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PERFORMANCE OF SOIL HEAT FLUX PLATES IN A FIELD COVERED WITH BRACHIARIA GRASS

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Abstract

Soil heat flux plates are used in studies of energy balance and water demand. The objective of this study was to evaluate two different models of heat flux plates in the soil, HFT3.1 and HFP01, called REBS and HUKS for dry soil season at the Federal University of Recôncavo da Bahia - UFRB, Campus Cruz das Almas, between October and December 2015. R^2 values were 99.34; 96.86 and 99.04% comparing plates of the model HFT3.1 (REBS1 x REBS2), of the model HFP01 (HUKS1 x HUKS2) and between the models REBS and HUKS respectively. The REBS model presented a greater measurement range in relation to the HUKS model, the difference can be attributed to the installation conditions of the plates.

Keywords: Energy balance; Soil heat flux; HFT3.1; HFP01.

DESEMPENHO DE PLACAS DE FLUXO DE CALOR NO SOLO EM ÁREA COM CAPIM BRANQUIÁRIA

Resumo

As placas de fluxo de calor no solo são utilizadas em estudos de balanço de energia e demanda hídrica. Objetivou-se, com este estudo avaliar dois diferentes modelos de placas de fluxo de calor no solo, HFT3.1 e HFP01, denominadas REBS e HUKS para período de solo seco na Universidade Federal do Recôncavo da Bahia - UFRB, Campus Cruz das Almas, entre outubro e dezembro de 2015. Os valores R^2, para o período de solo seco, foram de 99,34; 96,86 e 99,04 % comparando placas do modelo HFT3.1 (REBS1 x REBS2), do modelo HFP01 (HUKS1 x HUKS2) e entre os modelos REBS e HUKS respectivamente. O modelo REBS apresentou maior amplitude de medição em relação ao modelo HUKS, sendo que a diferença pode ser atribuída às condições de instalação das placas.

Palavras-chave: Balanço de energia; Modelos de placas; HFT3.1; HFP01.

RENDIMIENTO DE LAS PLACAS DE FLUJO DE CALOR DEL SUELO EM UM ÁREA DE HIERBA BRACHIARIA

Resumen

Las placas de flujo de calor del suelo se utilizan en estudios de equilibrio energético y demanda de agua. El objetivo de este estudio fue evaluar dos modelos diferentes de placas de flujo de calor en el suelo, HFT3.1 y HFP01, llamados REBS y HUKS para la temporada de suelo seco en la Universidad Federal de Recôncavo da Bahia - UFRB, Campus Cruz das Almas, entre Octubre y diciembre de 2015. Los valores de R^2 fueron 99.34; 96.86 y 99.04% comparando placas del modelo HFT3.1 (REBS1 x REBS2), del modelo HFP01 (HUKS1 x HUKS2) y entre los modelos REBS y HUKS respectivamente. El modelo REBS presentó un mayor rango de medición en relación con el modelo HUKS, la diferencia puede atribuirse a las condiciones de instalación de las placas.

Palabras-clave: Balance energético; Modelos de tablero; HFT3.1; HFP01.

1. INTRODUCTION

The soil heat flux (G) is one of the energy balance components and represent the amount of energy used for soil temperature variation below surface. According to Soares (2013), G represents the fraction of net radiation (Rn) transferred to lower levels into the soil, being therefore the energy absorbed or released at the surface in a given time interval (PAYERO et al., 2005). Quantifyin G is necessary for determination of the turbulent heat fluxes compnents of the energy balance, i.e., latent and sensible heat fluxes (GALVANI et al., 2001).

As Moura and Querino (2010) pointed out, G occurs by conduction due to temperature diferences in the soil profile over both daytime and nightime. Therefore, G is important in many studies that investigate the exchange of energy and matter in natural areas as well as in areas altered by humans (GALEANO et al., 2013).

According to Carneiro et al. (2013), G depends on the soil physical properties such as thermal conductivity and difusivity as well as heat capacity of the soil. Following Sauer and Horton (2005), many studies that need to know the soil heat flux density use different types of heat flux plates. These plates have well defined thermal properties which make them suitable for measuring the heat flux through the soil profile. The heat flux in the soil is proportional to the heat flux in the plate.

Heat flux plates can be used within the soil profie for long periods of time due to their resistance and they allow precise measurements at high frequency if needed (OCHSNER et al., 2006). There are several models of heat flux plates in the market each with its own calibration factor and performance under field conditions; some of them are sold as self-calibrating.

In view of the above, this work aimed at comparing measurements of soil heat flux made simultaneously with two models of plates in a Brachiaria grass field under variable ground cover.

2. METHODOLOGY

The experimente was carried out at the Universidade Federal do Recôncavo da Bahia (UFRB), municipality of Cruz das Almas, Bahia (12º40’39” S; 39º06’23” W; 225 m) from October to December 2015. According to *Silva et al. (2016)* the climate in the region is of the Am type following Köeppen classification (annual rainfall ten times the driest month). In the Thornthwaite classification the Climate is C1dA’a’. The annual precipitation averaged 1100 mm with mean relative humidity anda ir temperature around 81% and 24 ºC, respectively.

The experimental field was 1764 m^2 in area and entirely covered with a pasture of Brachiaria grass (*Brachiaria decumbens*, L.) that was intially clipped and let to grow without irrigation from October to December 2015. During this study measurements of atmospheric variables were made with an automated weather station within the experimental site. Instruments in the tower were connected to a CR1000 datalogger (Campbell Scientific, Logan, USA) which scanned the instruments at every 5 seconds and stored averages and totals at one hour interval for further analysis.

The net radiation (Rn) data were collected with a net radiometer model CNR4 (Kipp & Zonen, The Netherlands) placed on level at 1.5 m above ground. Rain was measured with a rain gage model TE525MM (Texas Electronics, Dallas, USA) with the top cross section on level and at 0.5 m above ground to minimize the negative effects of wind blowing across the instrument. Air temperature and relative humidity were measured with a thermohygrometer model HMP60 (Vaisala, Helsink, Finland) at 1.5 m tall. Wind speed and wind direction were taken with an anemometer set model 03001 (RM Young, MI, USA) placed at 3 m above ground.

In this study, soil heat flux data were collected by means of four heat fux plates positioned at 0.08 m below surface in four distinct points 10 m apart and about 15 m from the weather station each one. In two of the points (P1 and P2) the heat flux plate used was a HFT3.1 model (Radiation and Energy Balance Systems, WA, USA) (from now on REBS1 e REBS2). In the other two points (P3 and P4) a heat flux plate model HFP01 was used (Hukseflux Thermal Systems, Delft, The Netherlands) (from now on identified as HUKS1 e HUKS2).

Completing the set of instruments two thermocouples were installed right above the plate at 0.02 and 0.06 m to monitor heat change in the top layer. Besides, a TDR (time domain reflectometry) probe was also installed to monitor the water content in the soil (θ) for adjustment of soil heat capacity (C_s).

The soil heat flux at surface (G_0) was calculated from measurements at the 0.08 m depth (G_8) according to Equation 1 following Kustas et al. (2000):

$$G_0 = G_8 + \frac{(T_i - T_{i-1}) \cdot C_s \cdot z}{\Delta t} \qquad (1)$$

where,
G_0 - heat flux at the soil surface (W m^{-2});
G_8 - heat flux at 0.08 m below surface (W m^{-2});
T_i - soil temperature (ºC) at the instant i;
T_{i-1} - soil temperature (ºC) at the previous instant;
C_s - soi heat capacity (MJ m^{-3} ºC^{-1});
z - depth of heat flux placement (m);
Δt - time interval (s).

Monitoring the ground cover by the vegetation was made with digital photographs processed with the ImageJ® 1.48v software from zero to 100% ground cover. For this, the grass was clipped and the area cleaned. Pictures were taken at ten points chosen randomly over the area. The points where the heat flux plates were installed were among the ten where photograhs were taken every three days over the experimental period.

Measurements of soil heat flux (G_0 and G_8) were compared firstly between plates of the same type (REBS1 x REBS2; HUKS1 x HUKS2) and then between plates of diferent types (REBS x HUKS), i.e., from different manufacturers. Mean hourly values were used in the comparison that was done following the trend over time and by using linear regression.

The comparison between pairs of plates was done over the October to December 2015 period that turned to be a dry period at that year with very small precipitations spread over time. Since the vegetation was not irrigated the amount of water from rainfall was just enough to keep vegetation growing slowly but not to reach 100% coverage at the end of the period.

The data dispersion in the regression plot was evaluated through the standard error of estimate (SEE) and the regression coefficients were obtained from the ANOVA table as well as the statistical significance of the linear model.

3. RESULTS AND DISCUSSION

The rainfall regime over time is related to chemical, physical and biological processes at the surface which can alter the thermal and hydraulic characteristics of the soil, with direct influence on the heat flux in the soil profile. During this study (October - December 2015) the total precipitation was only 19.3 mm characterizing an abnormal dry period in the Cruz das Amas region.

The soil in the experimental area was classified as sandy-loam texture. The determination of soil density was made with the undisturbed soil samples from samples collected in the area during installation of the heat plates. The soil density averaged 1.75 kg dm^{-3}.

Since the field was not irrigated and preicpitation was small over time the soil water content (cm^3 cm^{-3}) in the top layer (0 - 0.08 m) measured with TDR probe was consistenltly low, around 1.5% showing very small variation. This trend in the water content of the soill was also observed by Peng et al. (2015) when they posicioned TDR probes at 0.02 m depth in their study. To the authors, this happens due to the existence of large gradients of water vapor concentration near the soil-atmosphere interface with a large porous space full of air is available for vapor diffusion.

Em terms of atmospheric parameters, during the experiment the air temperature averaged 25.1 ºC with a minimum of 18.5 °C and a maximum of 31.9 ºC. The relative humidity of the air ranged from 56% to 97% with an average of 76% while the mean wind speed was 2.1 m s^{-1} with peak around 5.8 m s^{-1}.

Figure 1 illustrates, as an example, the temporal variation of hourly soil heat fluxes G_8 (measured) and G_0 (calculated) in the interval from day of the year (DOY) 328 to DOY 333 measured with both types of heat flux plates. Each curve in the graph is an average of two plates of the same type.

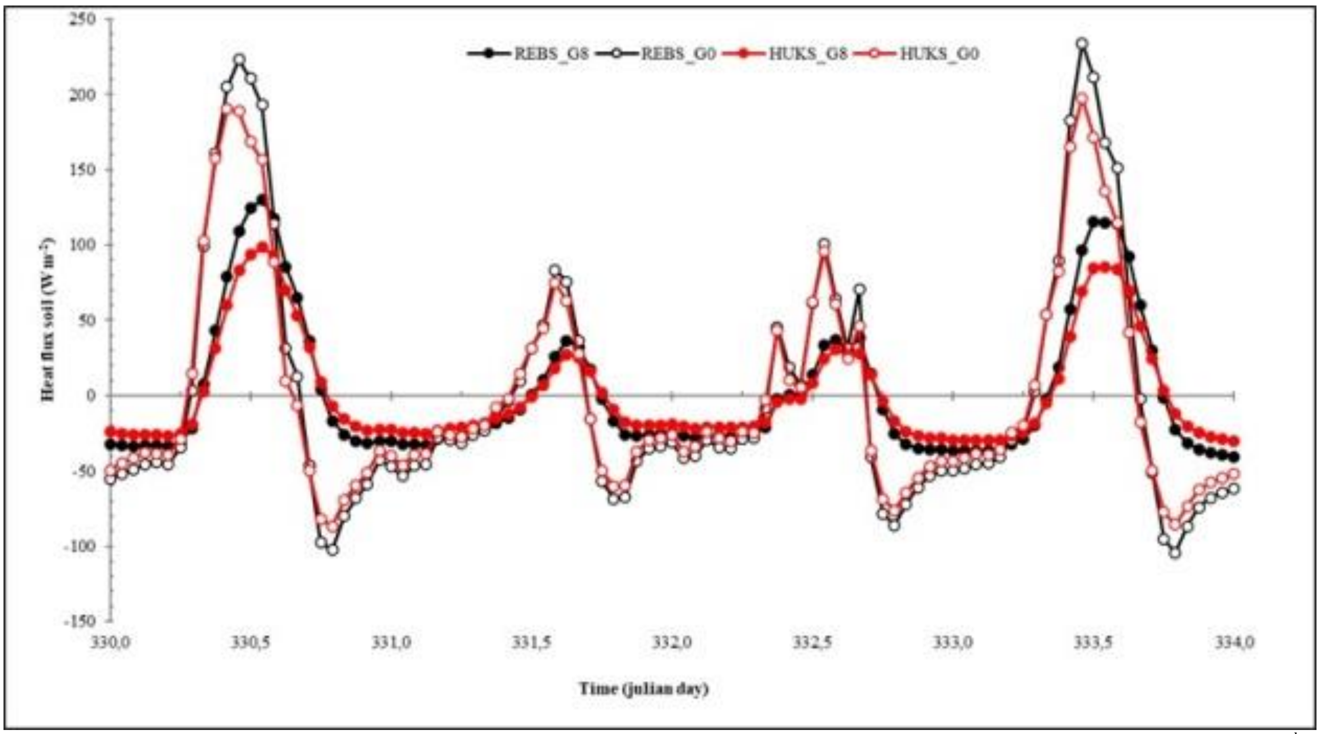

Figure 1 – Evolution of the mean soil heat flux (G_8 e G_0) with the plates HFT3.1 (REBS) and HFP01 (HUKS) between October 24th (DOY 328) and October 29th (DOY 333) 2015. Source: the author.

It can be observed from Figure 1 that at 8 cm depth (G_8) the plates follow each other very closely most of the time except around midday ($Rn > 0$) when REBS G_8 was higher than for HUKS G_8. Besides, the distance between G_8 curves at noon was larger in the first and fourth days because these were clear days and zero in the second and third days because these were cloudy days with atmospheric transmissivity around 0.25 and 0.31, respectively. The same applies to G_0. The presence of clouds limits the amount of radiation that reaches the soil surface with direct influence on the magnitude of G. Therefore, it is expected lower G in cloudy days compared to clear days (high atmospheric transmissivity).

The Figure 1 also shows that G_0 was higher than G_8 mainly during daytime when Rn was positive. Under negative radiation balance (nighttime, $Rn < 0$) G_8 curve was very similar for both types of heat flux plates. The same is valid for G_0. From DOY 328 to DOY 333 of Figure 1, the percentage of ground cover was small with 24% of average cover. As mentioned previously, the ground cover increased very slowly during the experiment due to the lack of water for plant growing (no irrigation and 19.3 mm of precipitation only).

Table 1 shows the coefficients of the linear regression model (Y = AX + B) that fitted the soil heat flux data for a range of combinations of plate types. Data at hourly time step used in this analysis covered all the experiment period and was applied to G_8 as well as G_0. Besides the regression coefficients, Table 1 also shows the coeficient of determination (R^2) and the standard error of estimate (SEE) as an indicator of data dispersion around the regression line for each pair of heat flux plates. In the last line of the tables average REBS data is compared to average HUKS data.

Table 1 - Linear regression coeficients (A, Wm^{-2}/Wm^{-2} and B, Wm^{-2}), coeficient of determination (R^2), and standard error of estimate (SEE, Wm^{-2}) for all heat flux plate combinations. Source: the author.

	G_8			
Heat flux plate pairs	**A**	**b**	**R^2**	**SEE**
REBS1 x REBS2	0,85	4,55	0,98	7,83
HUKS1 x HUKS2	1,12	2,88	0,97	7,89
REBS1 x HUKS1	0,65	-0,42	0,97	6,13
REBS1 x HUKS2	0,64	2,61	0,99	6,02
REBS2 x HUKS1	0,84	-3,27	0,98	7,03
REBS2 x HUKS2	0,83	-0,17	0,99	2,86
REBS x HUKS	0,73	-0,07	0,99	3,31
	G_0			
Heat flux plate pairs	**A**	**b**	**R^2**	**SEE**
REBS1 x REBS2	0,92	3,54	0,98	11,45
HUKS1 x HUKS2	0,91	3,94	0,93	21,32
REBS1 x HUKS1	0,82	-1,35	0,96	15,48
REBS1 x HUKS2	0,79	2,41	0,98	10,44
REBS2 x HUKS1	0,87	-4,36	0,95	18,88
REBS2 x HUKS2	0,85	-0,58	0,99	7,02
REBS x HUKS	0,83	-0,95	0,99	6,33

The linear model with the coefficients in Table 1 is valid for simulation of soil heat flux (G_8 and G_0) from HUKS plates based on measurements made with REBS plates and vice-versa since all combinations presented excelent agreement given by the high values of the coefficient of determination (R^2). When average data of the plates are used (last line of Table 1 for G_8 and G_0) the SEE decreased compared to individual pairs of plates.

Following the trend shown in Figure 1, R^2 decreased and SEE increased from G_8 to G_0. This happens because G_8 data is measured while G_0 data is estimated and therefore this one is subjected to errors associated to the calculation of the soil heat capacity from soil water content measurements.

An evaluation was made taken into account the average of the soil heat fluxes measurements from both models of plates, i.e, HFT3.1 (REBS) e HFP01 (HUKS) during daytime and nightime separately. This analysis per period of day allowed to investigate the behavior of the measurements made with the REBS (model HFT3.1) plates compared to those made with the HUKS (model HFP01) plates. During daytime the REBS plates averaged 28.14% higher than the HUKS plates. Similar result was observed in the nighttime period when REBS averaged 29.22% higher than HUKS plate model.

The tendency of REBS (HFT3.1) plates to measure higher than other plate models was also observed by Sauer et al. (2008) when these authors compared them to a new design of perforated plates under both field and laboratory conditions. The observed diferences could be atributes to the sensibility of the plates to the places where they were installed since soil has spatial variability even over small distances.

Since diferences were found between the models of heat plates analyzed in this study it is possible that the closure of the energy balance is affected differently based on what mode is used to measure G. The energy available for the turbulent heat fluxes (latent λE and sensible H) is determined by the difference between Rn and G, since $Rn - G = \lambda E + H$. Because the REBS plates averaged higher than HUKS model, the use of HFT3.1 would imply in less energy available to be portioning between λE and H.

The process of installation of heat fluxes plates in the soil profile should be carried with care otherwise several source of errors can appear that will impact the accuracy of measurements. One of the most important is the contact of the plates to the soil in both faces. The plate should be tightly inserted into the soil to avoid air gaps that would decrease its efficiency in measuring the heat flux. Besides, Weber et al. (2007) pointed out that significant errors can arise when measurements are made in subtrates with high porosity.

Weber et at. (2007) when testing HFP01 plates under laboratory conditions found that this model overestimated the heat flux in the soil compared to the method of temperature gradiente. On the other hand, the authors found a 26% underestimation with the same plate when tested under field conditions. The authors credited this diference to sensitivity of the sensor to installation in the soil. Peng et al (2015) when evaluating the HUKS plates in the field as compared to the method of temperature gradiente found the plate model to overestimate the heat flux at the 0.02 m depth while at the 0.06 and 0.10 m depths the plate underestimated the measured values by the temperature gradiente method.

4. FINAL CONSIDERATIONS

The soil heat flux measured by the heat flux plate model HFT3.1 (REBS) presented larger amplitudes over 24 hour period compared to the heat flux plate model HFP01, especially under clear sky conditions. The diferences between both models can impact the closure of the energy balance which defines the amount of energy available for heat and water transport through turbulent processes associated to the eschange of latent (λE) and sensible (H) heat fluxes.

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