Revista ARACÊ
ISSN: 2358-2472

ENERGETIC ASPECTS OF THE DEVELOPMENT OF CONILON COFFEE IN THE NORTH OF RIO DE JANEIRO. PART 2 - ENERGY BALANCE

https://doi.org/10.56238/arev6n3-305

Submitted on: 22/10/2024 **Publication date:** 22/11/2024

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ABSTRACT

Conilon coffee represents a good portion of Brazilian coffee growing and it is essential to understand how the crop relates to the energy available in the environment. Due to this, this work sought to determine the components of the energy balance of the Conilon coffee crop in the North Fluminense region during seven seasons. The experiment was conducted in a crop field in the area belonging to the Universidade Estadual do Norte Fluminense Darcy Ribeiro, in Campos dos Goytacazes, RJ, which contains a micrometeorological station that monitored environmental data between June 2015 and May 2022. With this information, the energy balance was performed by the Bowen ratio method, which made it possible to determine the crop evapotranspiration (ETc), the reference evapotranspiration (ET0) and the crop coefficient (Kc). The energy balance method by Bowen's ratio had satisfactory performance and indicated that 66% of Rn was converted into LE, 24% into H and 10% into G. The average evapotranspiration of the crop was 3.81 mm.day-1 and the average Kc per harvest tended to increase throughout the experiment and ranged from 0.82 to 0.92. Conilon coffee presented an average yield of 3.43 t.ha-1 (57.16 sc.ha-1) and it was concluded that an average of 0.08 g per MJ of net energy was produced.

Keywords: Coffea Canephora. Evapotranspiration. Energy Flow.

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ISSN: 2358-2472

INTRODUCTION

The study of the interaction of coffee plantations with solar radiation is of paramount importance for a better understanding and conduction of crops, since it is this that provides energy for the photosynthetic process, and also modulates several other plant physiological processes (Mares et al., 2021).

The energy balance is based on the principle of conservation of energy and in open systems, where there is constant exchange of matter and energy with the environment, the radiation balance (Rn) is divided into latent heat flux (LE), sensible heat flux in the atmosphere (H) and heat flux in the soil (G) (Silva et al., 2019). Some micrometeorological methods can be used to calculate these components, the most used being the Energy Balance method itself and the Bowen Ratio (β) (Pereira et al., 2021; Walls et al., 2020.

In Brazil and around the world, there are academic studies that involve the study of atmospheric variables and the physiological behavior of coffee trees (Costa et al., 2019; Angelo et al., 2019; Holwerda and Meesters, 2019). Some studies consider in their studies the radiation balance of coffee intercropped with other crops such as banana (Pezzopane et al., 2005), macadamia nut (Pezzopane et al., 2010), rubber tree (Araújo et al., 2016), *Erythrina poeppigiana* (Vezy et al., 2018), among others.

The radiation balance represents the accounting between the incident and reflected shortwave radiation and the incident longwave radiation emitted by the surface and represents the energy input into the medium (Querino et. al., 2022).

Latent heat flux is the transfer of mass from the surface of the soil-plant system to the atmosphere, resulting in the evaporation of water, and is governed by the available energy and water (Tchebakova et al., 2023). Usually this flux represents the largest fraction of the radiation balance (Dharshini et al., 2022).

The heat flux from the ground is influenced by external factors such as radiation balance, air temperature, cloudiness, wind and rain. The intrinsic factors for this process are topography, soil cover, and soil type. During the day, the soil stores energy in the form of heat, resulting in an increase in temperature, and at night the soil releases heat and reduces its temperature, an inverse process to what occurs during the day (Pereira et al., 2007).

The values of total radiation and soil heat flux are obtained through balance radiometers and flowmeters, however there is no reliable equipment to measure latent heat flux and sensible heat (Teixeira, 2001). Due to this, the Bowen ratio method is used for the

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estimates of these parameters, based on turbulent covariance and the law of conservation of energy (Dharshini et al., 2022).

Thus, this work aimed to evaluate the energy aspects and determine the energy balance on the Conilon coffee crop through the use of the Bowen Ratio (β) method and data from a micrometeorological station.

MATERIALS AND METHODS

The experiment was carried out in an existing crop field in an area belonging to the evapotranspirometric station of the State University of Norte Fluminense Darcy Ribeiro - UENF, located on the premises of the State Center for Research in Agroenergy and Waste Use - CEPEAA, of the Agricultural Research Company of the State of Rio de Janeiro PESAGRO-RIO, in Campos dos Goytacazes, RJ, Brazil, at geographic coordinates 21º 24' 48'' South latitude and 41º 44' 48'' West longitude and 14 m altitude, referring to Datum WGS84.

According to the Köppen climate classification, the climate of the region is classified as Aw, that is, a humid tropical climate, with a rainy summer, a dry winter and an average air temperature in the coldest month above 18ºC. According to the last climatological normal of the municipality (1991-2020), the average temperature is around 24.6ºC, with an average annual rainfall of 981.6 mm, the presence of dry spells in the months of January and February is common (INMET, 2023).

The soil of the experimental area has a flat topography and is classified as Dystrophic Tb Fluvic Neosol, according to the Brazilian soil classification system of EMBRAPA (1999).

The spacing used between the coffee trees was 2.5 m between rows and 1.5 m between plants in the row, totaling an area of 22.5 m2 per subplot and a useful area of the subplot with 15 m2. Each subplot consists of six plants, and the two ends are considered borders (Figure 1). The total experimental area was 1260 m² and the genotypes used were clones of the Vitória variety (Venâncio et al., 2020).

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Figure 1: Aerial view of the arrangement of plants and spacing in the experimental area, Campos dos Goytacazes, RJ. Source: Prof. José Carlos Mendonça.

In the cultivation area, a micrometeorological station was installed, with two levels of monitoring. For the measurements of global solar radiation (Rg) and reflected radiation (Rr) by the surface, two LI-200X Li-Cor pyranometers were used, Lincoln, NE, USA. The radiation balance (Rn) was obtained by a balance radiometer model NR-Lite Kipp and Zonen Campbell Scientific Inc., Logan, Utah, USA. The pyranometers and the balance radiometer were positioned 0.5 m from the canopy.

Temperature and relative humidity data were obtained using HMP45C-L probes, Vaisala, Helsinki, Finland, while wind speed and direction were measured by two Met One 03002 shell anemometers - L R. M. Young Wind Sentry Set, Campbell Scientific Inc., Logan, Utah, USA. Both the probes and the anemometers were installed 0.5 m and 2.5 m above the canopy, so that it was possible to obtain a gradient of temperature, air humidity and wind speed. Three flowmeters model HFP01SC-L Hux Flux Thermal Sensors, Campbell Scientific Inc., Logan, Utah, USA, at 0.02 m depth, were also used to account for the heat flux in the soil (G).

Data were collected every minute and stored at average values every 15 minutes by a CR1000 data collector from Campbell Scientific Inc., Logan, Utah, USA.

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The latent heat flux (LE) by the energy balance method was determined from Equation 1:

$$LE = \frac{RN - G}{(1 + \beta)} \qquad \text{Eq. 1}$$

Where:

LE is the latent heat flux, MJ $^{m-2.day-1}$;

Rn is the balance of radiation, MJ $^{m-2.day-1}$;

G is the heat flux from the soil, in MJ $^{m-2.day-1}$;

β is Bowen's reason.

To obtain β, like Souza et al. (2021), the equality between the diffusion coefficients of sensible heat and water vapor (Kh=Kv), and between the ratio (dT/dz)/(de/dz) and ΔT/Δe, where z is the distance between the measurements, was considered. Thus, the simplified equation below (Eq. 2) was used:

$$\beta = \Upsilon \frac{\Delta T}{\Delta e} \qquad \text{Eq. 2}$$

Where:

ϒ it is a psychrometric parameter;

ΔT is the difference in air temperature 0.5 m and 2.5 m above the canopy, ºC;

Δe is the difference of air vapor pressure 0.5 m and 2.5 m above the canopy, kPa.

The value of was obtained by Equation 3:ϒ

$$\gamma = \frac{Cp.P}{0{,}622.\lambda} \qquad \text{Eq. 3}$$

Where:

Cp is the specific heat of air at constant pressure;

P is the local mean atmospheric pressure;

λ is the latent heat of vaporization of water, a value of 2.45 $^{MJ.kg-1}$.

The air vapor pressure (ea in kPa) was obtained by Equation 4:

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$$ea = 0{,}6108e^{\frac{17{,}27\,To}{To+237{,}3}}$$ Eq. 4

Where:

To is the air temperature at the dew point, °C.

The average air saturation pressure was calculated from Equation 5:

$$es = 0{,}6108e^{\left(\frac{17{,}27.T}{237{,}3+T}\right)}$$ Eq. 5

Where:

The air temperature, °C.

As a residue of Equation 8, one can obtain the sensible heat flux by Equation 1:

$$H = Rn - LE - G$$ Eq. 6

Where:

H is the sensible heat flux, in MJ.m-2day-1;

LE is the latent heat flux, in MJ.m-2day-1;

Rn is the radiation balance, in MJ.m-2day-1;

G is the heat flux of the soil, in MJ.m-2day-1.

Based on the criteria proposed by Perez et al. (1999), inconsistent data from . Table 1 presents the summary of classes of errors generated by the Bowen energy balance ratio method.β

Table 1: Summary of the classes of errors generated by the Bowen energy balance ratio method (Perez et al., 1999)

Error classes	Condition
The	(Rn-G)>0, Δe>0 e β<-1+|ε|
B	(Rn-G)>0, Δe<0 e β>-1+|ε|
C	(Rn-G)<0, Δe>0 e β>-1+|ε|
D	(Rn-G)<0, Δe<0 e β<-1+|ε|
And	Rapid Changes in Vapor Temperature and Pressure

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The error (ε) was calculated taking into account the precision of the sensors used to obtain the temperature and humidity, and was calculated according to Equation 7:

$$\varepsilon = \frac{(\delta\Delta e - \gamma\delta\Delta T)}{\Delta e} \qquad \text{Eq. 7}$$

Where:

δΔe and δΔT are the resolution limits for the temperature and vapor pressure gradients, considering an accuracy of 0.2°C for temperature measurement and 2% for vapor pressure;

ϒ it is a psychrometric parameter;

Δe is the difference of air vapor pressure 0.5 m and 2.5 m above the canopy, kPa.

The values discarded by error were estimated by interpolation between values before and after the moment of the error, provided that the period of discarded data was not longer than two hours, as done by Righi et al. (2007). If the period of discarded data is longer than two hours, the data of the day were disregarded.β

All energy balance parameters were estimated for the daytime, i.e., when Rg>0, since at night there are more errors, due to atmospheric stability, which generate low vertical gradients and the latent heat flux at night is much lower than during the day (Righi et al., 2007).

The energy balance was carried out taking into account the volume between 2.5 m above the canopy and 0.3 m depth, in order to consider positive the heat fluxes that reach the referred volume and negative the fluxes that leave it.

RESULTS AND DISCUSSION

The Bowen-ratio energy balance method is a micrometeorological approach that associates the energy balance of the earth's surface with the Bowen ratio (β), which is the relationship between sensible heat and latent heat (Ataide et al., 2020). This is a method considered relatively practical and safe, in addition to favoring small time scales and requiring few input parameters (Dharshini et al., 2022).

To perform the energy balance on the Conilon coffee plant, the Bowen ratio was calculated in the experimental area every 15 min, and the results of these calculations were compiled in monthly averages, shown in Figure 7, shown below.

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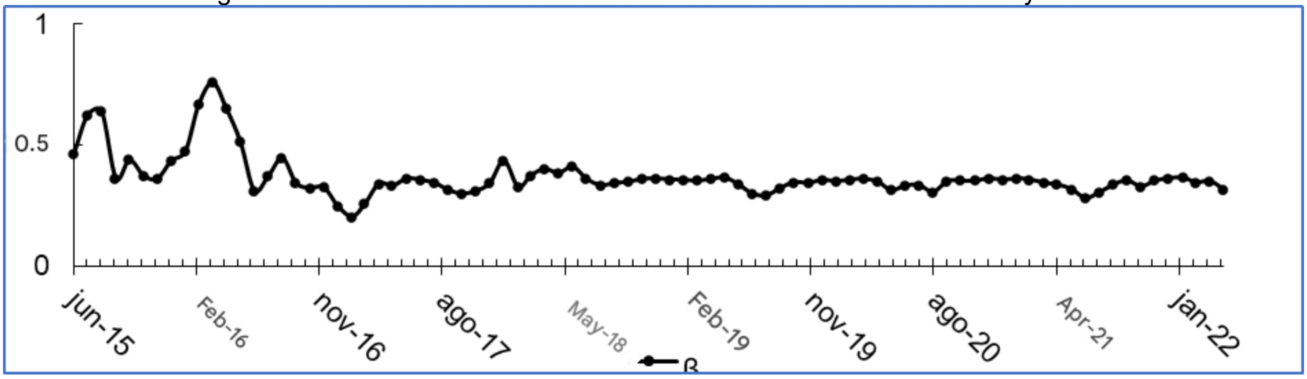
Figure 2: Bowen's ratio on Conilon Coffee between June 2015 and May 2022.



When looking at Figure 2, one can notice a stronger variation in β at the beginning of the experimental period. This behavior is due to the fact that in the first two harvests (2015/2016 and 2016/2017) the plants were still in the development phase, and in the 2017/2018 harvest, there was water scarcity, as also reported by Lazzarini et al. (2022) about the same plants.

From July 2018 onwards, the values were lower in the months of July, June and August, the driest period in the North Fluminense region. This result is the opposite of that obtained by Ataide et al. (2020), who observed higher β values in the dry season (averages of 0.44 in 2015 and 0.31 in 2016) and lower values in the rainy season (averages of 0.22 and 0.27, in 2015 and 2016, respectively).

However, these authors obtained this result in a forest in the Eastern Amazon, a region in which the dry period has higher average temperatures, contrary to what was observed in the present study. In semi-humid climate conditions, air temperature is the ecoclimatic element that most influences the β, followed by vegetation cover (Ren et al., 2022). In addition, as it is an irrigated crop, Conilon plants are less sensitive to rainfall variation (Venancio et al., 2020). According to Dharshini et al. (2022), both β and latent heat flux are strongly influenced by irrigation.

During the experiment period, the maximum value obtained from the Bowen ratio was 0.87, in April 2016, which is due to the temperature, which was above the average for the month, the RH was below the average for the period and the low rainfall, in addition to the fact that the plants had been submitted to pruning two months earlier. The minimum β observed was 0.20, in February 2017, a period in which the plants were in good water status after a period of stress due to water scarcity.

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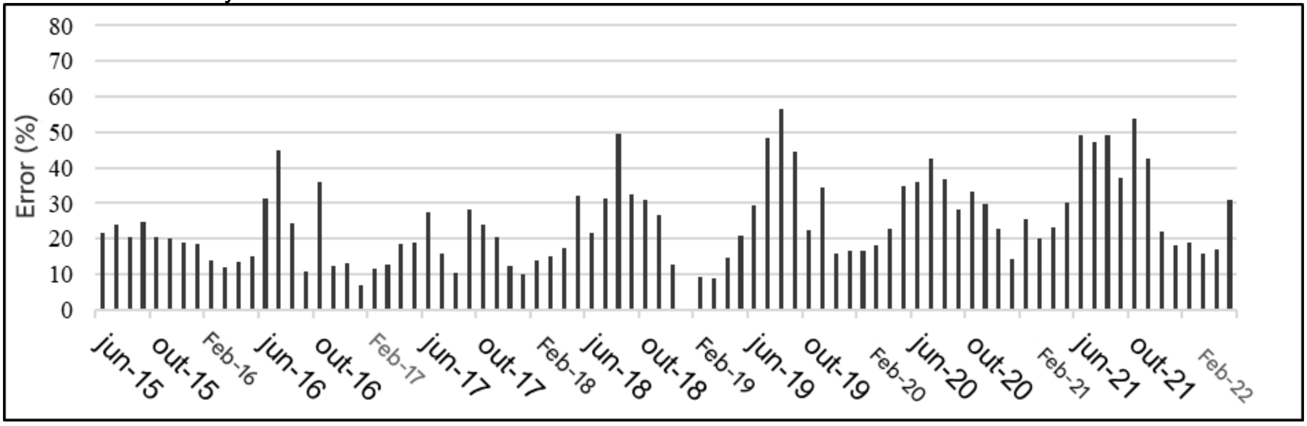
The mean value of the Bowen ratio obtained in the experiment was 0.41, a value higher than that obtained by Ataide et al. (2020). This difference can be explained by the vegetation studied, since the forest environment tends to have better vegetation cover, which tends to decrease the β value.

The methods of estimating the terms of the energy balance have limitations, the method of energy balance by Bowen's ratio is no different. Therefore, it is necessary to analyze the data to verify if the method is really representative. Figure 3 shows the monthly percentage of error in the data, according to the criteria of Perez et al. (1999).

Figure 3: Monthly percentage of inconsistent data for the Bowen Ratio method on Coniln Coffee between June 2015 and May 2022.



In Figure 3 it is possible to notice that there is a trend of a lower percentage of errors in rainier months, which tend to increase in drier months. This occurs because in very dry conditions or with energy advection, the method is less consistent (Soares et al., 2007). On the other hand, in more humid regions, the rainy season tends to present greater inconsistency in the data, since during rainfall events they interfere with the gradients necessary for the method (Pinto et al., 2022).

The months with the fewest inconsistencies in the data were January 2019, with 3.25%, and January 2017, which had 7.04% error in the data. In only 2 of the 84 months, errors were greater than 50%, these being August 2019 (56.66%) and October 2021 (53.99%).

For a better understanding of the quality of the data for the Bowen ratio method, Figure 4 shows the percentage of data with diurnal hourly errors.

In Figure 4, it can be seen that the data present errors in a low proportion at 5:00 a.m., but they present more and more inconsistencies, which occur in greater numbers in

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the period between 7:00 a.m. and 7:30 a.m., and from then on the errors become less frequent, until they arrive with minimum frequencies between 12:00 p.m. and 1:00 p.m. After that, the frequency of errors has a gentle increase until it reaches a second "peak" between 4:00 p.m. and 5:00 p.m., followed by a new drop to very low values (<1.00%), and this pattern in the inconsistency of the data is common, since in the early morning and evening there is an inversion in the heat flow, inverting the steam and temperature gradients (Perez et al., 1999; Pinto et al., 2022).

Figure 4: Hourly percentage of inconsistent data for the Bowen Ratio method on Conilon Coffee between June 2015 and May 2022.

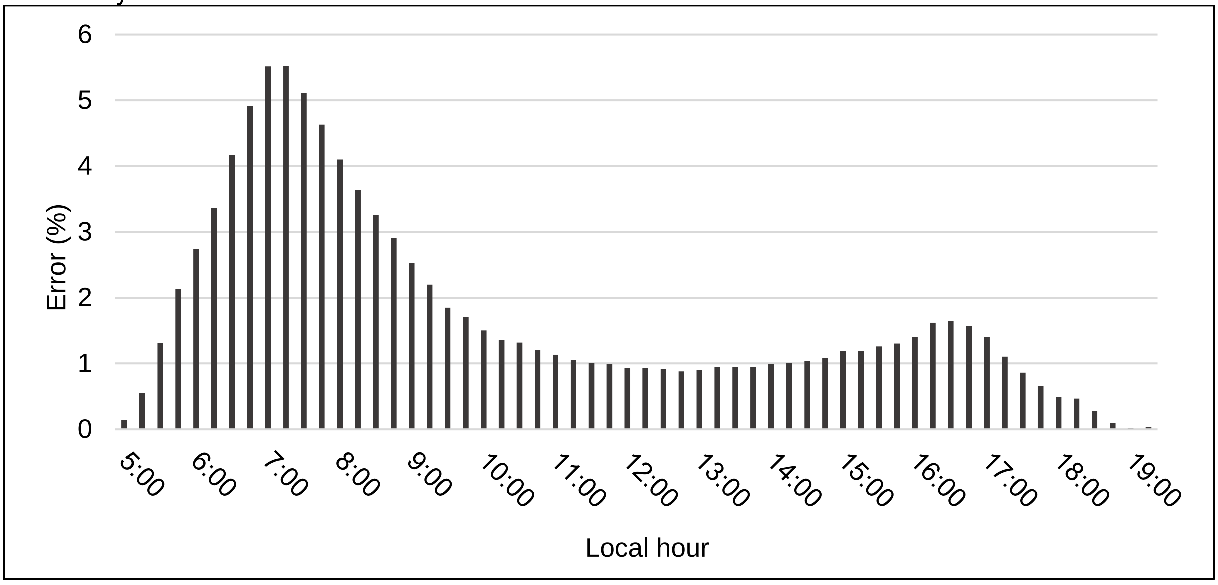

Table 2 presents the β values, the different types of error, the percentage of inconsistent and consistent data, by evaluated crop.

Table 2: Bowen's ratio (β), percentage of error types, inconsistent data (PDI) and consistent data (PDC) per evaluated harvest of Conilon coffee trees

Crop	B	Types of errors (%)					PDI (%)	PDC(%)
		A	B	C	D	And		
15/16	0.66	4.67	10.03	2.09	0.24	1.64	18.55	81.45
16/17	0.41	9.35	6.83	2.13	0.19	1.35	19.67	80.33
17/18	0.41	6.84	5.32	4.48	0.60	1.99	18.85	81.15
18/19	0.35	9.92	6.88	3.12	0.63	1.21	21.44	78.56
19/20	0.34	13.89	13.78	1.19	0.23	0.56	29.45	70.55
20/21	0.34	12.94	9.29	4.36	0.44	1.27	27.97	72.03
21/22	0.34	16.35	13.19	0.14	0.01	4.62	33.14	66.86
Average	0.41	10.57	9.33	2.50	0.34	1.81	24.15	75.85

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Looking at the β values in Table 3, it can be seen that the Bowen ratio decreased as the harvests went by, until it reached the value of 0.34 in the 19/20 harvest, which remained stable until the end of the period evaluated. The β value is inversely proportional to the latent heat flux, i.e., the higher the values, the more the available energy is being converted into sensible heat (Dharshini et al., 2022).

With this, it can be inferred that in the first harvests more energy was being converted into sensible heat, when compared to the last harvests. This scenario can be explained by the physiological immaturity of Conilon in the first two harvests, which implied a lower soil cover, a parameter that influences β (Ren et al., 2022). The third harvest, in turn, was impacted by a water deficit, which explains the higher β value, since the value of the Bowen ratio depends on the water condition of the evaporating surface (Ataide et al., 2020).

Regarding the types of error, it can be noted that the most common inconsistencies observed were type A and B, i.e., conditions of $Rn - G > 0$, $\Delta e > 0$ and $\beta < -1 + |\varepsilon|$, and $Rn - G > 0$, $\Delta e < 0$ and $\beta > -1 - |\varepsilon|$, respectively. Souza et al. (2021) also observed a high proportion of type B errors, being the largest type of error observed in their study, but did not find Type A errors, the most common in the present study. This difference can be explained by the very different climatic conditions between the North of Rio de Janeiro and the Northeast of Pará, where the study by these authors was conducted. On the other hand, Souza et al. (2021) also obtained low percentages of C, D, and E errors, as in this experiment.

Still on Table 2, it is possible to observe that 75.85% of the daytime data were consistent between June 2015 and May 2022. This value was higher than others found in the literature, such as 66.5% found by Pinto et al. (2022), 62.3% obtained by Pereira et al., (2017), and the 72.0% observed by Souza et al. (2021). In addition, the percentage of data consistency was above the minimum of 60% indicated by Perez et al. (1999), which indicates good precision of the results obtained in the present study.

It can also be observed that there was an upward trend in the percentages of inconsistent data as the harvests passed, reaching 33.14% of data with errors in the 2021/2022 harvest. However, even though this value is higher than in other years, it is still within the acceptable range for the methodology, since normally up to 40% of the data can be eliminated (Perez et al., 1999).

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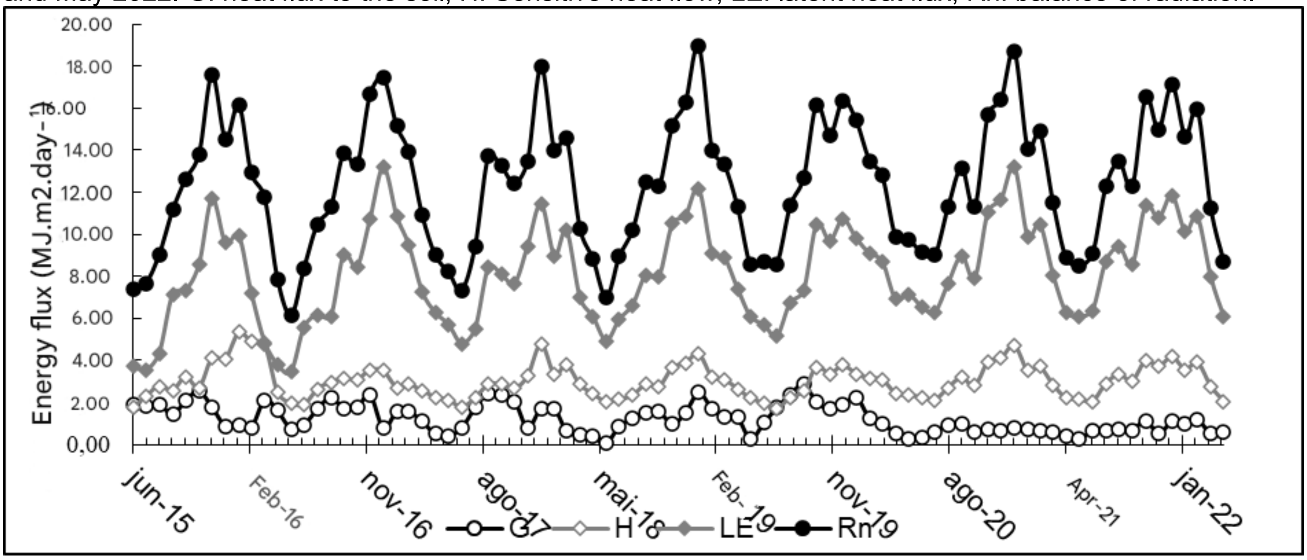
For a better understanding of the energy processes that occur in the cultivation of Conilon coffee, the Bowen's ratio energy balance method was used to determine the latent heat fluxes (LE), sensible heat (H) and the heat flux to the soil (G), based on the radiation balance (Rn). The components were calculated on monthly scales from June 2015 to May 2022 and are presented in Figure 5.

As previously explained, the net radiation was mainly influenced by the BOC variation, which in turn is modulated by the Rg. Thus, the Rn values are higher in the summer (rainy season) and lower in the winter (dry period).

Figure 5: Monthly variation of the components of the energy balance on Conilon Coffee between June 2015 and May 2022. G: heat flux to the soil; H: Sensitive heat flow; LE: latent heat flux; Rn: balance of radiation.



The component of the energy balance with the highest magnitude, except for Rn, was the latent heat flux (LE), which was higher than the others during the entire period evaluated, which indicates that, despite moments of water restriction, the crop continued to evapotranspire without major stomatal restrictions. This fact can be explained by the ability of the Conilon coffee plant to adapt to drought, which occurs through the greater efficiency of soil water extraction and the rate of water use (DaMatta and Ramalho, 2006).

Thus, it can be inferred that there was no excessively strong water stress, which can also be attested by the low variation of albedo, a characteristic responsive to vegetation cover and color. However, water deficit is a limiting factor in coffee production, can cause a reduction in bean size and lower productivity (Cintra et al., 2020). Also, the proportion of damage depends on the phenological stage of the plants and the duration of stress (DaMatta and Ramalho, 2006).

The maximum value of LE was 13.21 MJ.m-2.day-1, obtained in January 2017, a month with high temperature, low RH and considerable net energy availability, which indicates that the atmosphere had a high vapor pressure deficit. In addition, the previous three months had high volumes of rainfall. Thus, it can be inferred that in this period the plant had good water status and the atmosphere was eager for humidity, which culminated in a high LE value.

On the other hand, the minimum LE value observed was 3.44 MJ.m-2.day-1, in June 2016. This low value can be explained by the low radiation balance in the period, which also presents its lowest value in this month. In addition, the crop was subjected to pruning during this period, which decreases the leaf area, which directly affects the latent heat flow of the crop (Dharshini et al., 2022).

During the experiment period, the mean LE value was 8.14 MJ. $^{m-2.day-1}$, a value above the 7.29 MJ.m-2.day-1 found by Dharshini et al. (2022) evaluating irrigated sorghum (*Sorghum bicolor*), and very close to 8.12 MJ.$^{m-2.day-1}$ observed by Souza et al. (2021) when studying an irrigated açaí (Euterpe oleracea *Mart.) plantation and 8.00* MJ.$^{m-2.day-1}$ observed by Ataide et al. (2020) on a native forest in the eastern Amazon. The comparison between the crops reinforces the idea that in general the crop had good water supply, especially taking into account that the LE over Conilon was higher than that found over a native forest.

During most of the months evaluated, the heat flux in the sensible was the second component in which the Rn was converted the most and reached its value of 5.34 MJ.$^{m-2.dia-1}$, in February 2016, when there was a remarkable amount of net energy available and a period in which the plants had undergone pruning management. Agricultural practices that alter land cover can impact the entire energy balance (Liu et al., 2022). Thus, it can be inferred that pruning reduced the LE and, due to the high net energy available, there was an increase in H.

On the other hand, the minimum value obtained from H was 1.70 MJ.$^{m-2.day-1}$, in July 2019, the month in which the heat flux to the soil exceeded H. The low magnitude of this value is due, at first, to the low net energy available, but also to the good water status of the plantation, since in the previous month (May 2019) there was a significant volume of rain (Figure 2). According to Veloso et al. (2020), the presence of water in the medium increases the amount of energy used to be transformed into steam, which reduces the energy available to H.

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The mean value of sensible heat flux (H) was 3.02 MJ.$^{m-2.day-1}$, a value higher than 2.70 MJ.$^{m-2.day-1}$ found by Ataide et al. (2020) in a native forest of the Amazon and at 1.23 MJ.$^{m-2.day-1}$ obtained in a sorghum plantation by Dharshini et al. (2022). This superiority in value can be explained by the higher Rn available in the cultivation of Conilon.

Figure 5 also shows the monthly averages of heat flux in the soil (G), the component of the energy balance of the lowest magnitude during most of the experiment. The value of G was only higher than H in the first month evaluated and in the months of July to September 2019. Under normal conditions, G values vary as a function of Rn and the degree of soil exposure, which the more it is exposed, the more it heats up, increasing the flow of energy in it (Ataide et al., 2020).

The maximum G value was 2.86 MJ.$^{m-2.day-1}$, obtained in September 2019, when the soil was exposed by cultural treatments, with a considerable amount of net energy available and a considerable volume of rainfall, which increases soil moisture and consequently G (Veloso et al., 2020; Wu et al., 2020).

The minimum value, observed in June 2018, was 0.06 MJ.$^{m-2.day-1}$, due to the low available Rn, common for the period, and also due to the soil cover by spontaneous vegetation and low soil moisture, which was due to the low rainfall and longer intervals between irrigations, which resulted in up to 11 consecutive days without water entering the productive environment.

The mean G value during the experiment was 1.23 MJ.$^{m-2.day-1}$, a value lower than 1.38 MJ.$^{m-2.day-1}$ found by Dharshini et al. (2022) in sorghum, which can be explained by the size of the crop, causing Conilon to prevent more solar radiation from directly reaching the soil.

In general, it can be noted that LE and H vary in phase with Rn, with higher values in the hotter and rainier periods and lower in the colder and drier months. However, there are times when G has an increase in its values even with a decrease in Rn values and at other times there is a decrease in G values even with an increase in Rn values. This scenario can be explained by variations in moisture and soil cover.

Still on Figure 5, it is noticeable that the G values show greater amplitudes from the beginning of the evaluated period to the end of the 2019/2020 harvest, however from the beginning of the 2020/2021 harvest the heat flux in the soil becomes more stable. This fact is due to the greater maturity of the crop, which started to offer greater shade to the soil and present more resilience to biotic and abiotic factors and also due to the correct water supplementation.

As previously pointed out, the components of the Radiation Balance vary influenced by Rn, mainly Le and H. So, in order to better observe the energy fluxes more

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independently, Figure 6 shows the fractions in which Le, H and G represent Rn for each of the months studied.

Figure 6: Monthly variation in the ratio between heat fluxes and radiation balance over Conilon Coffee between June 2015 and May 2022. LE/Rn: ratio between latent heat flux and radiation balance; G/Rn: ratio between heat flux to the ground and radiation balance; H: ratio of sensible heat flux to radiation balance.

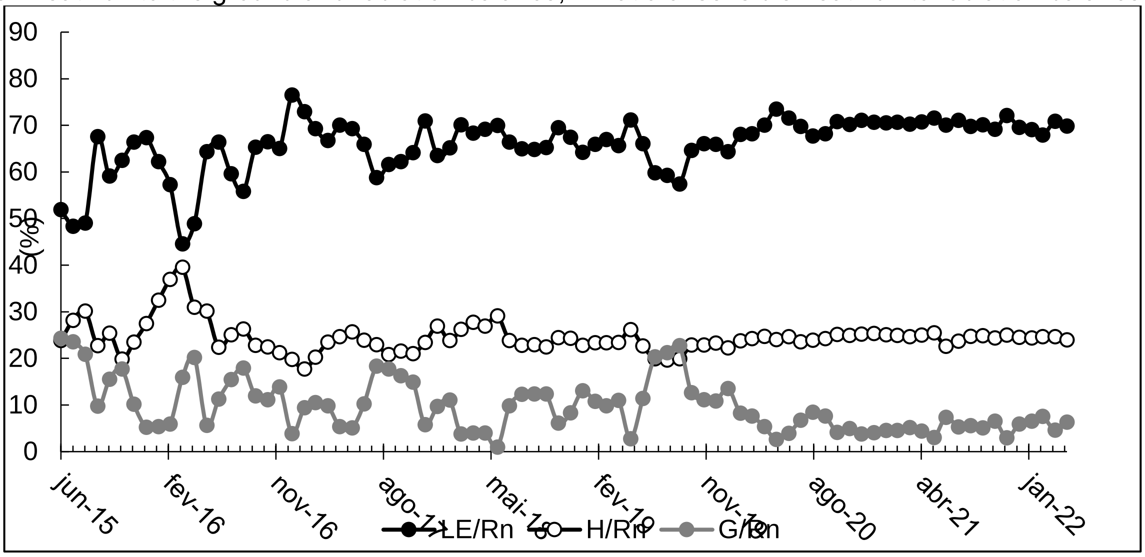

Figure 6 shows the oscillations between the heat flux ratios and net radiation, which occur in greater amplitude in the first two harvests, becoming milder in the 2017/2018 harvests and in almost the entire 2018/2019 harvest. It is also possible to observe that from May 2019 to January 2020 the amplitude of variations increased, especially in LE/Rn and G/Rn, which even exceeded the H/Rn ratio between July and September 2019, as previously mentioned. After this period, there is a remarkable stability in the relationship between heat fluxes and net radiation until the end of the analyzed period.

The largest fraction of Rn was converted into latent heat, on average 65.94% of the net radiation, which is common in agricultural environments with good water status (Azevedo et al., 2014; Dharshini et al., 2022; Pinto et al., 2022; Veloso et al., 2020; Teixeira, 2001). The maximum LE/Rn value was 76.48% in February 2017, one month after the maximum LE observed.

This observation is due to the high temperature, low humidity, and good water supply to which the plant was exposed and also to the plant's metabolism that tends to increase, since in this period in addition to grain filling, vegetative growth also occurs in Conilon, which increases the volume of evapotranspiration of the same (Covre et al., 2022; Ferrão et al., 2017).

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On the other hand, the minimum LE/Rn observed was 44.57% in April 2016, two months before the minimum LE obtained. This low fraction is mainly due to the lower leaf area due to the pruning carried out in February 2016, and the maturation phase in which the crop was, characterized by a slightly slower metabolism, therefore, there is less evapotranspiration (Ferrão et al., 2017).

The H/Rn ratio has an average of 24.46%, the second highest ratio, only after LE/Rn, as observed by Azevedo et al. (2014) in sugarcane (*Saccharum* spp.) and Pinto et al., (2022) on Tahiti acid lime (*Citrus latifolia*). However, there are reports of crops where H/Rn is lower than G/Rn, as in the study on banana (*Musa* spp.) irrigated by Teixeira (2001), who attributes this fact to the moisture advection of the São Francisco River and in the study on sorghum by Dharshini et al. (2022), which can be explained by the lower cover that the plants offer to the soil, given their morphology.

Also in Figure 6, it can be observed that the maximum value of H/Rn, 39.50%, was observed in April 2016, the month of the lowest value of the LE/Rn ratio, as well as the minimum H/Rn, 17.68%, was obtained in January 2017, when the LE/Rn was the maximum. This scenario is due to the competition between latent and sensible heat fluxes, since both use the same energy source, Rn.

The available energy is preferentially converted into latent heat flux, as long as the environmental conditions offer conditions for this (atmospheric water demand, soil moisture and considerable leaf area), thus, for higher H values, one or more environmental conditions are necessary to reduce the LE (Azevedo et al., 2014; Veloso et al., 2020)

The G/Rn ratio had an average of 9.60% in the period evaluated, and ranged from 0.97% in June 2018 to 24.29% in June 2016. This maximum G/Rn is due to the lower soil cover due to the fact that it is still a young crop, in addition to the moisture present in the soil due to the above-average rainfall in the period, which contributes to the increase in G values.

For a better understanding of the variations that occurred between the evaluated harvests, Table 4 presents the means of the radiation balance components (Rn, LE, H and G) and the ratios between heat fluxes and radiation balance (LE/Rn, H/Rn and H/Rn) for each of the seven evaluated harvests.

Table 4: Mean of the components of the radiation balance* and diurnal partition of the radiation balance in different Conilon Coffee crops in Campos dos Goytacazes

Crop	Rn	LE	H	G		LE/Rn	M/Rn	G/Rn

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	MJ.m-2.dia-1					(%)		
15/16	11.88	6.81	3.42	1.65		57.08	28.40	14.52
16/17	12.22	8.04	2.76	1.42		66.51	23.00	10.49
17/18	11.97	7.77	2.91	1.29		65.73	24.22	10.05
18/19	12.37	8.22	2.93	1.23		66.83	24.05	9.11
19/20	12.50	8.12	2.80	1.58		65.24	22.48	12.28
20/21	12.84	9.00	3.17	0.67		70.15	24.69	5.17
21/22	12.90	9.01	3.14	0.76		70.06	24.39	5.55
Average	12.38	8.14	3.02	1.23		65.94	24.46	9.59

*Rn: radiation balance; LE: latent heat flux; H: Sensitive heat flow; G: Heat flow in the soil.

The radiation balance showed an increase between the 15/16 and 16/17 harvests, but showed a small decrease in the 17/18 harvest, due to lower Rg and lower Kt in the hottest months of this harvest. From the 18/19 harvest there was a slight growth each agricultural year until the 21/22 harvest, which presented the highest average value of Rn.

The latent heat flux (LE) and its fraction of the net energy, as well as the Rn, showed an increase between the first two harvests, followed by a decrease in the third, which was caused, in addition to the decrease in the Rn, by the period of water deficit that occurred. Between the third and fourth harvests (17/18 and 18/19, respectively) there was a new increase in LE and LE/Rn, followed by a small decrease in the fifth harvest, which can be explained by the metabolic variation that occurs in Conilon, given its biennial characteristic (Melo et al., 2022; Mendonça et al., 2011). The 20/21 and 21/22 harvests had the highest values of LE (9.00 MJ.m-2.day-1 and 9.01 MJ.m-2.day-1, respectively) and LE/Rn (70.15% and 70.06%, respectively).

The sensible heat flux and its fraction of the net radiation, which has its highest values in the first harvest (3.42 MJ.m-2.day-1 and 28.40%, respectively), shows a decrease between the 15/16 and 16/17 harvests and increases in the 17/18 harvest, due to the same reason as the fall in LE. In the 17/18 to 18/19 harvests, H and H/Rn remained almost constant, falling in 19/20, followed by a slight increase, and remaining stable in the last two harvests.

The heat flux in the soil and its fraction of the radiation balance, as well as H and H/Rn, had their highest values in the 15/16 harvest (1.65 MJ.m-2.day-1 and 14.52%, respectively) and decreased until the 18/19 harvest. In the 19/20 harvest there was a large increase in G and G/Rn, which was motivated by the cultural treatments applied in the cultivation (pruning and weed control) (Zheng et al., 2021). After that, in the 19/20 harvest

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there was a big drop in G and G/Rn, which reached their lowest values (0.67 MJ.m-2.day-1 and 5.17%, respectively), which remained almost the same in the last harvest.

In general, it can be noted that there was a trend of growth of LE and decrease of H and G during the harvests, however the variation of the values of H/Rn is much lower than that observed for G/Rn (4.01% and 8.97%).

For a better understanding of the energy partitioning in Conilon coffee according to its phenology, Table 5 presents the means of the components of the radiation balance and the percentage that each energy flux represents of Rn according to the phenological stage of the plants.

Table 5: Average of the energy balance components and diurnal partition of the radiation balance at different vegetative stages of Conilon Coffee in Campos dos Goytacazes

Stadiums	Rn	THE	H	G		LE/Rn	M/Rn	G/Rn
	MJ.m-2.dia-1					(%)		
Pre-flowering	8.09	5.35	2.08	0.68		66.04	25.65	8.31
Flowering	10.19	6.37	2.43	1.36		62.58	23.81	13.61
Bb gun	12.88	8.14	2.98	1.70		64.07	23.25	12.68
Fruit expansion	14.81	9.94	3.48	1.44		67.54	23.48	8.98
Hail	16.11	10.89	3.91	1.28		68.47	24.31	7.23
Maturation	12.19	8.12	3.22	0.88		66.97	26.29	6.74
Average	12.38	8.14	3.02	1.23		65.94	24.46	9.59

*Rn: radiation balance; LE: latent heat flux; H: Sensitive heat flow; G: Heat flow in the soil.

It is possible to observe in Table 5 that from the pre-flowering phase to the granation stage there is growth in Rn values, followed by a decrease in the maturation phase, which occurs due to the climatic conditions of each phase. Pre-flowering takes place in the months of lower Rg (winter), which are the intermediate months of the year, as explained earlier. The flowering phase occurs at the end of winter, when the Rg increases again. The pellet phase occurs in spring, while fruit expansion occurs in the transition between spring and summer.

The granation stage has a higher value of Rn because it occurs during the summer when Rg is maximum, while maturation occurs in the transition from summer to autumn, when Rg starts to decrease. It can be noted that the available energy is highly dependent on Rg, which occurs due to the low variation of BOL and the low variation of albedo that occurred in the coffee plant.

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It is also possible to notice in Table 5 that LE and H show the same trend of variation as Rn, increasing from flowering to granation, followed by reduction during maturation, however the LE values are more than double that of H in all stages.

G, in turn, shows growth from pre-flowering to pellet, and from then on shows a reduction in values. This decrease in G values is due to the greater soil cover, caused by the larger leaf area of Conilon from the fruit expansion phase, in which there is an increase in metabolic activity, and consequently, vegetative growth (Ferrão et al., 2017).

When paying attention to the partitioning of Rn, it is noted that from the pre-flowering phase to flowering there is a decrease in LE/Rn and H/Rn and a significant increase in G/Rn, which is due to the low leaf area of the period and the soil moisture promoted by irrigation, which tend to cause an increase in G (Veloso et al., 2020; Wu et al., 2020).

In the pellet to granation stages, there was an increase in LE/Rn, which occurs due to the intensification of metabolic activities, larger leaf area, and the increase in temperatures (Covre et al., 2022; Ferrão et al., 2017). H/Rn, on the other hand, oscillated between increment and decrement, in the first stages, until it showed constant growth from the expansion phase of the fruits to the granation. This observation can be explained by the reduction of G, causing H/Rn to grow, even with the growth of LE/Rn. From the pellet phase onwards, there was a decrease in the G/Rn ratio, which reached its lowest ratio in the pellet phase.

At maturation there is a drop in the LE/Rn ratio and an increase in H/Rn, which happens due to the lower metabolic rate of the plants during this phase, reducing LE, making more energy available for H (Covre et al., 2022; Veloso et al., 2020).

CONCLUSIONS

In view of the results, it was concluded that the municipality of Campos dos Goytacazes is suitable for the cultivation of Conilon coffee, as long as it is managed correctly.

The application of the energy balance method by Bowen's ratio was satisfactory and through this it was observed that LE received the highest partition of Rn throughout the experiment, followed by H and G. In addition, LE, ETc and Kc tended to increase between the harvests, while H and G decreased. It was observed that from pre-flowering to granation there is an increase in the values of Rn, LE, H, G.

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The energy balance method by Bowen's ratio had satisfactory performance and indicated that 66% of Rn was converted into LE, 24% into H and 10% into G. The average evapotranspiration of the crop was 3.81 mm.day-1 and the average Kc per harvest tended to increase throughout the experiment and ranged from 0.82 to 0.92. Conilon coffee presented an average yield of 3.43 t.ha-1 (57.16 sc.ha-1) and it was concluded that an average of 0.08 g per MJ of net energy was produced.

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