SOIL TEMPERATURE IN MAIZE CROPS AS FUNCTION OF SOIL TILLAGE SYSTEMS

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Abstract
The objective of this study was to evaluate differences in soil temperature in maize cropped in no-tillage and conventional tillage systems. A field experiment was conducted in Eldorado do Sul, Brazil (30°05'S; 51°39'W), during the cropping season of 2002/03, in a subtropical climate. The maize was sown in rows spaced of 0.75 m, with a population of 65000 plant ha^{-1}. Around 5 t/ha of dry matter of a winter mixture composed by *Avena strigosa* + *Vicia sativa* were added to the soil. The temperature was monitored at different soil layers in the root zone. At the beginning of plant growth the highest soil temperatures occurred in the conventional system in all soil layers. Differences among daily averages reached to 5°C in maximum and 2°C in minimum temperatures, at 2.5 cm depth. After 30 days from plant emergence the highest temperatures occurred in the no-tillage system, which was related to the interception of solar radiation by leaves. However, variations among the cropping systems decreased as the plants covered the soil surface. The daily trend of the soil thermal regime was similar for both the tillage systems. A crescent delaying on maximum and minimum temperatures when increasing the soil depth was observed.

Additional Keywords: soil temperature, heat flux, no-tillage, maize, mulching.

Introduction
Several chemical, physical and biological processes into the soil are affected by its thermal conditions, which may affect the plant growth and crop production. Increases in the soil temperature reduce the period of germination-emergence of seedlings and increase processes such as microbiological activities, growth and activity of plant roots, also affecting the permeability of root cells to water. However, an optimal range limits these positive effects, which decrease more and more at high temperatures in the soil profile.

The soil thermal regime depends on the energy changes at its surface and the heat flux in the subsuperficial layers. The heat flux into the soil depends on the weather conditions, the presence if soil coverage and the physical properties of the soil profile. The magnitude of the heat flux in the soil is related to its thermal conductivity, calorific capacity and vertical thermal gradient, which are affected by the water content in the soil profile. Both the soil coverage and water content in the soil are influenced by the tillage system. Hence, the soil thermal regime must be different in no-till soils when compared to soils submitted to conventional tillage systems.

The soil moisture affects its thermal regime by increasing its calorific capacity and thermal conductivity. However, the most relevant factor affecting the soil temperature seems to be the presence of coverage on the soil surface, when comparing the no-tillage to conventional systems. The straw in the surface intercepts and reflects a great part of the incoming solar radiation (Baver *et al*., 1972), reducing the heat flux toward the soil profile in comparison to conventional tillage systems (Azzoz *et al*., 1997). Nevertheless, the influence of the straw on the soil thermal regime depends on several physical characteristics such as color, quantity and distribution of straw on the surface, which are variable over the time. The straw on the soil surface may affects also the content of organic matter into the superficial soil layers and hence the soil thermal regime. The organic matter may allow increments on the water storage in those soil layers, increasing its calorific capacity.

As a consequence of this set of influences, diurnal soil temperatures may be reduced in no-tillage system, in comparison to conventional soil management. Decreases of about 10°C (Lal, 1975) or 15°C (Derpsch *et al*., 1985) due to the presence of straw on the surface of no tilt soils were registered. However, differences of about 4 to 5°C in both maximum temperatures and daily thermal amplitudes are frequent to occur, if comparing the no-tillage and conventional tillage systems (Sidiras and Pavan, 1986).

Decreases in the soil temperature close to the surface may allow good stands of crops such as soybeans and maize, during periods of high incoming solar radiation (Derpsch *et al*., 1985). According to Neumaier *et al*. (2003) injuries in soybean seedlings may occur if the soil temperature overpasses 35°C. Besides, dumping off in soybean seedlings was observed around 45°C (Neumaier *et al*., 2003). According to Lal (1974) soil temperatures of about 37-38°C may affect stands of maize crops. Considering the importance of the soil temperature to field cropping systems, this study had the purpose to evaluate differences in the soil thermal regime into maize crops submitted to no-tillage and conventional soil tillage systems.

Materials and Methods

Measurements of soil temperature were taken in a field experiment carried out during the cropping season of 2002/03, in the Agronomic Experimental Station of the Universidade Federal Rio Grande do Sul (EEA/UFRGS), in Eldorado do Sul, Brazil (30°05'S e 51°39'W, altitude 40 m). The regional climate is a humid subtropical Cfa type (Köppen classification), that prevails in the South Region of Brazil. The annual mean precipitation is 1440 mm and 425 mm occur from November to February, in the experimental period. Maximum global solar radiation corresponds to December, as a mean of 26 MJ m^{-2} dia^{-1} (Bergamaschi *et al*., 2003). The soil was classified as a Paleudult.

The experimental area has around 0.5 ha, divided in two plots whose soil management are no-tillage and conventional tillage, since 1995. Both plots used to be cultivated with a mixture of *Avena strigosa* + *Vicia sativa* during the winter season and maize in summer season. In the no-tillage system the winter mixture was dissected with herbicide (glyphosate) and 5 t ha^{-1} of straw was rolled to the soil surface, producing coverage of 90% in the no-tillage system. In the conventional tillage the green biomass was incorporated to the soil by plough, in the same day of the herbicide application. In the conventional system, the soil was revolved again just before the maize sowing, in order to eliminate weed seedlings and to uniforms the soil surface. An early maize hybrid (Pioneer 32R21) was sown in November 25th of 2002, in a row spacing of 0.75 m and population of 65000 plants ha^{-1}. The soil fertilization followed the recommendation of the extension services, in order to obtain a grain yield of around 10000 kg ha^{-1}.

A line of sprinklers spaced of 6 m each other was installed along the divisor line, between the two tillage systems. So, a full irrigation treatment (field capacity) was applied close to the sprinkler line, and a non-irrigation level was maintained along the lateral strips. The irrigation control follows the soil water potential at 0.45 m, measured by mercury tensiometers. The amount of water applications was quantified in a weighing lysimeter.

The soil temperature was registered in the irrigated plots during all the entire crop cycle by using thermocouples of copper-constantan. The sensors were installed at 2.5, 5, 10, 20, and 40 cm depth in the soil profile, in a distance of 18cm from the plant row. They were monitored by a multiplexer which was connected to a Campbell CR10 datalogger and plugged into a storage module. Measurements were taken every 30 seconds, while its mean values were stored each 15 min.

Results and Discussion

At the beginning of the crop cycle, when the leaf area was low, the mean soil temperature was higher in the conventional tillage system than in the no-tillage system. After 30 days from the plant emergence the soil temperature got lower in the no-till soil, in comparison to the conventional system. This pattern was observed along the entire analyzed soil profile, but the highest differences occurred at 2.5 cm of soil depth. Daily maximum and minimum values of soil temperature decreased according to the leaf area evolution in both the soil tillage systems, as function of the plant growth.

Several authors have observed decreases of temperature in no-till soils in comparing to conventional systems, at the beginning of the crop cycle (Morote *et al*., 1990; Bragagnolo and Mielniczuk, 1990; Salton and Mielniczuk, 1995). This may be attributed to the presence of the straw on the no-till soil surface. The mulching reduces the solar energy absorbed by the soil profile by increasing the reflectivity of the surface. Besides, it acts as a porous layer over the surface, reducing the transfer of heat to the soil due to the high air content of the straw (Sidiras and Pavan, 1986). As a consequence of the microbiological decomposition after the crop emergence, the straw layer get dark and thin, reducing its effects on the heat flux into and out the soil profile and hence differences between the two tillage systems.

An opposite tendency was observed after 30 days from the plant emergence, with lower temperature in the conventional system than in the no-tillage system. This tendency was related to differences in the soil shading by plants. According to Bergamaschi *et al*. (2004) alterations on the leaf architecture could be observed, when comparing the two tillage systems. Reductions of intercepted solar radiation by leaves were detected in maize plots cropped in no tilt soil. Otherwise, there were no differences in the leaf area index among tillage systems.

Differences among systems were higher in maximum (i.e. diurnal) than in minimum soil temperatures. Besides, the variations were higher during sunny than in cloudy days (Figure 1). Early in the crop cycle differences in maximum temperatures raised to about 5°C at 2.5 cm depth in sunny days, with lower values in the no-tillage than in the conventional tillage system. Meanwhile, at the same soil depth the minimum temperature was higher in the no tilt soil by a difference of about 2°C than in the conventional system. Similar to the case of maximum temperatures, the tendency observed on minimum temperatures may be attributed to the effect of the straw layer. It tends to act as a physical barrier reducing the heat flux between the soil profile and the air above the surface, either during the day and the night. The straw mulching acted as an isolating layer over the soil surface, reducing both the heat flux into and out the soil. It tends also to increase the reflectivity of the surface to the solar radiation early in the crop cycle. Besides, it may modify several processes of heat and water vapor exchanges between soil and air, at the surface level.

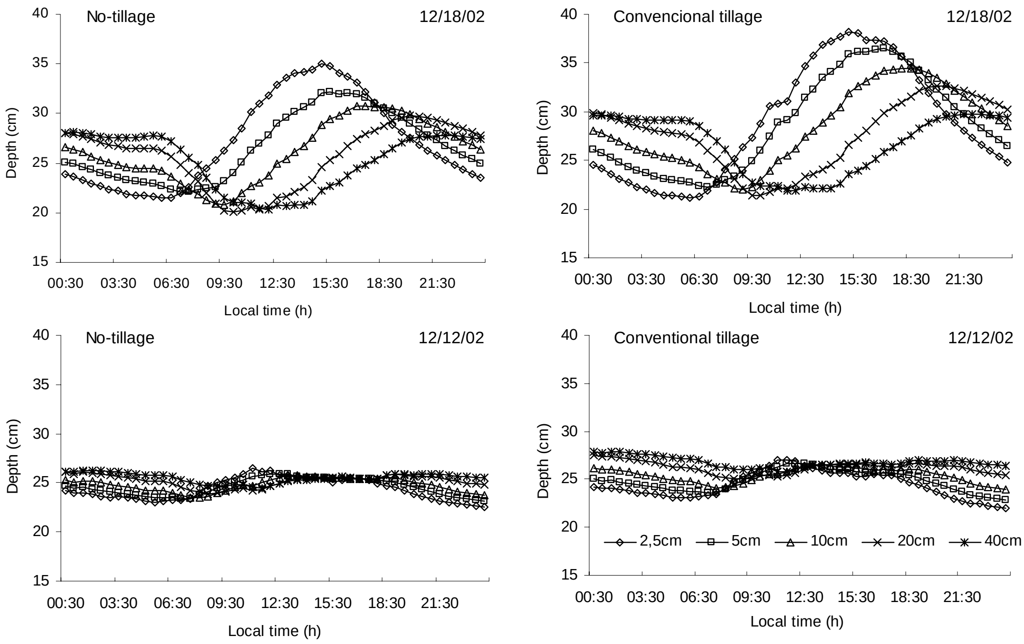

Figure 1. Temperature at different soil depths in maize cropped in no tillage (left) and conventional tillage (right) systems, in December 18th of 2002 - sunny day (above) and December 12th of 2002 - cloudy without rain day (bellow). EEA/UFRGS, Eldorado do Sul, Brazil.

Despite the similar tendency between the systems (Figure 1), a higher thermal amplitude was observed in the conventional tillage system during a sunny day, as a consequence of a higher maximum temperature, when comparing to the no-tillage system (Figure 2). Maximum temperature raised to about 38°C at 2.5 cm of soil depth in the conventional system, while it was close to 35°C in the no-tillage system. Considering a small effect on the minimum temperatures, the results allow to consider the no-tillage system as able to maintain a higher stability in the soil thermal regime than the conventional system, as observed by Sidiras and Pavan (1986). That is very important for several processes into the soil-plant system, as related before. Reductions in maximum temperatures may allow better conditions to seedlings emergence and root expansion and activity early in the cycle of several species like maize and soybeans in tropical and subtropical regions, as Lal (1974) and Neumaier *et al*. (2003) observed.

The occurrence times of the extreme temperature (maximum and minimum) was not modified by the tillage system, that were 6 and 14 h of local time, respectively. However, a progressive delaying in the occurrence of maximum and minimum temperatures as the soil depth increases was observed in both the tillage systems (Figure 1). This can be attributed to the low speed by which the heat wave flows into the soil profile, as observed by several authors. Moreover, a small thermal difference among the tillage systems was observed during a cloudy day, even without rain, due to low radiation balances. At these conditions the effect of the straw coverage on the soil is expected to be very low, as observed by Vieira *et al*. (1991).

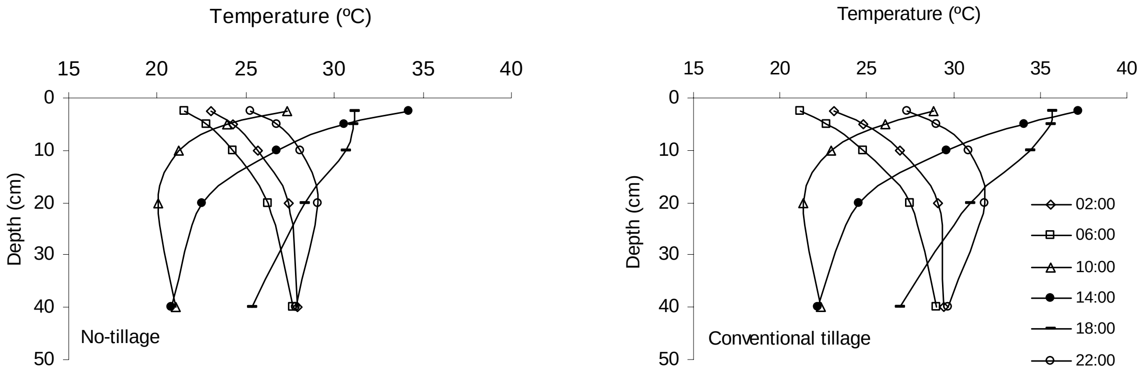

Figure 2. Soil temperature profiles in maize cropped in no-tillage (left) and conventional tillage (right) systems, at different times of a sunny day - December 18th of 2002. EEA/UFRGS, Brazil.

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