-cane area consisted of 15 rows, 100 m long, spaced at 1.4 m, as shown in Figure 1, comprising an area of 2100 m^2. The central row was used for soil temperature measurements, each treatment being 16 m long and separated by borders 4 m long, also maintained bare. Soil temperatures were measured along the transect shown in Figure 1, meter by meter, at 84 points along a transect and at depths of 0.03, 0.06 and 0.09 m, which are within the top soil layer, and in which the sugar-cane roots and rhizome predominate and are therefore affected by soil temperature regimes. The transect covers all treatments and borders. Treatments had 4 replicates, each with 4 sampling points. Measurements were made at selec-

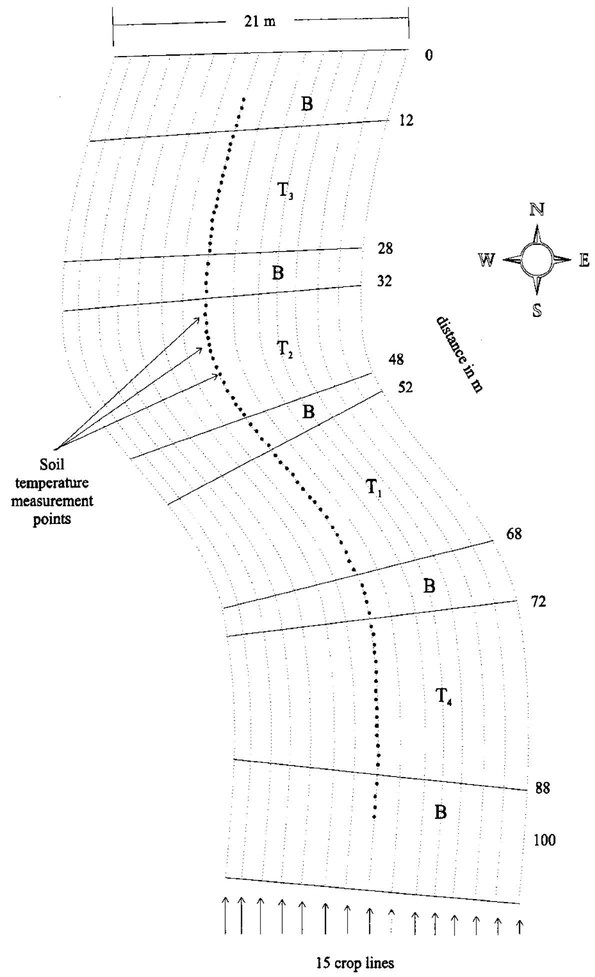

Figure 1. Scheme of experimental layout. T_1 and T_2: mulched with trash; T_3: bare soil; T_4: burned residues; B: border

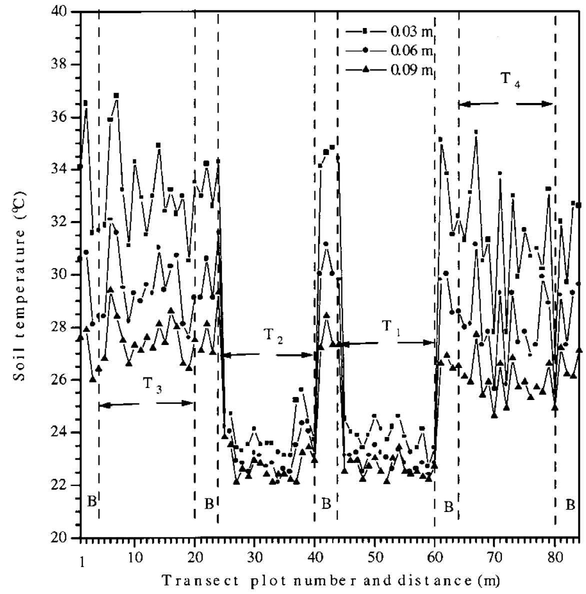

Figure 2. Soil temperature transect for 18 November 1998. T_1; mulched; T_2: mulched; T_3: bare; T_4: burned residues; B: borders.

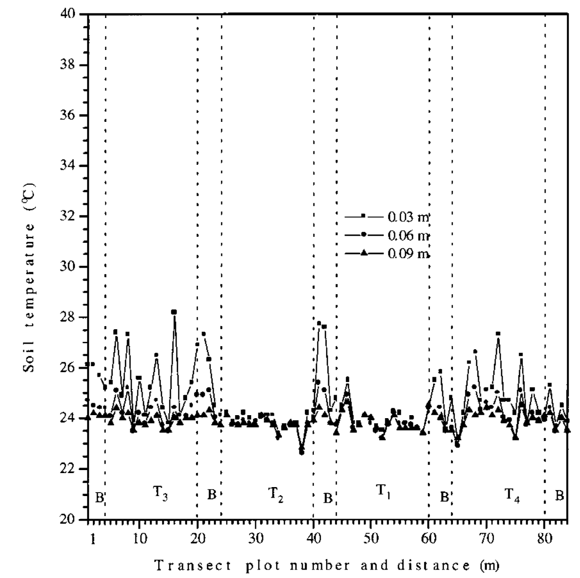

Figure 3. Soil temperature transect for 18 December 1998. T_1: mulched; T_2: mulched; T_3: bare; T_4: burned residues; B: borders.

ted dates, always at noon (11:00 to 12:00) in order to detect maximum differences.

Digital stick thermometers were inserted into the soil to the desired depth and, after equilibrium (about 180 s), readings were made. Comparisons of soil temperature data among treatments were made by analysis of variance, using ANOVA software, for completely randomized designs.

At the same points of the transect, soil water contents of the 0–0.15 m depth were also measured using a surface neutron probe, type CPN, Model MC-3.

Crop growth and development were evaluated only at harvest, which occurred in October 1999.

Results and discussion

Soil temperatures measurements started to be performed on November 18, 1998, and the first are shown in Figure 2. The differences between mulched (T_1 and T_2) and non-mulched (T_3 and T_4) treatments can be seen very clearly, even for the greatest depth. For the average temperature of all depths (0.03 to 0.09 m

Table 2. Average soil temperatures (4 replicates, each with 4 sampling points) for the 0.03 to 0.09 m layer, at selected dates. T_1: mulched; T_2: mulched; T_3: bare; T_4: burned. Maximum, minimum, and mean air temperatures are also shown

Day	Average soil temperature (°C)				Temperature air (°C)		
	T_1	T_2	T_3	T_4	T_{max}	T_{min}	T_{mean}
Nov. 18, 1998	23.1 c	23.3 c	30.1 a	28.3 b	32.8	19.7	26.3
Dec. 02, 1998	23.1 b	22.8 b	29.8 a	30.2 a	35.0	18.0	26.5
Dec. 18, 1998	23.9 bc	23.8 c	24.5 a	24.4 ab	27.6	20.8	24.2
Jan. 12, 1999	23.1 b	23.3 b	23.8 b	28.3 a	29.8	20.0	24.9
Feb. 05, 1999	23.8 a	23.8 a	23.5 b	23.4 b	33.7	19.8	26.8
Mar. 04, 1999	22.7 a	22.9 a	22.7 a	22.3 b	32.0	18.4	25.2
Apr. 07, 1999	22.3 b	22.6 a	22.6 a	22.1 c	32.2	18.4	25.3
May 14, 1999	17.4 a	17.4 a	17.7 a	17.6 a	22.5	9.0	15.6
Jun. 29, 1999	15.5 b	15.6 b	16.3 a	15.3 b	27.8	14.2	21.0

Averages within days followed by the same letter do not differ significantly at the 5% level by Tukey.

layer) ANOVA did not indicate differences between T_1 and T_2, and very significant differences between these and the non-mulched treatments T_3 and T_4 (Table 2, November 18, 1998). For this early date, when the crop covered no more than 10% of soil surface, the ash residues of T_4 significantly affected soil temperatures compared to the bare soil of T_3. The situation on December 12, 1998 was very similar except for no difference between treatments T_3 and T_4, indicating that there was no more effect of the residues of the burned trash. On December 18, 1998, a cloudy day, the significant differences shown in Table 2 have no physical meaning since the average values are very close. For December 18, Figure 3 shows that the most variable data belong to the shallow depth of 0.03 m.

Figure 4 refers to data of January 12, 1999, when plants were about 1 m tall. Although Table 2 indicates no difference between T_1, T_2 and T_3, it can be seen that the average temperature of the bare treatment T_3 is slightly higher than that of the mulched treatments T_1 and T_2, at least for the greater depths of 0.06 and 0.09 m. The greater difference between these treatments and T_4 is likely due to a delay in plant growth for the burned trash treatment. On February 5, 1999, also a cloudy day, the differences shown in Table 2 have no physical significance. The same can be said for all other dates (March 4, April 7, May 14 and June 29), which were not cloudy, the last of them shown in Figure 5, when plants were already shading completely the interrows, so that treatments did not affect soil temperatures anymore. The slightly higher temperatures of the beginning of the transect (0–15 m) on June 29, are due to clearings of wind-fallen canes.

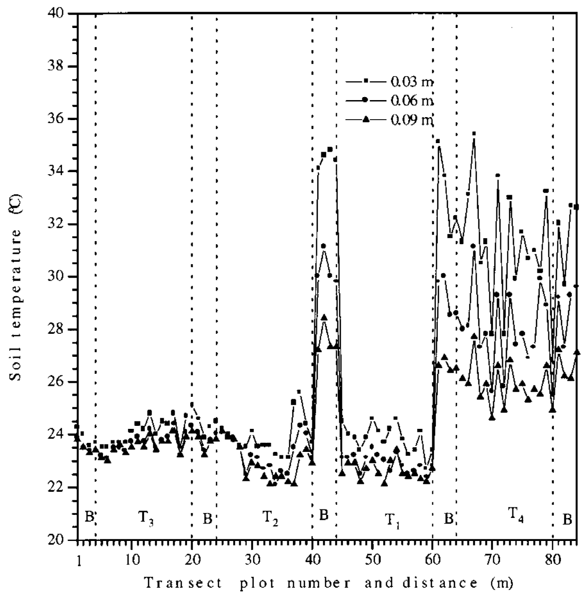

Figure 4. Soil temperature transect for 12 January 1999. T_1: mulched; T_2: mulched; T_3: bare; T_4: burned residues; B: borders.

Table 3. Plant growth evaluation at harvest (October 1999). NS=Number of stalks per meter; WS=Wet weight of stalks per meter. Averages of 16 replicates per treatment

Treatment	NS	WS
T_1	39.7 b	51.1 b
T_2	40.3 b	55.3 ab
T_3	47.8 a	63.2a
T_4	45.2 ab	58.1 ab

Averages within treatments followed by the same letter do not differ at the significance level of 5% by Tukey.

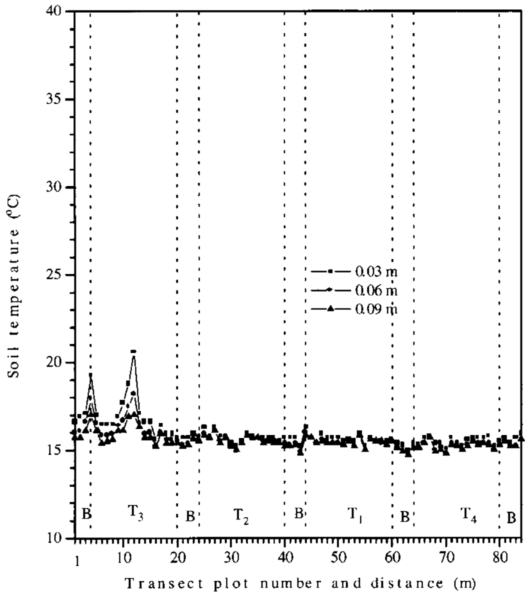

Figure 5. Soil temperature transect for 29 June 1999. T_1: mulched; T_2: mulched; T_3: bare; T_4: burned residues; B: borders.

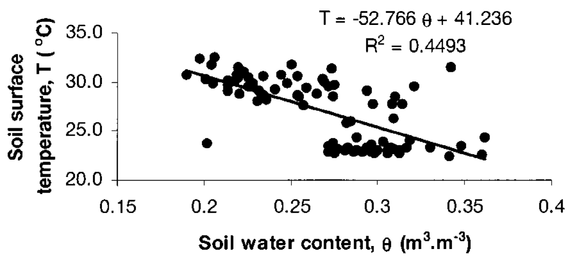

Figure 6. Correlation between average soil temperature (0.03–0.09 m) and average soil water content (0–0.15 m).

In Table 2, it can be seen that the temperature difference between the non-mulched treatments (T_3 and T_4) and the mulched (T_1 and T_2) reached values as high as 7 °C in November, decreasing to almost zero in February. Peak values, at the shallow depth (0.03 m), reached temperatures as high as 37 °C similar to those reported by Derpsch et al. (1985) and, since soil temperature profiles are in general exponential, soil surface temperatures must have reached much higher values. The Southern Hemisphere spring-summer period is very important for the establishment of the ratoon crops, and it is expected that milder soil temperatures due to mulching would favor crop growth, as mentioned by Gasho et al. (1973). Although being a relatively short period of the crop cycle, it is the period in which the crop rhizome is young and more sensitive to the high temperatures. Yield data presented in Table 3 show, however, a negative response of the mulch on growth, since at harvest (October 1999) T_1 and T_2 had significantly lower values for wet mass and number of stalks per meter of row, in relation to T_3 and T_4, exception made for number of stalks in T_4. An explanation for that is the establishment of a too humid microclimate in the straw layer, which had, initially, a thickness of 0.20 to 0.30 m. This microenvironment could have promoted fungi and microorganism growth which affected rhizome sprouting and stalk development. The mulch also has an effect on soil water content, which is studied in detail elsewhere (Dourado-Neto et al., 1999), using geostatistical methodologies and the state-space approach. Figure 6 presents a correlation between soil water content at the surface layer (0–0.15 m), measured with the surface neutron gauge, and the average soil temperature (0.03, 0.06 and 0.09 m depths) on November 18, 1999, suggesting the possibility of replacing a more difficult measurement like soil water content, by an easier and quicker one like temperature.

The relatively good correlation (significant at the 1% probability level) indicates clearly that the cooler points of the transect have higher soil water contents. Morkoc et al. (1985) also present such a relation, for soil surface temperature measured with a hand-held infra-red thermometer, with an R^2 value of 0.64, better than the one presented in Figure 6 (0.45).

Conclusion

The effect of soil surface mulching in sugar-cane ratoon crops, as a consequence of the adoption of new harvest practices with no straw burning, can reduce average soil surface layer temperatures by about 7 °C, avoiding peak surface temperatures during the initial period of the ratoon crop establishment. The mulch can, however, affect negatively the crop development reducing the number of stalks and their weight, in the present case by about 13%.

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