Notas Científicas

Temperature changes in soil covered by black oat straw

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Abstract – The objective of this work was to evaluate the effect of different amounts of black oat (*Avena strigosa*) straw covering soil surface on soil temperature at different depths. The treatments consisted of 0, 3, 6, and 9 Mg ha^{-1} straw. Soil temperature was measured hourly by a thermocouple inserted at different depths (0, 5, 15, 30, and 50 cm) and was used to adjust an equation correlating the temperature of covered soil with that of bare soil. With the correlations, it was possible to observe a point value of temperature (inversion temperature of straw effect), below which the presence of straw acts positively on the maintenance of soil temperature and above which the presence of straw acts negatively on soil heating.

Index terms: *Avena strigosa*, inversion temperature, mulch effect, no-tillage, plant residue, soil thermal regime.

Alterações da temperatura em solo coberto de palha de aveia-preta

Resumo – O objetivo deste trabalho foi avaliar o efeito de diferentes quantidades de palha de aveia-preta (*Avena strigosa*) em cobertura do solo sobre a temperatura do solo em diferentes profundidades. Os tratamentos consistiram de 0, 3, 6 e 9 Mg ha^{-1} de palha. A temperatura do solo foi medida a cada hora por meio de termopares inseridos em diferentes profundidades (0, 5, 15, 30 e 50 cm) e usada para ajustar uma equação que correlaciona a temperatura do solo coberto com a do solo descoberto. A partir dessas correlações, foi possível observar um valor pontual de temperatura (temperatura de inversão do efeito da palha), abaixo do qual a presença de palha atua positivamente na manutenção da temperatura do solo e acima do qual a presença de palha atua negativamente no aquecimento do solo.

Termos para indexação: *Avena strigosa*, temperatura de inversão, efeito da palha, plantio direto, resíduo vegetal, regime térmico do solo.

Worldwide, around 111 million hectares are cultivated under no-tillage system (Derpsch et al., 2010). In Brazil, 32 million hectares (FEBRAPDP, 2012) are planted under this direct-seeding system, for which soil cover by crop residues is recommended. The presence of straw cover affects soil temperature (Ts), which is attributed to the changes in the albedo surface and to the lower thermal conductivity of the straw layer compared with that of the soil.

Straw mulch has been shown to reduce Ts (Silva et al., 2006; Webler et al., 2016) and thermal amplitude (Dahiya et al., 2007; Furlani et al., 2008; Coelho et al., 2013). Ramakrishna et al. (2006) and Liu et al. (2014) found that, during cold periods, Ts of covered soil is greater than that of bare soil; however, the inverse was observed during hot periods.

It should be noted that, in several studies, it may not have been possible to detect increases in Ts of mulching soil, because only daily or weekly Ts averages were measured. In fact, Ts of soil covered by straw may remain higher than that of bare soil at night or during periods of Ts depletion (Silva et al., 2006; Chen et al., 2007). Besides, most researches do not take into account the variation in straw amounts.

The objective of this work was to evaluate the effect of different amounts of black oat straw covering soil surface on soil temperature at different depths.

The study was carried out in the experimental area of Universidade Federal de Santa Maria, in the state of Rio Grande do Sul, Brazil (29°43'40"S, 53°43'11"W, at an average altitude of 101 m). The climate of the region is of the Cfa type according to Köppen (Peel et al., 2007). The soil was classified as an Argissolo Vermelho distrófico arênico, according to the Brazilian soil classification system (Santos et al., 2013), i.e., a Rhodic Paleudalf (Soil Survey Staff, 2014). The textural characterization of the soil, classified as sandy loam, showed: 665 g kg^{-1} sand, 212 g kg^{-1} silt, and 123 g kg^{-1} clay in the 0–20-cm soil layer; 628 g kg^{-1} sand, 244 g kg^{-1} silt, and 128 g kg^{-1} clay in the 20–37-cm layer; and 637 g kg^{-1} sand, 251 g kg^{-1} silt, and 112 g kg^{-1} clay in the 37–50-cm layer.

The treatments consisted of different mulch amounts: 0 (bare soil), 3, 6, and 9 Mg ha^{-1} dry mass of black oat (*Avena strigosa* Schreb.) straw. The straw was distributed on 6-m^2 (2x3 m) experimental units on 11/24/2014 and renewed (i.e., picked up and replaced by fresh dry straw) on January 12, March 11, April 24, June 13, August 13, and October 22, 2015. The straw was collected in an adjacent area where black oat was sown in May 2014; the whole plant was harvested in full bloom, dried under the sun, and stored in a covered place. The pre-emergent herbicide flumyzin was applied when the straw was renewed, in order to avoid the appearance of plants in the experimental units.

Ts was measured in the period from 12/1/2014 to 12/6/2015. In 2015, data recorded between October 7 and 22 were disregarded since intense winds moved the straw from soil surface. Ts was measured using the type T copper-constantan thermocouple. A polyethylene cap (3 cm of width and 0.6 mm of diameter), filled with epoxy resin to avoid metal alloy oxidation, was placed at the extremity of each sensor. The sensors were connected to a CR1000 datalogger (Campbell Scientific, Inc., Logan, UT, USA), programmed to perform instantaneous Ts measurements and to automatically record data every hour. The sensors were installed at a depth of 0 (soil surface), 5, 15, 30, and 50 cm in the central zone of the plot, in order to eliminate the effect of the adjacent treatments.

For each depth (0, 5, 15, 30, and 50 cm) and each treatment (0, 3, 6, and 9 Mg ha^{-1}), Ts of soil covered by straw (Ts_{st}) was correlated to the respective Ts of bare soil (Ts_{bs}), both measured at exactly the same time. The linear regression equation, $Ts_{st}=b_0+b_1Ts_{bs}$, was adjusted using the least squares method to estimate the b_0 and b_1 coefficients.

The b_0 and b_1 coefficients were compared with those of the equation of the 1:1 line, where $b_1 = 1$ and $b_0 = 0$, indicating that $Ts_{st} = Ts_{bs}$ and that there was no straw effect on Ts. The coefficients were compared by the t-test, considering the hypotheses $b_0 \neq 0$ and $b_1 \neq 1$, at 5% probability of error. The intersection of the $Ts_{st} = b_0 + b_1Ts_{bs}$ line with the $Ts_{st} = Ts_{bs}$ line, calculated by the equation $Ts_{bs} = b_0/(1 - b_1)$, indicates the inversion set point of the mulch effect on Ts, i.e., when the temperature values for Ts of bare soil and of soil covered by straw were equal.

The b_1 and b_0 coefficients (Figure 1) were statistically different from 1 and 0, respectively, indicating that the presence of straw on soil surface modified Ts up to a depth of 50 cm. In all cases, the b_1 coefficient remained lower than 1 and the b_0 coefficient remained higher than 0. A b_0 higher than 0 indicates a higher Ts in soil covered by straw at the beginning of the day, and a b_1 lower than 1 indicates that the heating and cooling rates of soil with straw covering are lower than that of bare soil. In addition, the reflectivity and albedo of straw are greater than those of bare soil (Liu et al., 2014), which reduces the amount of energy available for heating the surface of mulched soil. In the straw mulch layer, a depletion of heat flux also occurs due to its low heat conductivity, which reduced both soil heating (during the day) and cooling (during the night) in depth. These results are in alignment with those described by Webler et al. (2016), indicating lower energy losses in covered soil.

The temperature at the intersection point of the Ts_{st} regression line with the 1:1 line was referred to as the inversion temperature of straw effect (Tinv). Therefore, when Ts_{bs} is higher than Tinv, covered soils have lower temperatures than bare soils; however, when Ts_{bs} is lower than Tinv, the opposite is observed (Figure 1). At the same depth, Tinv showed variations of up to 0.5°C between treatments (Figure 1). On average, on soil surface, Tinv was 19.6°C and, at 50 cm-depth, 16°C. Higher Tinv values near soil surface may be associated with the larger temperature amplitudes of the surface layers. Studies on the effect of straw cover on Ts at a 5-cm depth showed Ts_{st} lower than Ts_{bs} when Ts_{bs} was greater than 23°C (Furlani et al., 2008) and 20°C (Ribas et al., 2015). However, Almeida (2011) found Ts_{bs} values lower than Ts_{st} when Ts_{bs} was 15.6°C.

The increment in the straw amount caused an increase in b_0 and a decrease in b_1 (Figure 1), indicating that the difference between Ts_{bs} and Ts_{st} is positively related to the amount of straw. The increase in straw amount reduced soil energy losses, resulting in a higher temperature for Ts_{bs} and a lower one for Tinv. However, if Ts_{bs} is greater than Tinv, the effect is the opposite.

The increase in straw amount reduced both the downward and upward heat flux densities by increasing the path of heat through the straw (ΔZ) as the straw layer became thicker. As a result, the heat propagation from straw surface to soil surface, and vice-versa, takes place with a small thermal gradient ($\Delta T/\Delta Z$). Considering that the thermal conductivity (k) of the medium (straw and air) is similar in all straw amounts, the Fourier equation, $q = k(\Delta T/\Delta Z)$ (Dong et al., 2015), indicates a decrease in the heat flux density (q) with the decrease in the $\Delta T/\Delta Z$ thermal gradient.

The greater the depth, the lower the straw effect on Ts variation, i.e., the b_1 angular coefficient is close to 1 and the b_0 intersection value to 0. Consequently, the line that correlates Ts_{st} and Ts_{bs} is close to the 1:1 line, clearly indicating that changes in Ts caused by mulch decrease with depth. As a result, the straw cover effect on Ts was canceled out at depths below 50 cm.

According to several authors, mulch effects on soil temperatures vary with the presence of crop. Dalmago et al. (2004) and Silva et al. (2006) reported no effect of straw cover on soil temperature at 10 cm-depth under corn (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) vegetative canopies. In turn, Furlani et al. (2008), at 5-cm depth, found that soil temperature was not affected under the vegetative canopies of black oat and radish (*Raphanus sativus* L.). This indicates that the effect of mulch on temperatures at different soil depths depends on the conditions of the crop and on the interception of solar radiation. Since, in the present study, no plant was cultivated, solar radiation directly

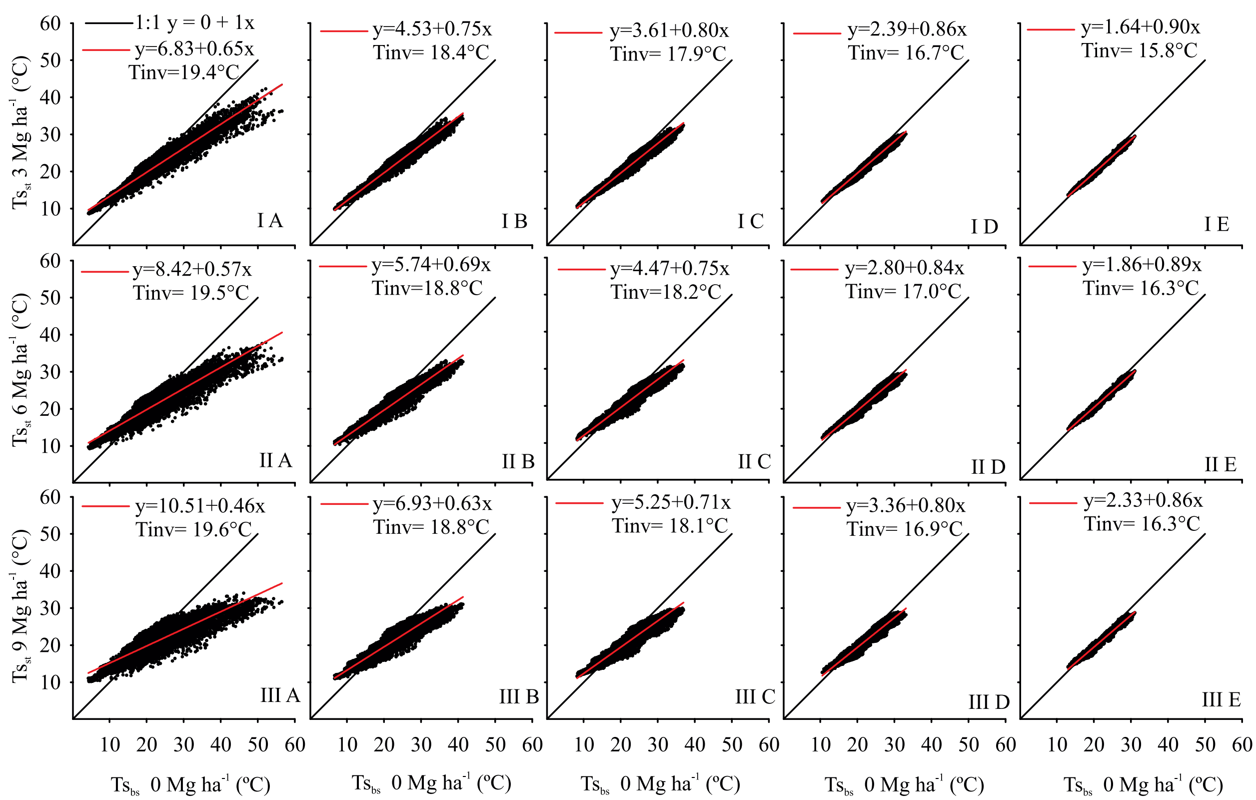

Figure 1. Relationship between the temperatures of soil (Ts_{st}) covered by 3 (I), 6 (II), and 9 (III) Mg ha^{-1} straw and of bare soil (Ts_{bs}) at the following soil depths: 0 cm (A), 5 cm (B), 15 cm (C), 30 cm (D), and 50 cm (E). Tinv, inversion temperature of straw effect.

impacted bare soil and the surface mulch layer. This might have resulted in higher thermal gradients in bare soil, compared with those in covered ones, consequently causing higher temperature variations in depth between treatments.

The obtained data showed that Ts was higher at the beginning of the day in soil covered by straw, but, that, throughout the day, heating penetration was dampened, compared with bare soil. The straw heats and cools the soil before and after bare soil reaches a given temperature, defined as the inversion temperature of straw effect. The inversion temperature decreases with depth; however, at the same depth, it is not affected by the amount of straw on soil surface. Black oat straw affects soil temperature up 50-cm depth, and the greater the amount of mulch, the more intense is the effect.

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