Universidade Federal de Santa Maria
Ci. e Nat., Santa Maria v.42, Special Edition: Micrometeorologia, e39, 2020
DOI:10.5902/2179460X53222
ISSN 2179-460X
Received: 17/08/20 Accepted: 17/08/20 Published: 28/08/20



**Special Edition**

# Balanço de energia na renovação de canavial com período de pousio e cultivo de soja

## Energy balance in a renewal sugarcane area with fallow period and soybean cultivation

**Rubmara Ketzer Oliveira** [I]
**Luciano Sobral Fraga Junior** [II]
**Larissa Brêtas Moura** [III]
**Debora Regina Roberti** [IV]
**Felipe Gustavo Pilau** [V]

[I] Universidade de São Paulo, São Paulo, Brazil. E-mail: rubmara@usp.br.
[II] Universidade de São Paulo, São Paulo, Brazil. E-mail: lucianosobral@usp.br.
[III] Universidade de São Paulo, São Paulo, Brazil. E-mail: larissa.bretas@usp.br.
[IV] Universidade Federal de Santa Maria, Santa Maria, Brazil. E-mail: debora@ufsm.br.
[V] Universidade de São Paulo, São Paulo, Brazil. E-mail: fgpilau@usp.br.

## ABSTRACT

Brazil is the main sugarcane producer in the world, which is intended for various purposes, from food to power generation. Soybean cultivation in areas of sugarcane under renewal has been growing progressively in Brazil. Quantifying energy fluxes at different stages of this process is essential for better management. The work was carried out in Piracicaba city, with the objective of analyzing the behavior of energy fluxes and the closing of the energy balance in a sugarcane renewal area with a fallow period followed by soybean cultivation. The latent and sensitive heat fluxes were obtained with the “Eddy covariance” method. The closing of the energy balance in the fallow period with straw-covered uncovered and soybean-cultivated soil presented a correlation coefficient of 0.88, 0.78 and 0.71, respectively. In the period without cultivation, the sensible heat flux was predominant in relation to the latent heat flux, varying according to the rainfall regime. The presence of straw under the soil in the fallow period affected the latent heat flux. With soybean cultivation, the latent heat flux surpassed the sensible heat flux.

**Keywords**: Eddy Covariance; Bowen Ratio; Energy partition.

## RESUMO

O Brasil é o maior produtor de cana-de-açúcar no mundo, a qual é destinada para diversos fins, seja alimentação até a geração de energia. O cultivo da soja nas áreas de canavial em renovação vem crescendo progressivamente no Brasil. Quantificar os fluxos de energia nas diferentes etapas deste processo é essencial para realizar um manejo mais adequado. O trabalho foi realizado no município de Piracicaba, com o objetivo de analisar o comportamento dos fluxos energéticos e o fechamento do balanço de energia em uma área de renovação de canavial com período de pousio seguido por cultivo soja. Os fluxos de calor latente e sensível foram obtidos com o método "Eddy Covariance". O fechamento do balanço energético no período de pousio com solo coberto por palha, sem cobertura e com cultivo de soja apresentaram coeficiente de correlação de 0.88, 0.78 e 0.71, respectivamente. No período sem cultivo o fluxo de calor sensível foi predominante em relação ao fluxo de calor latente, variando conforme o regime de chuvas. A presença de palha sob o solo no período de pousio afetou o fluxo de calor latente. Com o cultivo de soja o fluxo de calor latente superou o fluxo de calor sensível.

**Palavras-chave**: Correlação de Turbilhões; Razão de Bowen; Partição de Energia.

## 1 INTRODUCTION

From the solar energy that reaches the terrestrial surface, whether it is reflected or absorbed, it is possible to characterize the energy exchanges that interfere with the thermal regime of the soil, water, air and vegetation. These energy exchanges can be estimated or measured according to the magnitude of these fluxes at each location at different time scales.

The interaction between the management performed in an area and the energy balance, that is, the distribution of energy utilization, is of great importance for understanding the processes of energy and mass exchange. Net radiation (Rn) is partitioned between the processes of soil heating (soil heat flux, G), air heating (sensitive heat flux, Hs) and the change of water status (latent heat flux, LE) (PEREIRA et al., 2002). The energy balance can be represented by equation 1, given by:

$$Rn = LE + Hs + G \quad (1)$$

There are many techniques used to measure surface flux measurements. Among them, the Eddy Covariance (EC) technique (AUBINET et al., 2012) is the most used for in situ measurement of mass and energy exchanges between land surface and the atmosphere. Through this technique it is possible to evaluate the various interactions of gas, water and energy exchanges between the environment and the atmosphere, in different management situations.

Brazil has more than 40% of the world's sugarcane cultivation (FAO, 2018). Brazilian production in the 2017 reached about 10 million hectares planted and a production of more than 700 million tons, intended for various purposes, from food to power generation. Within this, the state of São Paulo stands out, with over 50% of the area and national productions (IBGE, 2018). In Brazil, about 10% of the planted area is under renewal all year round (CONAB, 2018).

The renewal of Brazilian sugarcane fields consists of a period, usually of one year, between the end of a successive sugarcane cultivation cycle (on average, totaling 5 years) and the establishment of a new sugarcane plantation in the same area. The management used in the area during the renewal period usually consists of the fallow of the area and soil preparation for the cultivation of the new sugarcane. The soybean (*Glycine max*) has been progressively occupying areas under sugarcane renewal in the state of São Paulo, being an important component in sugarcane production due to the type of production and potential added value (CONAB, 2018 & PAVÃO et al., 2015).

In this work, the energy balance components were analyzed in a sugarcane cultivation area (*Saccharum* spp.) from different soil cover management and dry and wet intervals, it was possible to observe the behavior of energy transfers during each stage of management and the closure of energy balances.

## 2 MATERIAL AND METHODS

The study was carried out in a traditional sugarcane cultivation area in Piracicaba - São Paulo, with latitude -22°46'S and longitude -47°34'W. With a total cultivation area of approximately 320 ha, a portion of 3.7 ha was delimited for analysis. The climate of the site is classified as Cwa (subtropical, with hot summer) and presents a distinctive distinction with a dry winter and rainy summer (PEEL et al., 2007).

Sugarcane harvesting in the area took place on June 26, 2017 and the renewal of sugarcane began. After harvesting, the area was fallow with the residual straw of five consecutive years of cultivation (and mechanized harvesting) on the soil for 64 days. On September 01, 2017, the area underwent soil management with incorporation of residual straw in subsurface soil and the site was left with bare soil for 84 days. On November 24, 2017, soybean was seeded in the area, with 120 days of cultivation, until March 23, 2018, reaching the harvesting point.

Within the period with fallow area and mulch covered (called "FLW_straw"), there was a distinction between a dry period (FLW_straw_dry") and a rainy period (FLW_straw_moist). The same occurred for the period with bare soil (classified as "FLW_nc"), with very distinct dry (FLW_nc_dry) and rainy (FLW_nc_moist) periods. The soybean growing season was called "Sb" and has no dry season.

To measure meteorological variables and mass and energy fluxes, a micrometeorological tower was installed inside the study field with the Eddy Covariance (EC) data collection system, consisting of an integrated EC150 open-path gas analyzer in a CSAT3 sonic anemometer, a sonic barometer and sonic temperature sensor, all of Campbell Sci®, enabling the Hs and LE data to be obtained. Radiation balance component measurements were performed using a CNR4 net-radiometer (Kipp & Zonen®), the soil heat flux (G) was measured by two model HFP01 (Hukseflux®) flux plates and the flux rate was resulted from the average of the values measured by the plates. In conjunction with the EC system, temperature and air humidity and precipitation data were measured. All data obtained were stored and preprocessed (with integration for 30-minute averages) in the field in a datalogger.

The determination of the LE and Hs fluxes was performed in the *datalogger* by programming inserted according to the calculation methodologies proposed by Aubinet et al. (2012). The flux data obtained by the EC system requires a series of quality control processes to eliminate spurious data that were performed according to the guidelines presented by Mauder & Foken (2006) and Foken et al. (2012). After data quality control, a *footprint* filtering was performed. *Footprint* is a mathematical relationship that associates the spatial distribution of flux sources and their degree of intensity, and is essentially an estimate of the area of origin corresponding to each measured flux.

High frequency raw data collected (without corrections or calibration) were entered into the EddyPro Software (LI-COR®) to estimate the area against the wind that contributed to obtain the measured fluxes. The estimation of the parameters that compose the *footprint* was performed by the model of Kormann & Meixner (2001), resulting in a set of distances that express the instrument's area of vision. These distances were divided into: maximum distance (peak distance) from the anemometer in the direction in which the largest individual contribution relative to flux originates; and displacement distances, where the area between the anemometer and displacement provides up to 1, 10, 30, 50, 70 and 90% of the total flux.

The study area was divided into 17 circular sectors that covered approximately 93% of its total, to perform data filtering within the footprint. Each circular sector has two radius of the same measurement (corresponding to the peak distance) and a corresponding angle, from 0 to 360 degrees, forming a limiting polygon for the filtering, covering the study area. Each 30-minute flux measurement was related to its corresponding wind direction and peak distance, compared to the circular sector radius. Data that had a peak distance (greater contribution of the 30-minute flux measurement) greater than the radius of the circular sector corresponding to the wind direction angle were discarded as they were not within the study area.

After data quality control and footprint filtering, 2.11% of all data (30-minute scale) were discarded due to initial failures (prior to treatment). For LE flux, 6.20% of data was outside the maximum and minimum (unrealistic data), 2.29% of data in rainy periods and 17.53% of data outside the *footprint* were discarded. To Hs flux, 0.56% was discarded due to unrealistic data, 4.52% due to rainy period and 18.11% of data outside the *footprint*.

Flux data discarding is within the range as normal, according Papale et al. (2006) this percentage can reach 60%. The largest source of data discarding is *footprint* filtering because the data likely to come from outside the study area is discarded, not representing the site evaluated.

The data obtained by the Eddy Covariance method cannot reach the equality of equation 1 presented above, generating a residue. The flux data obtained by the Eddy Covariance method do not reach the equality of equation 1 presented above and it is not possible to "close" the energy balance due to the residue generated by the measurements of its main components (WILSON et al., 2002), because the energy of radiation processes is greater than the energy used in turbulent processes. The residue generated by the EC method is not related to a equipment problem, but it has a strong relationship with terrain heterogeneity, which influences turbulence and energy storage by vegetation (FOKEN et al., 2012).

The residue (Res) generated by not closing the energy balance is obtained by equation 2:

$$Res = Rn - G - Hs - LE \tag{2}$$

The closure of the energy balance obtained by the EC method can be performed by the Bowen ratio (β) method (BOWEN, 1926), assuming a similarity condition between the fluxes (equation 3). The energy balance adjustment can be performed by proportional distribution between Hs and LE of the generated residue (equations 4 and 5).

$$\beta = \frac{H}{LE} \tag{3}$$

Being defined $LE^{*}$ and $Hs^{*}$ after energy distribution as:

$$LE^{*} = \frac{(Rn - G)}{(1 + \beta)} \tag{4}$$

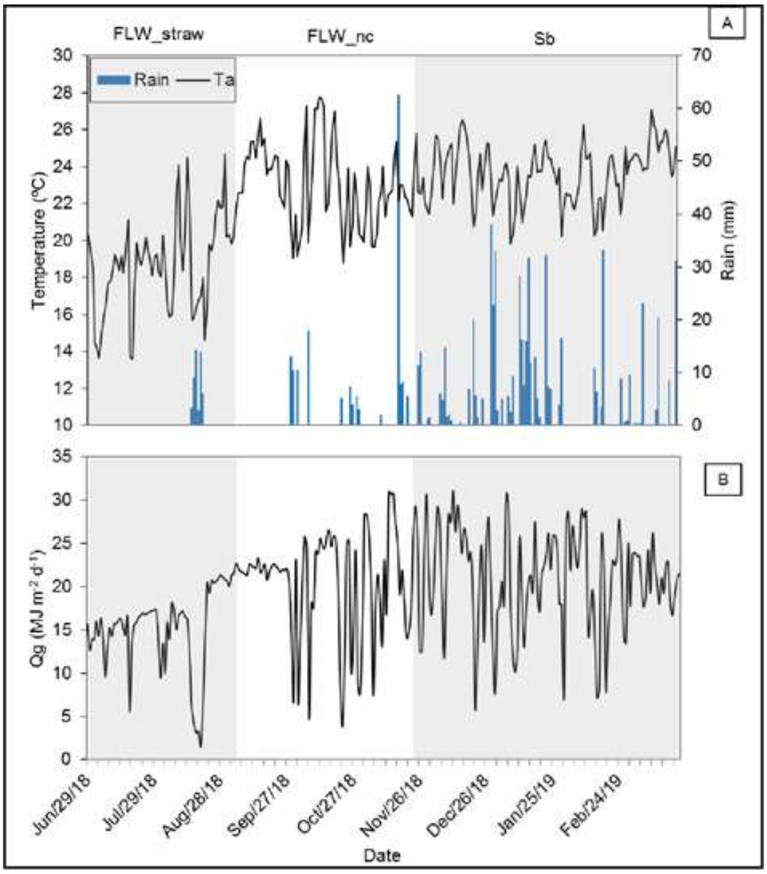
$$Hs^{*} = \frac{\beta(Rn - G)}{(1 + \beta)} \tag{5}$$

## 3 RESULTS AND DISCUSSION

Global solar radiation (Qg), mean air temperature, and accumulated rainfall over the study period can be seen in Figure 1 A and B, which shows the transition between months of analysis and land cover management. Global solar radiation averages 14.8, 20.4 and 21 $MJm^{-2}d^{-1}$ for the FLW_straw, FLW_nc, and Sb periods, respectively. During the canavial renewal period, the air temperature and the availability of solar radiation showed the transition between the seasons (winter, spring and summer) in each subsequent period of coverage management of the area.

The total rainfall of the fallow period with straw management was 49.5 mm and the average air temperature (Ta) was 18.6 ºC. With the bare soil, the total precipitation was 164.8 mm with Ta of 22.9 ºC. For soybean cultivation, the accumulated precipitation was 582.4 mm and a Ta of 23.6 ºC.

Figure 1 – Mean air temperature (Ta), total daily rainfall (Rain) (A) and global solar radiation (Qg) (B) during the study period. The gray-hatched area on the left represents the straw-covered fallow soil (FLW_straw), in the center, the fallow and bare soil period (FLW_nc) and the right-hatched area corresponds to the soybean-growing period (Sb)




The daily cycle (formed by 30-minute averages over 24h) for each land cover management is presented in Figure 2 A to E, where the seasonality of radiation availability (amount of available energy) for each cover management can be observed by the occurrence of the highest averages of Rn near noon in all periods. On average, the highest energy availability (Rn) for the dry and wet periods of “FLW_straw” was 430.8 and 404.5 W $m^{-2}$, respectively. For the dry and wet periods of “FLW_nc” and for the “Sb” period, averages were 609.5, 596.7 and 601.4 W $m^{-2}$. Even with the variation of the energy availability between the periods of different soil coverings, it was verified the effect of the soil surface alteration in the energy balance partition, mainly in relation to Hs and LE.

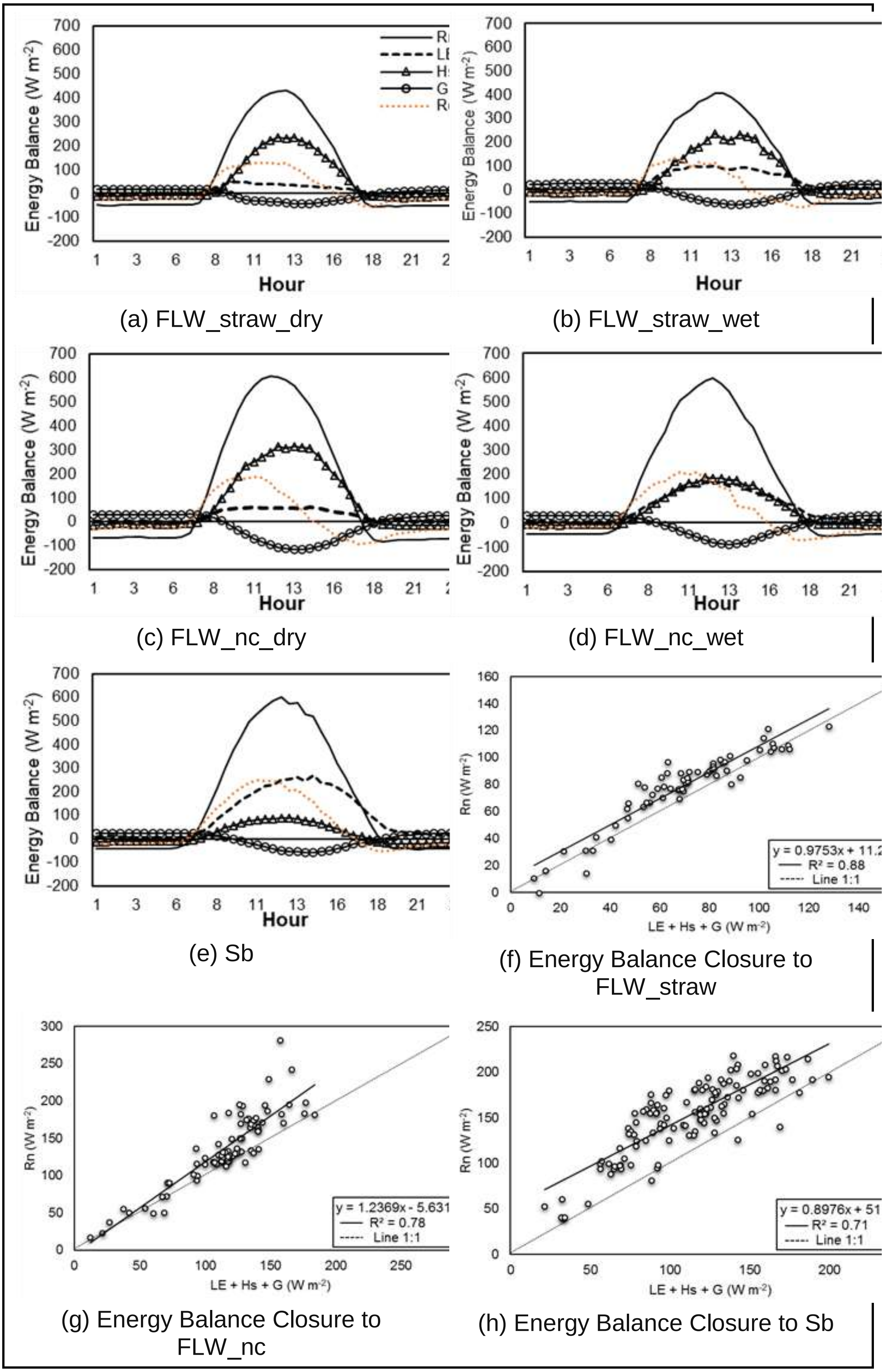
Sun et al. (2018) state that the energy balance varies as a function of ground cover and time of year. The flux partition is significantly affected by the presence of photosynthetically active vegetation under the ground, while dead vegetation usually has a high albedo value which causes a decrease in Rn values.

In periods without photosynthetically active vegetation (FLW_straw and FLW_nc) the Hs flux predominates under LE (Figure 2 A and C), as found by de Souza et al. (2015), where the sensive heat flux is maximized by the occurrence of prolonged drought. With the occurrence of rain and increase of surface humidity, the flux of LE increases by evaporation of soil water and the differences between the fluxes of Hs and LE are smaller than in the dry season (Figure 2 B and D). With increasing energy availability (Rn) the evaporative power also increases, as shown in Figure 2D. The straw covering the soil, forms an impediment layer for the water to escape from the system, so in the FLW_straw period the increase in LE does not occur markedly (Figure 2 B). With the presence of live vegetation under the ground (Figure 2 E) the flux of LE predominates in relation to Hs due to the evapotranspiration process.

The closure of the energy balance allows the evaluation of the Eddy Covariance method to obtain the energy partition and the effect of soil cover on the area's microclimate. The closure of the energy balance in the FLW_straw period obtained a correlation coefficient ($R^2$) of 0.88 with 64% Hs in the dry period and 54% in the wet period. The flux of LE was 17% and 41% in the dry and wet periods, respectively. In the FLW_nc period the closing of the energy balance obtained $R^2$ equal to 0.78, with 64% of Hs in the dry period and 36% in the wet period, as well as 17% and 43% for LE in the same periods. In the period Sb the closure of the energy balance reached an $R^2$ equal to 0.71 with 11% of Hs and 61% of LE.

Imukova et al. (2016), evaluated the energy balance in a winter wheat crop in southwest Germany and obtained $R^2$ equal to 0.71 in 2012 and 0.64 in 2013 to closure of energy balance during the crop growth period. The lowest value in the year of 2013 was due to higher rainfall this year in the period studied, about 50% higher than 2012.

Figure 2 – A to E: Energy balance components averaged 30 minutes over a day for the fallow period with soil straw cover (FLW_straw) and bare soil (FLW_nc), and soybean cultivation period (Sb) according to the water regime (dry and wet). F to H: Closure of the energy balance for each period




(a) FLW_straw_dry

(b) FLW_straw_wet

(c) FLW_nc_dry

(d) FLW_nc_wet

(e) Sb

(f) Energy Balance Closure to FLW_straw

(g) Energy Balance Closure to FLW_nc

(h) Energy Balance Closure to Sb

Figure 3 shows the course of energy fluxes throughout the experimental period. Energy availability is increasing as occurs the transition from winter to spring and summer. Energy fluxes are more stable during dry periods. From the beginning of soybean cultivation can be observed a change in the Bowen Ratio behavior obtained by the EC method. As view previously in Figure 2, Bowen Ratio presents higher values in dry periods, when Hs predominates in relation to LE. In wet and cultivated periods, Bowen Ratio assumes lower values because latent heat flux tends to increase. At the end of soybean cultivation there is an increase in Bowen Ratio due to plant senescence at the end of the cycle.

The average energy partitions for each land cover management are presented in Table 1. The average values of Rn, G, Hs and LE for the whole period were 130.72, 3.68, 38.40 and 61.56 W $m^{-2}$. Webler et. al (2013) studied a pasture area in wet and dry periods and the transition between them during 5 years. The authors obtained average fluxes of 117.93 W $m^{-2}$ for Rn, 81.3 W $m^{-2}$ for LE, 36.15 W $m^{-2}$ for Hs and 0.47 W $m^{-2}$ for G. They also point to the change in energy partition between LE and Hs according to wet and dry period.

With the fallow soil with straw cover, there is a greater reflectance of the straw compared to the period of soil without cover, influencing the sensitive heat flux. The layer of straw over the soil provides greater protection, avoiding the loss of water by evaporation of the soil, which can be understood by the smaller partition for the latent heat flux in this period.

With a greater availability of solar radiation in combination with the removal of straw from the soil surface and consequently the increase of the exposed soil surface, it is facilitated the entry and exit of water in the soil, influencing the latent heat flux.

Figure 3 – Net radiation and energy fluxes over the study period. The gray-hatched area on the left represents the straw-covered fallow soil (FLW_straw), in the center, the fallow and bare soil period (FLW_nc) and the right-hatched area corresponds to the soybean-growing period (Sb)

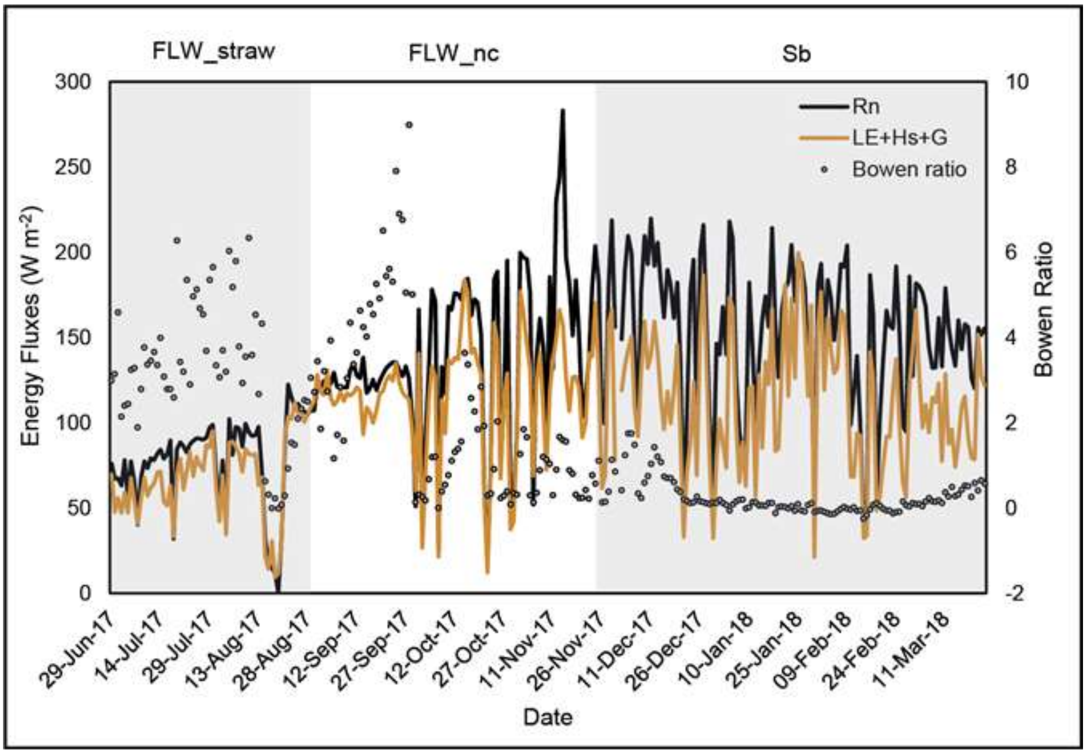



Table 1 – Averages of energy balance components for each land cover management period

| Soil cover | Fluxes (W $m^{-2}$) | | | | Bowen Ratio |
|---|---|---|---|---|---|
| | Rn | G | Hs | LE | |
| FLW_straw_dry | 79,61 | 2,79 | 50,57 | 13,64 | 3,81 |
| FLW_straw_moist | 77,13 | 2,14 | 42,01 | 31,95 | 1,42 |
| FLW_nc_dry | 126,59 | 14,27 | 80,70 | 21,32 | 4,44 |
| FLW_nc_moist | 143,29 | 3,84 | 50,90 | 60,96 | 1,06 |
| Sb | 153,62 | 1,69 | 17,24 | 94,46 | 0,25 |

*Fallow period with covered mulch and dry season is FLW_straw_dry and rainy period is FLW_straw_moist. Period with bare soil with dry season is FLW_nc_dry and rainy season is FLW_nc_moist. The soybean growing season was called Sb.

## 4 CONCLUSION

In the period without cultivation, the sensible heat flux was predominant in relation to the latent heat flux, varying according to the rainfall regime. The presence of straw under the soil in the fallow period affected the latent heat flux, as it is a barrier to the soil water outflow. With soybean cultivation the latent heat flux surpassed the sensible heat flux.

The fallow period with straw cover and bare soil (with the removal of straw on the surface) obtained 64% of the energy partition for the sensitive heat flux, decreasing with the occurrence of precipitation. With soybean crop in the area, the latent heat flux obtained 61% of the energy partition.

The Bowen Ratio showed the highest values when sensitive heat predominated in the energy balance, decreasing in wet periods and with soybean cultivation.

## ACKNOWLEDGMENTS

The authors wish to thank the Micrometeorology laboratory at UFSM for its assistance in processing the data, to the project Immediate Prediction of Intense Storms and Understanding of Physical Processes Inside the Clouds: the *SOS-CHUVA* (Severe Weather Forecast and Observation System), process nº 2015/14497-0, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), for providing the necessary equipment to carry out the study and Cooperative of Sugarcane Planters of the State of São Paulo - COPLACANA, for providing the area for the study. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. We also appreciate the Fundação de Estudos Agrários Luiz de Queiroz (Fealq) and Department of Biosystems Engineering (ESALQ/USP) for financial support.

## REFERENCES

AUBINET, M.; VESALA, T.; PAPALE, D. **Eddy Covariance: A Practical Guide to Measurement and Data Analysis**. Springer, 460 pp. 2012.

BOWEN, I. S. **The Ratio of Heat Losses by Conduction and by Evaporation from any Water Surface**. Physical Review, v. 27, n. 6, p. 779–787, 1926.

CONAB – Companhia Nacional de Abastecimento. **Série histórica das safras**. Available in: www.conab.gov.br. Access in: Accessed on Oct 02, 2019.

DE SOUZA, L. S. B.; DE MOURA, M. S. B.; SEDIYAMA, G. C.; DA SILVA, T. G. F. **Balanço de energia e controle biofísico da evapotranspiração na Caatinga em condições de seca intensa**. Pesquisa Agropecuária Brasileira, 50(8), 627-636, 2015.

FAO, Food and Agriculture Organization of the United Nations. **Crop information**. Website, 2018. Available in: www.fao.org/land-water/databasesand-software/crop-information/soybean/en/. Access in: Accessed on Oct 02, 2019.

FOKEN, T.; LEUNING, R.; ONCLEY, S. R.; MAUDER, M.; & AUBINET, M. **Corrections and data quality control**. In: Eddy covariance. Springer, p. 85-131. Dordrecht, 2012.

IBGE - Instituto Brasileiro de Geografia e Estatística. **Produção Agrícola Municipal**. Available in: https://sidra.ibge.gov.br. Access in: Accessed on Oct 02, 2019

IMUKOVA, K.; INGWERSEN, J.; HEVART, M.; STRECK, T. **Energy balance closure on a winter wheat stand: comparing the eddy covariance technique with the soil water balance method.** Biogeosciences. 2016.

KORMANN, R. & MEIXNER, F.X. **An Analytical Footprint Model For Non-Neutral Stratification**. Boundary-Layer Meteorology, 99, 2, p. 207-224, 2001.

MAUDER, M., & FOKEN, T**. Impact of post-field data processing on eddy covariance flux estimates and energy balance closure**. Meteorologische Zeitschrift, Vol.15, Nº 6, p. 597-609, 2006.

PAVÃO, M. A.; ALENCAR, L. D.; ZANELLO, C. A., DE MORAIS, J. P. G.; CARDOSO, J. C. **Cultivo e produção de soja em reforma de canavial**. Revista Ciência, Tecnologia & Ambiente, 2(1), 17-25, 2015.

PAPALE, D.; REICHSTEIN, M.; AUBINET, M.; CANFORA, E.; BERNHOFER, C.; KUTSCH, W.; LONGDOZ, B.; RAMBAL, S.; VALENTINI, R.; VESALA, T.; YAKIR, D. **Towards a standardized processing of Net Ecosystem Exchange measured with eddy covariance technique: algorithms and uncertainty estimation**. Biogeosciences, 3, 571 – 583, 2006.

PEEL, M. C.; FINLAYSON, B. L.; MCMAHON, T. A. **Updated world map of the K¨oppen-Geiger climate classification**. Hydrology and Earth System Sciences, 11 (5), 1633–1644, 2007. Available in: http://www.hydrol-earth-syst-sci.net/11/1633/2007/. Access in: Accessed on Oct 02, 2019.

PEREIRA, A. R.; ANGELOCCI, L. R.; SENTELHAS, P. C. **Agrometeorologia: fundamentos e aplicações práticas**. Guaíba: Agropecuária, 478 p., 2002.

SUN, X.; ZOU, C. B.; WILCOX, B.; STEBLER, E**. Effect of Vegetation on the Energy Balance and Evapotranspiration in Tallgrass Prairie: A Paired Study Using the Eddy-Covariance Method**. Boundary-Layer Meteorology**,** 2018.

WEBLER, A. D.; GOMES, J. B.; AGUIAR, R. G.; DE ANDRADE, N. L.; AGUIAR, L. J. **Mudanças no uso da terra e o particionamento de energia no sudoeste da Amazônia**. Revista Brasileira de Engenharia Agricola e Ambiental-Agriambi, 17(8), 2013.

WILSON, K. *et al*. **Energy balance closure at FLUXNET sites**. Agricultural and Forest Meteorology, 113(1), 223-243, 2002.