MOISTURE AND HEAT FLUX THROUGH SOIL PROFILE

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ABSTRACT: Temperature and soil heat flow importance to plants, is based on theirinfluenceon water and nutrient uptake, seed germination, root development. On the other hand, soil moisture is one of the most important variables in the soil-plant-atmosphere exchange process, as well as for infiltration, drainage, hydraulic conductivity and irrigation studies. It was aim to study the heat flowin the soil profile at different depths in response to soil moisture. The experiment was conducted in an experimental area of the Department of Biosystems Engineering (LEB) of the Luiz de Queiroz School of Agriculture (ESALQ/USP) located in Piracicaba, SP. Thermocouples were installed in the soil profile at depths of 5, 20 and 35 cm. The treatments consisted of soil conditions without and with irrigation in the field capacity. The results were analyzed with the F test at 5% significance. From the results obtained, it is concluded that, the variations in the heat flow generally decrease with soil depth increases, and the effect of the moisture on the heat flow in the soil is accentuated in the condition of greater humidity for 5 cm depth.

KEYWORDS: Soil temperature, moisture, irrigation, soil heat flux.

UMIDADE E FLUXO DE CALOR ATRAVÉS DO PERFIL DO SOLO

RESUMO: À importância da temperatura e do fluxo de calor no solo para as plantas, ocorre desde a sua influência na absorção de água e nutrientes, germinação de sementes, desenvolvimento radicular, entre outros. Por outro lado, a umidade no solo constitui-se numa das variáveis mais importantes nos processos de troca entre o solo e a atmosfera. Neste sentido, objetivou-se estudar o fluxo de calor no perfil do solo em diferentes profundidades em resposta a umidade. O experimento foi conduzido em área experimental do Departamento de Engenharia de Biossistemas da Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ/USP) em Piracicaba, SP. Foram instalados termopares no perfil do solo, nas profundidades de 5, 20 e 35

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cm. Os tratamentos consistiram em condições de solo sem e com irrigação na capacidade de campo. Os resultados foram analisados com o teste F a 5% de significância. Através dos resultados obtidos, conclui-se, que as variações no fluxo de calor diminuem à medida que aumenta a profundidade no perfil do solo, sendo este acentuado na condição de maior umidade para a profundidade de 5 cm.

PALAVRA-CHAVE: Temperatura do solo, umidade, irrigação, fluxo de calor no solo.

INTRODUTION

The high demand for water resources makes agricultural activities increasingly competitive, demanding a better efficiency use of water in areas where its availability isa limiting factor (FAO, 1998). In the last years soil and water conservation issues have been extensively treated. For Cristofidis (2005) in Brazil the fight against hunger and food safety emphasize the need for improvements in the efficiency of crop management.

The information on the behavior of soil temperature dynamics is an excellent decision-making tool for agricultural production systems, since it has a great influence on the plants, influenced by their water and nutrients uptake, germination of seed, root development, also influencing microbial activity, soil crusting and hardening (LAL, 2004).

Soil temperature is determined by the intensity and duration of the solar radiation, air humidity and wind conditions, being influenced by factors such as geographic location, slope, rainfall or dry periods, anthropic action, level of soil coverage, water content, composition and soil density (HILLEL, 1998, KAISER et al., 2002).

High temperatures affect the initial growth of plants, such as corn, and reduce nodule formation and nitrogen fixation in soybean, as well as affecting other biological processes (TAIZ & ZEIGER, 2004). Particularly for protected environments, in which significant volumes of vegetable species are produced, many times in pots, the soil temperature is especially important, because in these conditions, the substrate temperature tends to reach higher values than those observed under field conditions, with implications for the aerial and root development of the plants, on the microbial activity and may also compromise the nutrient uptake by the plants (Carvalho et al., 2005; Coelho et al., 2013).

Several types of management are adopted in order to modify these scenarios, thus facilitating the development of plants; the permanent maintenance of the soil covered results in lower maximum temperatures and thermal amplitudes of the soil, aspects that are important for the hotter regions, these critical limits are usually reached during the implantation and development of the summer crops in the Central Region of Brazil, when naked soil temperature with conventional tillage usually exceeds 40°C (OLIVEIRA, 2005).

Vegetation residues deposited on soilsurface significantly affects the thermal regime of soil profile, mainly by the reflection and absorption of the incident energy, which is related to the color, type, quantity and distribution of the straw, acting as attenuator of the thermal amplitude (CARNEIRO et al. 2014, LU et al., 2016; MAHDAVI et al., 2017). In this sense, the soil cover obtained by developing plants is also effective, acting by shading the soil, which reduces the incidence of radiation, absorption of energy for transpiration and by the formation of an air mattress, which, because of its lower thermal conductivity, slows the heating of the soil and temperature oscillation over time (PEZZOPANE, 1996). This retardation is stimulated by the presence of mulching, which reduces evaporation, keeping soil moisture and, thus, increasing the soil heat capacity (KIRKHAM, 2005).

With respect to the positive effects of soil mulching it is worth emphasizing that this cover protects the surface of the soil and, consequently, its aggregates of the direct action of the sun's rays and of the wind action; reduces the rate of evaporation consequently keeping the soil layers appropriated for a series of chemical and biochemical reactions based on water; this layer of straw allows increased infiltration and storage of water in the soil and maintains the temperature cooler in the most superficial layer, reducing its amplitude, and favoring the development of plants and soil organisms. When incorporated into the soil, its decomposition is slow and gradual, promoting increase of the organic matter (HECKLER et al., 1998). In this way, the objective of this study was to evaluate the variations in temperature and soil heat flux, in three soil depths, with and without irrigation.

MATERIAL AND METHODS

Location and characterization of the experimental area. - The experiment was carried out in a greenhouse, located at the experimental area of the Biosystems Engineering Department (LEB) in Luiz de Queiroz School of Agriculture (ESALQ /USP) located in Piracicaba, SP. According to Köppen classification, the climate of the region is a *Cwa* type, that is, subtropical humid, with three months drier (June, July and August), characterized by rains in the summer and dryness in the winter.

The greenhouse had used, closed sides with type of black screen, with approximately 50% interception of global radiation. The structure had a floor space of approximately 160 m^2, 96 asbestos cement boxes with a volume of 100 L (dimensions of 60 x 40 x 45 cm), arranged in four strips with spacing of 80 cm between rows and 50 cm between boxes, keeping a distance of 100 cm from the sides of the greenhouse**.**

The experiment was performed between November 16 to 22, 2013, totaling seven days of data. The treatments consisted in the management of vegetation cover in the soil using sugar cane straw with irrigation MPCI and without irrigation MPSI, arranged in a random distribution design with two replications, totaling four plots.

The soil used to fill the boxes was classified as Yellow Red Latosol, with sandy loam texture, following the steps: (i) alignment of the boxes; (ii) insertion of a layer of approximately 1 cm of gravel; (iii) inclusion of a geotextile blanket above the gravel; (iv) soil filling up to 40 cm depth.

Vegetal cover - in order to represent field conditions, in which there is usually a residue of straw and pointers in the order of 15 t ha^{-1} (value range from 5 to 20 t ha^{-1}), for this we weighed 360 g for an area of 0.024 m².

Monitoring soil moisture - soil moisture monitoring was performed using TDR probes (model TDR100 (Campbell Scientific, Logan-Utah)).

Monitoring soil temperature - the soil temperature was measured at three depths, 5, 20 and 35 cm below the surface (Figure 1), using 12 Copper - Constantan thermocouples.

Monitoring heat flux-the soil heat flux was determined using heat flux plates (fluorimeters) model HFP01 from Hukseflux manufactured by Campbell Scientific, 5 cm below the soil surface.

Monitoring of meteorological data **-** the following meteorological elements were monitored: global solar radiation, air temperature and relative humidity. The sensors were installed in the center of the greenhouse and above the boxes (Figure 1).

All data were stored in a data acquisition system (datalogger) with readings performed at 15-minute intervals.

Calculations and estimates **-** beside the measured data mentioned above, the heat flux in the soil were also estimated for the 5 to 20 cm and 20 to 35 cm layers. These calculations were performed base do equation 1:

$$G = -k\left(\frac{\Delta T}{\Delta z}\right) \qquad (1)$$

Where k is a proportionality factor, which is the thermal conductivity of the medium, given by equations 2 and 3 as proposed by Johansen (1975) for dry (K_{sec}) and saturated soils (K_{sat}):

$$K_{sec} = \frac{0{,}135 \cdot d_g + 64{,}7}{2700 - 0{,}947 \cdot d_g} \qquad (2)$$

where$d_g$is the overall or apparent density

$$K_{sat} = \lambda_s^{(1-PT)} \cdot \lambda_{ag}^{(PT)} \qquad (3)$$

wherePTisthe total porosity; λ_s is the thermal conductivity of the minerals andλ_{ag} is the thermal conductivity of the water.

RESULTS AND DISCUSSIONS

Soil moisture along the experiment is shown in Figure 2. The experiment started with soil moisture near 17% (cm^3 cm^{-3}), maintaining for with irrigation (MPSI) between 15 and 16% over the first six days, rising to 19% on the last day due to rain occurrence. For treatment without irrigation (MPCI), the first irrigation took place on November 18, 2013, rising soil moisture atfield capacity over 26%, maintaining around 25% on other days, with an increase to 26% on the last day.

Figure 3 shows that thermal conditions of soil surface begin to change more significantly during daily cycles, in such a way that the variation comes to assume quite high order values. According to Diniz et al. (2013), soil temperatures in regions close to the surface present greater variability than the others due to their greater ease in losing (nocturnal period) and gaining (daytime) heat during the daily cycles. Therefore, it can be concluded that the daily variability of soil temperatures is inversely related to depth (GASPARIM et al., 2005).

Another important detail is that the maximum temperature in the 5 cm layer from the surface exhibits a peak temperature behavior while the other layers in the soil profile will exhibit this temperature peak hours later and with less intensity. According to Geiger (1980), this change in comparison to the more superficial layer is a consequence due the slowly heat flux into the soil leading to this behavior of temperature peak delay.

It is possible to observe the variation of the heat flux behavior in the soil, as well as the temperature fluctuation in different depths for the plot submitted to the treatments of with and without irrigation shown in Figure 3A and 3B.In Figure 3A, it is observed that the heat flux in the soil remained homogeneous in almost all the analyzed period with few oscillations during the period. As the values of temperatures observed as a function of soil depth were also small, the values between the maximum and minimum temperature presented a thermal amplitude varying from 2 to 3 degrees from the superficial layer at 5 cm to the layer located at 35cm deep. Coinciding with that suggested by Pillar (1995), that as one proceeds in depth, there is a lower soil temperature variability, remaining almost constant during the daily cycles (in general, the variations did not exceed 2°C). On the other hand, the air temperature showed a thermal amplitude of approximately 20 degrees during the day. It was evident that the soil straw showed to be a good soil temperature modulator.

In Figure 3B in the treatment without irrigation, the behavior is very similar to that presented in Figure 3A, for both the heat flux and the temperature in the soil as a function of the depth.

The variation of the soil temperature whit depth during the day showed that there is a greater amplitude of variation in the depth of 5cm. For the depths at 20 and 35cm the temperatures show a smaller variation throughout the day, a profile that is exemplified for the 21/11/2013 in Figure 4. The same figure also exemplifies what happens for treatments with soil under influence of irrigation. For treatments with irrigation, at 5 cm depth, soil moisture due to a higher heat capacity presented lower daily thermal amplitude, agreeing with the work of Mahdavi et al. (2017).

As soil depth profile increases, it is observed that the values of the average temperature generally increase in the hours of 19, 23 and 05 hours, and decrease in the hours of 9 and 13 hours (Figure 4A and 4B), evidencing that the thermal regime of the soil is determined by heating from its surface by the solar radiation and the transport of heat sensitive to its interior by the conduction process, with depths close to 30 cm showing damping of the daily heat wave (PEREIRA; ANGELOCCI and SENTELHAS, 2002).

The heat flux measured at 5 cm and the estimated heat fluxes for the 5 to 20 cm and 20 to 35 cm layers are shown in Figures 5 and 6 for the MPCI and MPSI treatments, respectively. As already discussed in the methodology for the estimation of heat flux, it is necessary to use a proportionality factor, which is the thermal conductivity of the soil. This was calculated to give the values of 0.27 Wm^{-1} $°C^{-1}$and 2.2 Wm^{-1} $°C^{-1}$, for dry and saturated soil respectively (SAUER, 1998).

In the MPCI treatment, flux between the lower layers was underestimated when a coefficient of proportionality k = 0.27 Wm^{-1} $°C^{-1}$was used (Figure 5A), this can be explained by the fact that this coefficient be recommended for dry soils with low humidity. When using a coefficient k = 2.2 Wm^{-1} $°C^{-1}$, it is observed that the estimated flux for the 5-20 cm layer increases to values close to the measured flux at 5 cm. In the MPSI treatment, Figure 6A, there is an increase in the relationship between the fluxmeasured at 5cm and the estimated at the 5-20cm layer, but it is still low because the soil moisture does not reach dry soil levels.

CONCLUSIONS

According to the results, the temperature and the heat flux in the soil vary according to depths and moisture conditions. As the depth in the soil profile increases, variations in temperature and heat flux values generally decrease, with the irrigated treatment presenting greater amplitude of variation.

The behavior of the temperature and the heat flux in the soil during a diurnal cycle was similar in all the studied days, always having the smaller variation in the depth of 35 cm and the greater variation at 5 cm of depth, independent of the condition of soil moisture.

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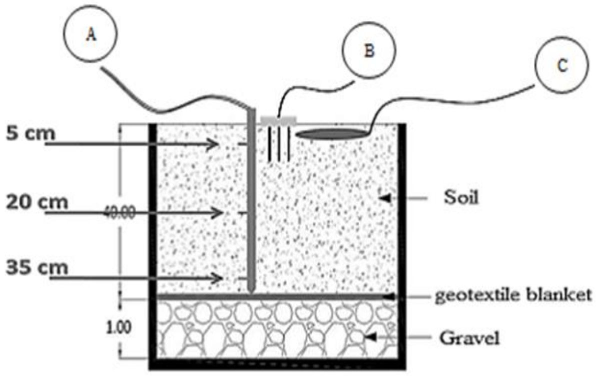

Figure 1. Schematic model of the temperature measurement system using T-type thermocouples (A), at three depths 5, 20 and 35 cm; TDR probe (B) for soil moisture measurement and fluorimeters (C).

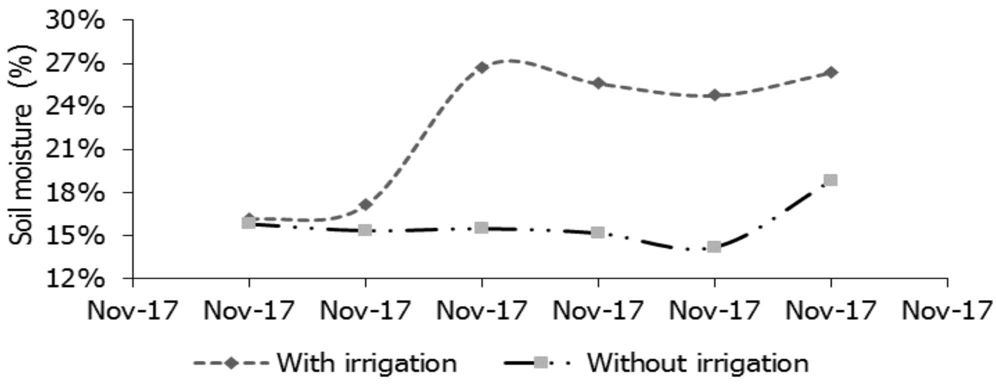

Figure 2. Soil moisture for treatments with and without irrigation.

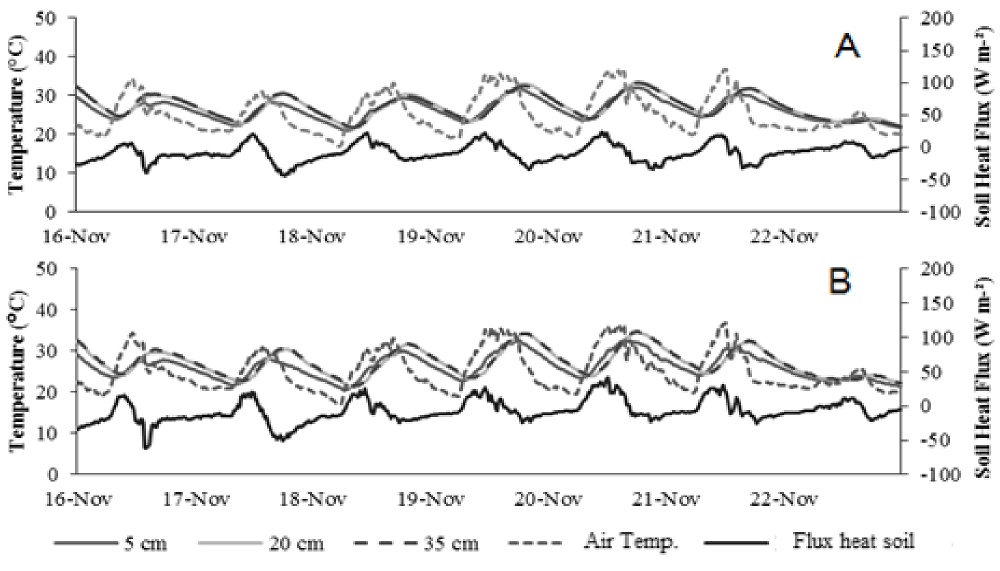

Figure 3. Soil temperature at depths of 5, 20 and 35 cm, air temperature and soil heat flux at depth of 5 cm corresponding to the period from November 16 to 22, 2013, submitted to treatment with (A) and without irrigation (B).

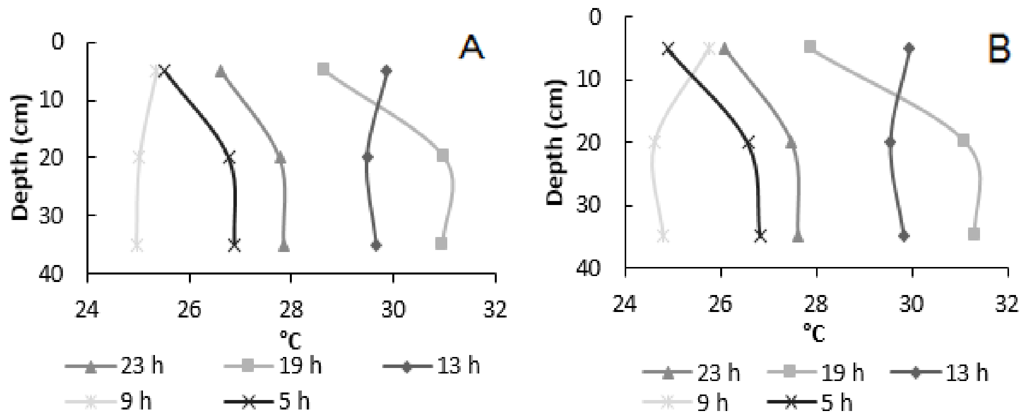

Figure 4. Profile of temperature variation (x-axis) with depth (y-axis) for 11/21/2013, under treatments with straw cover with (A), and without irrigation (B).

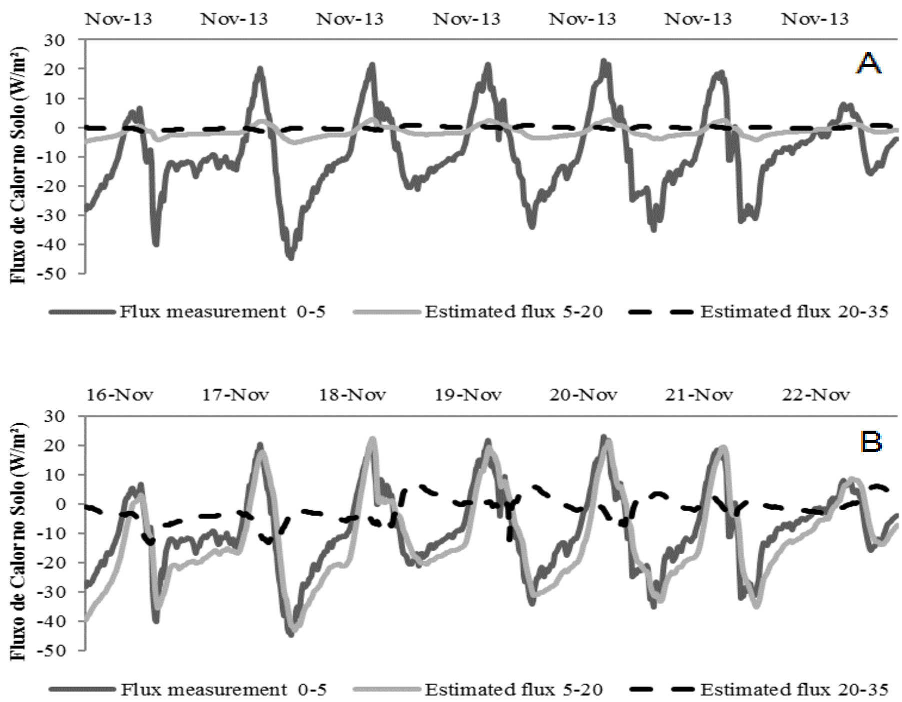

Figure 5. Soil heat flux measured at 5 cm and estimated in the two layers below, in the treatment with irrigation, for a k of 0.27 Wm^{-1} $°C^{-1}$(A) and k of 2.2 Wm^{-1} $°C^{-1}$(B).