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Performance and uncertainty of the all-wave net radiation space-time integrators by treetops

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ABSTRACT

The quantification of electromagnetic energy exchanged between plants and their environments is important for ecophysiological studies. Measurement techniques have been developed for the determination of these changes in different spatial scales. In the literature are found some studies describing the use of devices carrying radiometers rotating around isolated trees. Otherwise, when it comes to plantations with spatial arrangement of trees in hedgerows, it is more convenient to use a notional cylindrical geometry of measurement. In this paper we described technical details of assembling devices moving along a stretch of the planting line, generating a notional cylindrical geometry for space-time integration of the all-wave radiation absorbed by the trees in hedgerow. Throughout the experiments it was verified the need for minor modifications which led to the improvement of mobile systems of measurement. Tests with the device free of plants indicated that the errors arising from the null deviation in this condition were sufficiently small. Analyses of measurements of each net radiometer over several days and, also comparison with measurement of daily latent heat calculated from sap flow in 24-hr period indicated that the proposed system gives accurate measurements, being reliable for testing the results of physical-mathematical models.

Introduction

The radiation exchanges of vegetate surfaces is often a necessary measure for micrometeorological studies. Net radiation (NR) represents the available energy that is partitioned into sensible and latent heat fluxes. In fact, under no advection condition, this available energy should equal the sum of that fluxes, in general being addressed to energy balance closure (Bowen, 1926).

The method used in this quantification depends on canopy features and the study purposes. Once considered flat and homogeneous, radiation exchange can be easy measure choosing the more appropriated net radiometer, positioned level horizontally on the surface, measuring short and long wave incoming and outgoing radiation (Field et al., 1992; Halldin and Lindroth, 1992; Vogt et al., 1996; Michel et al., 2008).

However, when the interest is to have measures of a specific part of the canopy, such as the crown of trees, it must be considered that the surface of exchanges is not necessarily planar, and the arrangement and spacing between plants should be considered to individualize this part of the canopy. In such cases, if the spacing between plants is large, it may be necessary to carry out the measurements considering "isolated" trees within the canopy or, if the case is to make the measure in a group of plants practically together and forming a hedge, part of the hedgerow will be sampled.

In order to generate a geometry allowing the measurement of the input and output radiation flows, a set of radiation sensors are properly positioned around the object under study, forming a notional geometric figure of measures. So, the measurements made by the sensors can be space and time integrated to calculate the radiation absorption by the object.

The measurements made by the sensors are considered representative sample points of the body surface and their integration allows the estimation of absorption by the object inserted in the notional geometric figure. The general principle of this type of measurement was originally used to determine the radiation balance of a standing human body (Funk, 1964). Landsberg et al., (1975) and Thorpe (1978) used this principle to determine crown net radiation of an apple tree of an orchard in hedgerows by using linear net radiometers statically placed around the tree, simulating a notional horizontal cylinder of measure.

McNaughton et al., (1992) introduced a methodology using punctual sensors fixed on a vertical circular frame, rotating around the foliage of a small tree, in a spherical geometry of measurement. It allowed space-time all-wave radiation and photosynthetic active radiation absorbed by a single plant. This procedure introduced the use of crown scanning with sensors rotating around the tree, thus allowing space-time integration of the sensors measures.

The "Whirligig", as termed by the authors, showed to be experimentally functional, with consistent measures of all-wave radiation and it was used in studies in New Zealand (Green 1993; Green et al., 1995; 2001 and 2003) and, with minor modifications, in Brazil for isolated trees of acid lime (Angelocci et al., 2004) and oranges (Pilau and Angelocci 2015), both growing in orchards with large plant spacing.

This use of mobile radiation sensors in these measurements is an interesting aspect that can allow a better sampling of the radiative exchanges between a vegetated area forming hedgerow plantations and the atmosphere. Our group has developed mobile systems for net all-wave radiation balance space-time integration in coffee plantations in hedgerow plantings and acid lime orchards (Marin et al., 2005; Angelocci et al., 2008; Pilau and Angelocci, 2014; Simon and Angelocci, 2014).

It is highly interesting to deepen the technical details and performance of the built devices, which would benefit other research groups for saving time and funds on the design and improvement of devices for such applications. Therefore we intend to provide the technical background of our development trajectory and discuss their performances reliability and accuracy.

Material and methods

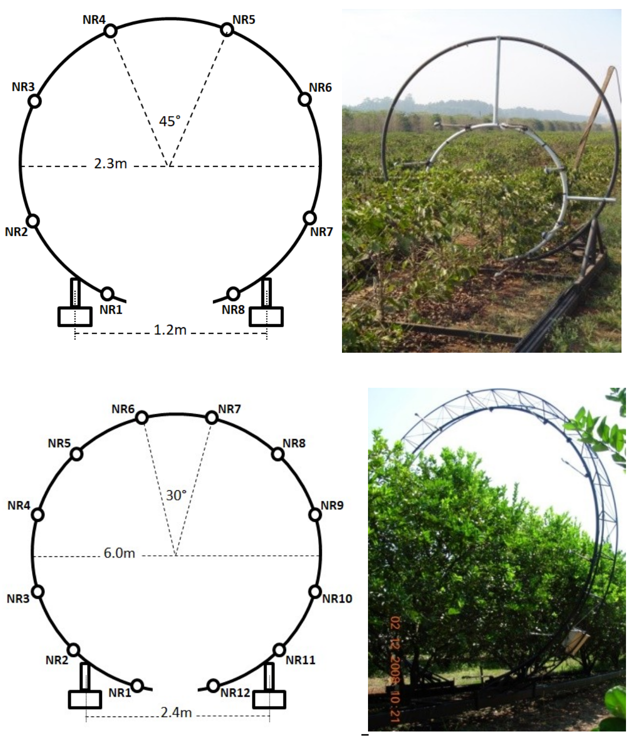
Mobile systems designed

Our first designed mobile system was set up with eight net radiometers fixed on the circular frame at latitudinal intervals of 45°, as designed by Landsberg et al., (1975) and Thorpe (1978) (upper). The second mobile system designed had twelve net radiometers fixed on the circular frame at latitudinal intervals of 30° from each other (bottom).

Both mobile systems performed linear paths on rails, creating a notional cylindrical geometry of measurement (construction engineering information can be access in Marin (2003); Pilau (2005) and Simon (2010)).

In the notional cylindrical geometry of measurements, each net radiometer is assumed to sample 1/n of the lateral surface of the notional cylinder, without taking into account the radiation exchange by the bases of the cylinder (Landsberg et al., 1975; Thorpe 1978). Thus, the integrated value of all-wave radiation balance of the scanned hedge-

Figure 1. Disposition of the net radiometers on the frame of coffee plantations and views of the systems operating (the internal frame was used for growing plantation) (upper figures), and disposition of the net radiometers on the frame of the orchard and view of the systems operating in the orchard (bottom figures). The bottoms of the frames were open to allow the passage of tree trunks.



row length d_h in can be computed by:

$$NR = \left(\frac{1}{n} \sum_{n=1}^{n} NR_i \right) d_h .2.R.\pi$$

where NR_i is the net radiation measured by each net radiometer, n is the number of net radiometers used and R is the radium of the imaginary cylinder.

Net radiometers were model REBS Q7.1 (Campbell Scientific, Logan, UT, USA) with time constant of about 30s and, because of this high measurement frequency, it is assumed that numerical integration was the best option for summing up daily values. In 2002, the net radiometers had recently been purchased, with no previous use in the field. So, its sensitivity factors provided by the manufacturer were adopted. However, in 2008-2009, to keep measurements, considering the recommendation to check the system performance, a calibration test was done. All net-radiometers were leveled side-by-side on a homogeneous grass surface, and each sensor voltage output was compared with net radiation measured by a new sensor of the same trademark, recently purchased and not yet used in the field, adopted as a reference.

Although the sensitivity was checked with sensor detectors in horizontal position, they can be considered valid for any angle different from this position, because instruments of this trademark in variable slopes from 0 to 90° showed an effect lesser than 2% on the calibration, leading to a negligible effect in the daily results less than 1% (McNaughton et al., 1992).

During measurements net radiometers signals were sampled each minute (0.0166 Hz) by dataloggers (model CR10X and CR1000, Campbell Scientific, Logan, UT, USA), recording average each 15 min.

Null deviation test

Before first measurement of all wave net radiation in the crop fields, null deviation tests were done. For it, the mobile systems, with the net radiometers properly installed, carried out measurements free of plants inside the notional cylindrical geometry of measurement.

In 2002, the first designed mobile systems were placed on a paved surface keeping a Southeast-Northwest orientation (SE-NW), following the orientation of the target crop planting lines.

In 2008, before the second measurement campaign, the same device was again tested for null deviation. At this second time we performed the test keeping the equipment in two different alignments, N-S and E-W. Results presented no differences between the two directions. So, based on it, it was decided to evaluate the second designed mobile system only for the target crop orientation line plantation, East-West (E-W). The null deviation results represent the averaged according to the net-radiometers number of each device.

Sites and measurements

Our designed mobile systems for all-wave net radiation balance space-time integration were used in two experimental fields at the Campus "Luiz de Queiroz" (University of São Paulo), Piracicaba, São Paulo, Brazil (Lat.: 22º42´30´´S; Long.: 47º38'00"W; 546 m AMSL). The soil of the experimental sites was a Rhodic Hapludox (33.6% sand, 21.0% silt, and 45.4% clay). The climate of the region is Tropical Cwa (Köppen) with wet summer and dry winter. The mean annual temperature is 22.3°C, annual rainfall of 1,347 mm and global solar radiation of 16.4 MJ m^{-2} day^{-1}.

In 2002 the first one was used to measure all wave net radiation of a mature coffee plantation (5 year-old) of *Coffea arabica* cv. Mundo Novo, grafted on *Coffea. canephora* cv. Apuatã. Trees were spaced 1.0 m x 2.5 m forming hedges with 2.5 m-high and 1.6 m-wide. Plant rows were oriented SE-NW (azimuth 161°). In 2008-2009, the same mobile system was transferred to a coffee plantation (7 year-old) of *Coffee arabica* cv. Obatã IAC 1669-20. Trees were spaced 3.5m x 0.9m forming hedges with 2.0 m-height and 1.7 m-wide. Plant rows were also oriented SE-NW (azimuth 161°). In 2009, the second mobile system was installed in an adult acid lime orchard (7 year-old) [*Citrus latifolia* L. (Yu Tanaka, Tanaka cv IAC 5)]. Plants were spaced of 7.0 m x 4.0 m, forming hedges with 4.5m-high and 4.0 m-wide. Plant rows orientation were E-W (azimuth 91º).

The mobile systems were always set up at the middle part of the crops (812 plants ~ 0, 2ha of *Coffea arabica* cv. Mundo Novo; 2.9 ha of *Coffee arabica* cv. Obatã IAC 1669-20; 1.0 ha of acid lime Tanaka cv IAC 5), in a central plant row.

Crops fertilization was handled according to technical guidance (Raij et al., 1997). Natural herbaceous vegetation between crop lines was kept 10-15cm height by periodic mowing. There was no incidence of pests and diseases during the study seasons.

Weather data

Solar radiation (SR) and grass net radiation (NRgrass) measured in a weather station installed about 100 m far from the coffee and 2,500 m from the acid lime orchards were used. SR and NRgrass were respectively measured with a pyranometer, C3-model (Kipp & Zonen, Delft, The Netherlands) (SR) and a net-radiometer model Q7.1 (Campbell Scientific, Logan, UT, USA).

Results

Null deviation analysis

To visualize the possible measurement errors from mobile systems, three days null deviation (ND) tests out of the measurement coffee and acid lime seasons have been selected (Figures 2, 3 and 4).

Data of ND recorded by the first designed mobile system in 2002 (Figures 2) throughout measurements following SE-NW orientation showed the recordings of two biggest deviations in the morning. First, a negative deviation close to sunrise (6:45 to 7:00 a.m.), ranging from -4.4 W m^{-2} to -6.5 W m^{-2}. It was always followed by a positive one of higher magnitude, from 10.8 W m^{-2} to 12.0 W m^{-2}. After that, until sunset (6:30p.m.) ND kept close to zero, oscillating from -2.5 to 1.5 W m^{-2}.

About the second assessment done with the same mobile system in 2008, due to no differences between performance tests keeping the equipment in two different alignments, N-S and E-W, we decided to present only E-W results. The ND results from E-W direction (Figure 3) generated measurements with a similar pattern previously recorded (Figure 2). The negative deviation kept a similar range from SE-NW orientation, reaching -5.27 W m^{-2}. The positive deviations were smaller. This time, the maximum value recorded was 5.77 W m^{-2} (Figure 2), 50% lower than the deviations previously measured. After that the deviations recorded until sunset were no less than -0.28 W m^{-2} and no more than 1.90 W m^{-2}.

The second designed mobile system null deviation test, considering the difference in circular frame size and the number of net radiometers (twelve), also showed two peaks of deviation just after sunrise (Figure 4). The magnitude of negative deviations (-4.6 W m^{-2} to -9.8 W m^{-2}), first to be recorded, and then positive ones (4.5 W m^{-2} to 13,6 W m^{-2}) were similar to what happened with the other mobile system (Figures 2 and 3). However, the timing of the positive deviation was different, happening between 11:00 to 11:30a.m. Another pattern in relation to the recorded deviation peaks was related to the longer timing of increasing values until reaching the peaks, and also decreasing after that.

The measurements taken overnight further charac-

Figure 2. Daily course of incoming solar radiation (SR) and null deviation (ND). ND relative to Southeast-Northwest (SE-NW) device orientation.

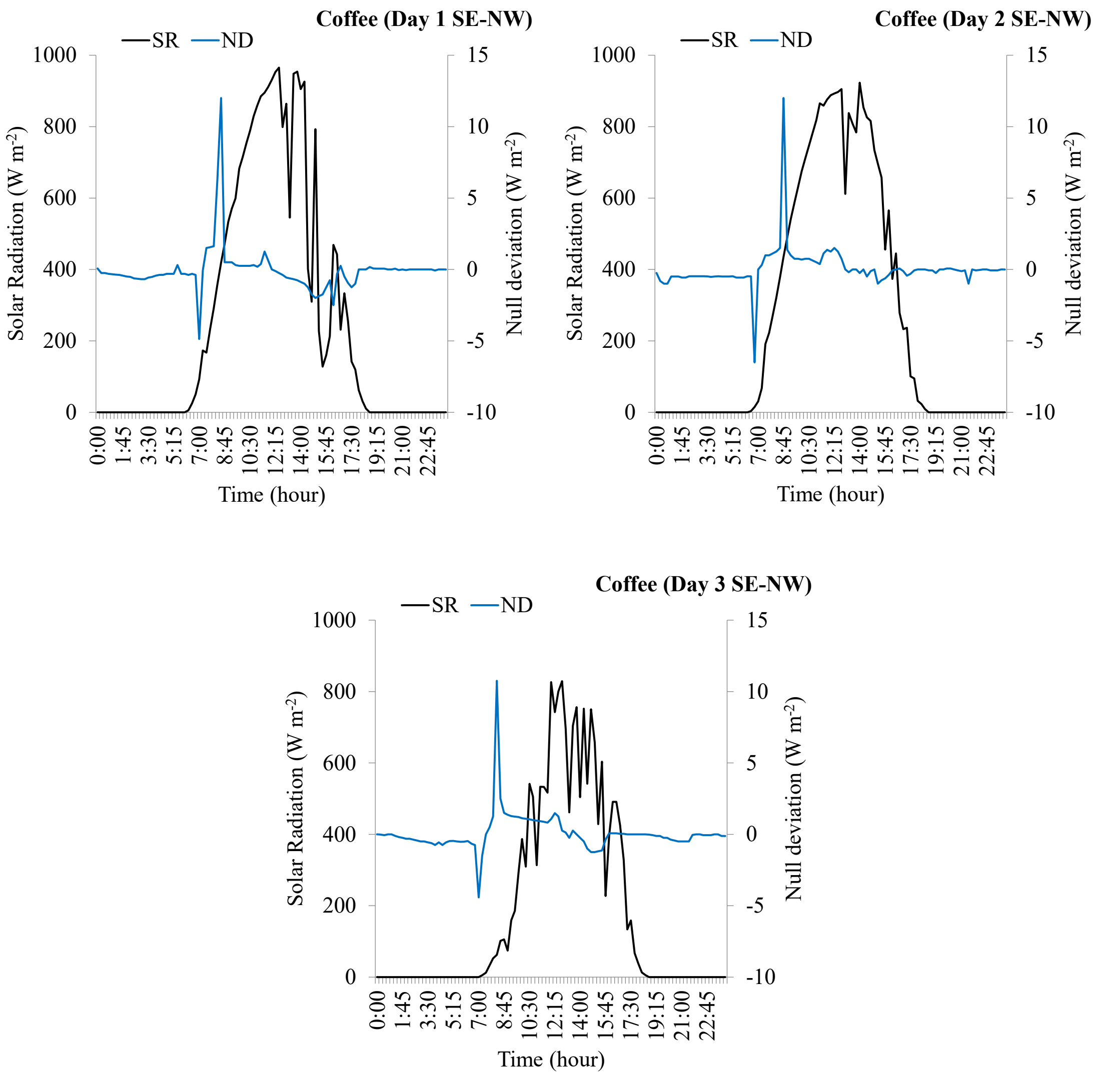
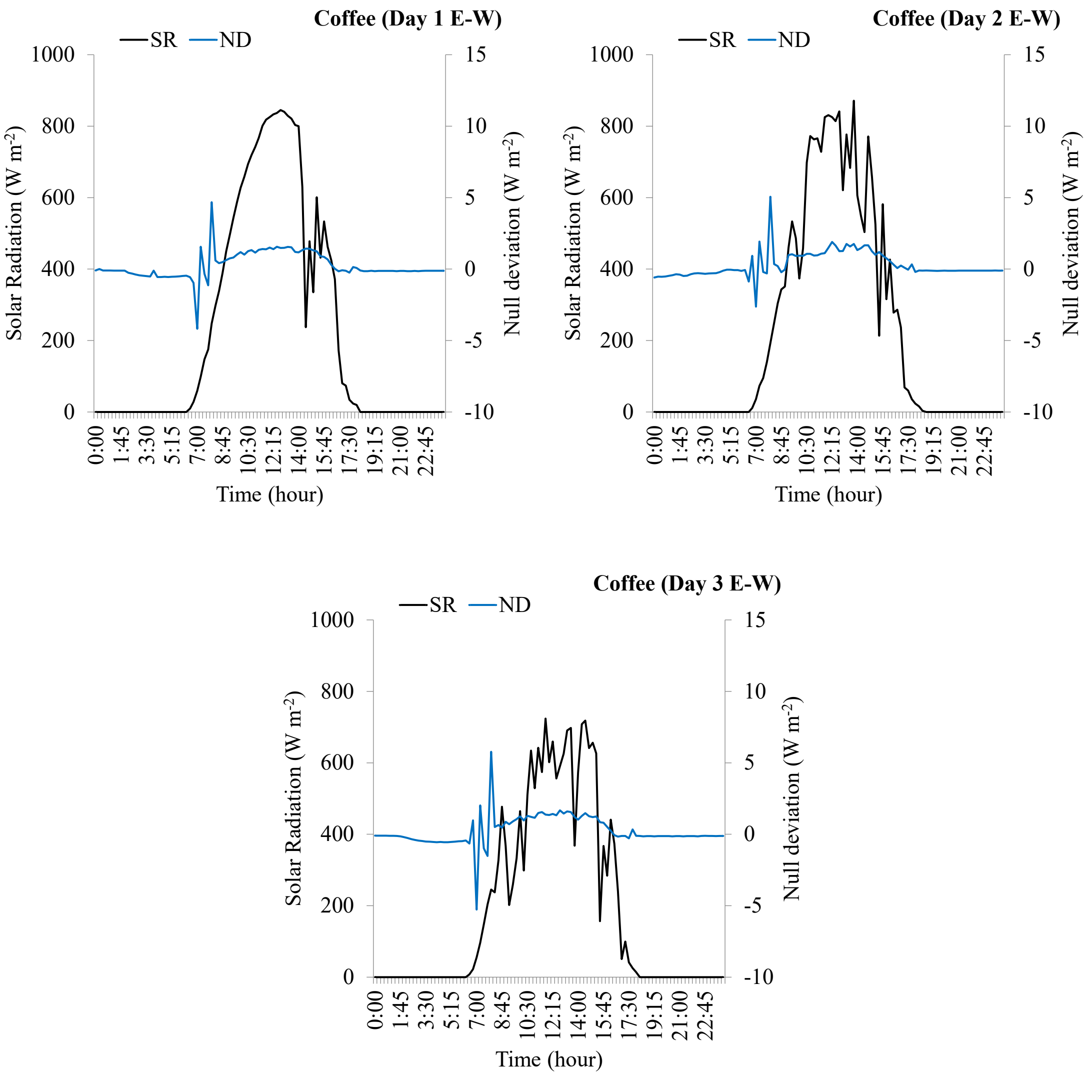


Figure 3. Daily course of incoming solar radiation (SR) and null deviation (ND). ND relative to East-West (E-W) device orientation.



terized the reliability and accuracy of the mobile systems. With net-radiometers correctly aligned; the longwave radiation balance was practically null. The small deviations did not exceed -1.26 W m^{-2} and 0.54 W m^{-2}, negative and positive peaks (Figures 2, 3 and 4).

On average, the temporal values of null deviation were low even considering the peaks (Table 1). Pronounced negative and positive deviations, especially observed in the morning (Figure 2, 3 and 4) are compensated for by each other. According to mean integrated values recorded in the morning, the maximum deviation was 0.028MJ m^{-2}. Considering the amount of incoming solar radiation (SR) it rates about only 1% of it. The results of afternoon and nighttime were even better. Therefore, our results did not exceed about 5% under high incoming solar radiation, which was also observed by McNaughton et al., (1992).

All-wave net radiation measurement: coffee and acid lime cases

Analysis of the daylight and night-time courses of the all-wave radiation measured by the net radiometers and the total absorbed by the hedgerows also allows a discussion about the devices performance and the obtained results. We chose to present and discuss data over a clear (Figure 5a) and an overcast (Figure 5b) sky condition. In coffee plantation, due to the hedgerows approximately oriented SE-NW, the daily course of net radiometers measurements in a clear day (Figure 5a) presented an expected temporal (morning and afternoon) symmetry of the absorbed radiation for each one of the four upper net radiometers (SR3 and SR4 facing to SE, SR5 and SR6 to NW quadrants). On an overcast day (Figure 5b), this symmetry is not well defined due to the predominance of diffuse radiation, but the largest contribution of the upper-half canopy was always present.

The data of sensors in opposite symmetry, despite the difference in order of magnitude as a function of the shading by the foliage (leaf area of 4.21 m^2 m^{-1}), highlight the balance between the incoming and outgoing short and long waves being correctly performed for the treetops

Figure 4. Daily course of incoming solar radiation (SR) and null deviation (ND). ND relative to East-West (E-W) second design device orientation.

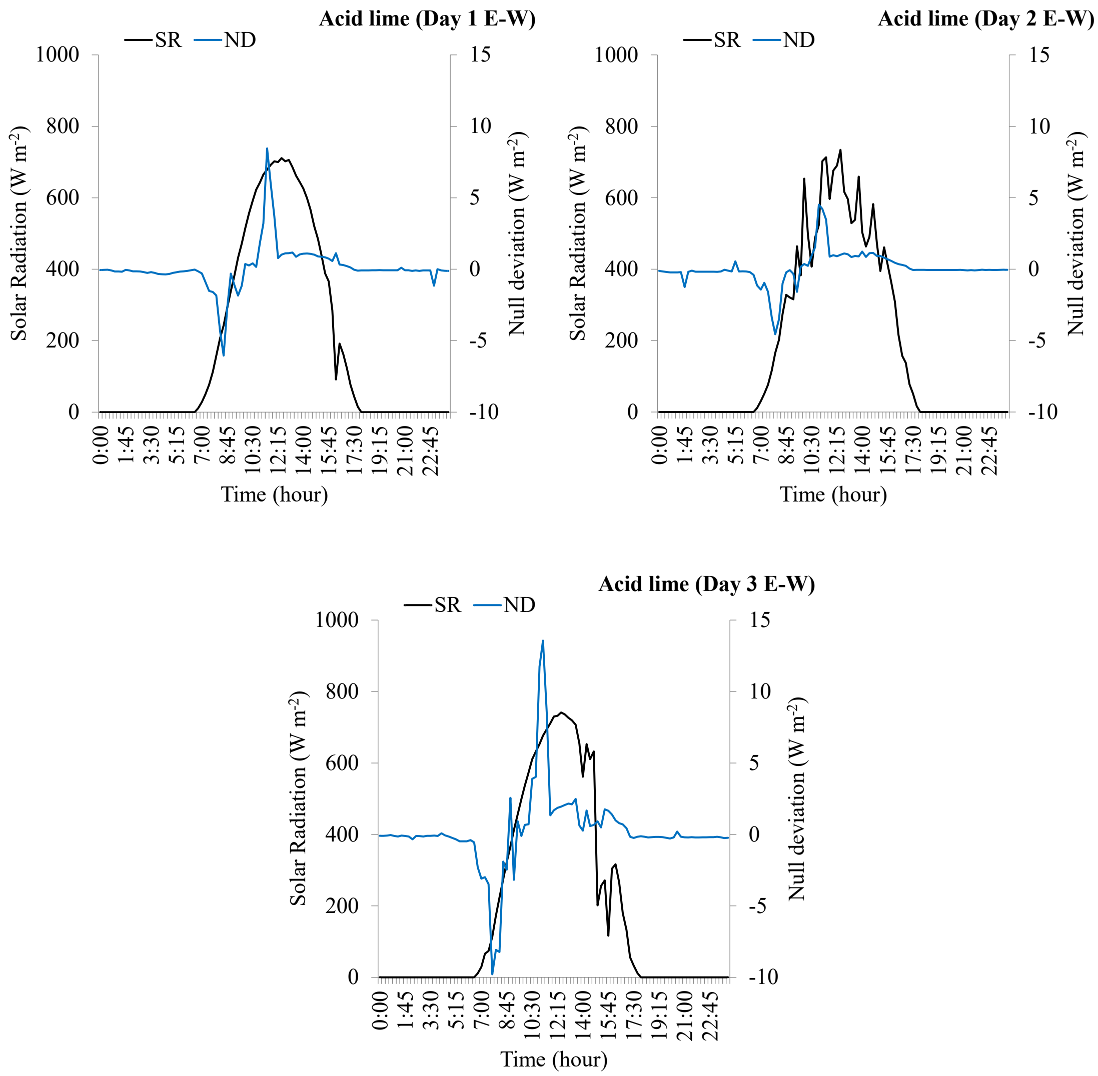


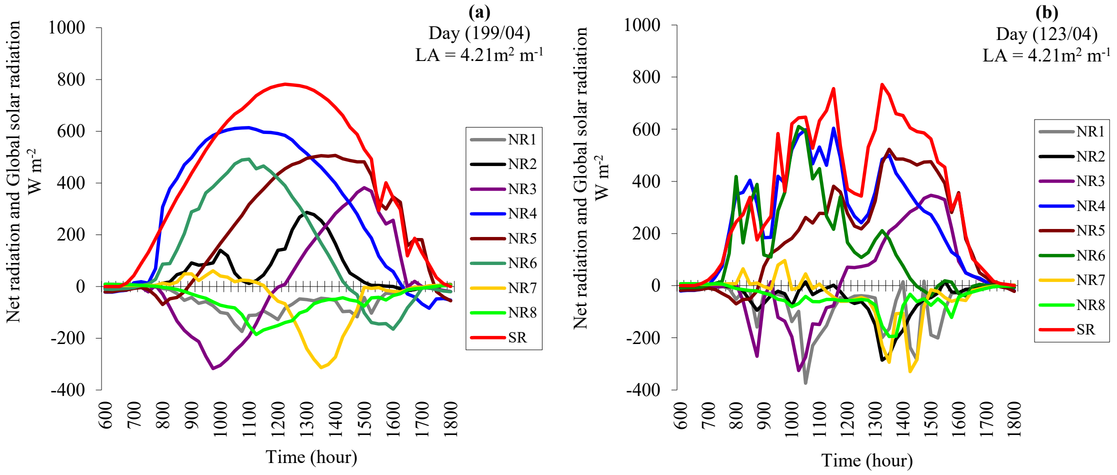
Table 1. Mean integrated values of null deviation (ND) by periods (MJ m^{-2}) and the ratio (%) of null deviation and incoming solar radiation (SR). The first designed mobile system is named Device 1 and the second as Device 2. In parenthesis the displacement orientation.

Time	Device 1 (SE-NW)		Device 1 (E-W)		Device 2 (E-W)	
	ND MJ m-2	ND/SR (%)	ND MJ m-2	ND/SR (%)	ND MJ m-2	ND/SR (%)
Morning	0.224	1.11	0.200	1.09	0.028	0.17
Afternoon	-0.089	-0.44	0.107	0.58	0.147	0.89
Nighttime	-0.122	-0.60	-0.115	-0.63	-0.068	-0.41
Daily	0.006	0.03	0.178	0.97	0.095	0.58

(Figure 5). At midday, with clear sky (Figure 5a), the upper radiometers (SR4 and SR5) recorded highly positive values, between 450W m^{-2} and 600W m^{-2}, while the sensors below the canopy (SR1 and SR8) recorded negative values, around -50 to 100W m^{-2}. From these punctual results we can conclude that the canopy transmittance for short waves was 10 to 20%, as expected for such foliage condition (Monsi & Saeki, 1953). Due to SR4 e SR5 placement, all-wave net radiation registered by them may be higher than global solar radiation early morning and late afternoon, because SR measurements are horizontally done.

In Figure 6 we present data of diurnal net radiation measured by each net-radiometer installed around the acid lime canopies hedgerow, once again with data collect-

Figure 5. Diurnal course of global solar radiation (SR) and net radiation (NR) measured in the coffee plantation cv. Mundo Novo. Leaf area (LA) expressed per unit of row length in the planting line.

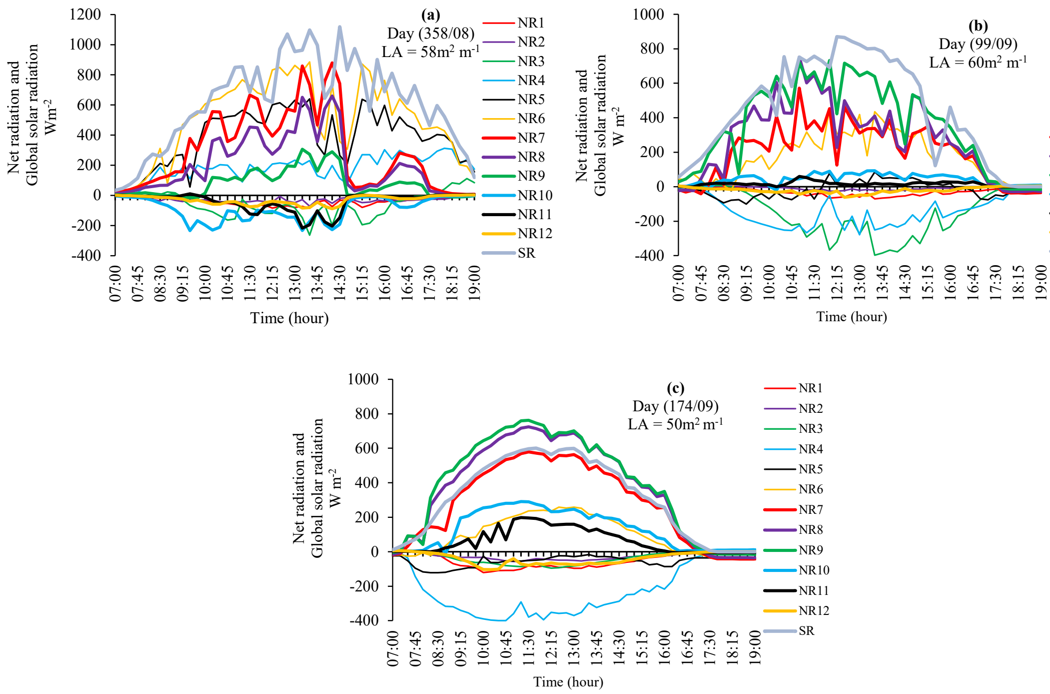


ed under different sky conditions. First, we present data collected on December 24, 2008 (358/08), right close to the summer solstice (Figure 6a). Another measurement day is April 9, 2009 (99/09) near the autumnal equinox (Figure 6b). Finally, measurements were done from June 23, 2009 (174/09) close to the winter solstice (Figure 6c).

Due to the nearly E-W orientation of the acid lime hedgerows (Figure 6), the time course pattern of the measurements is quite different from those observed in the coffee plantations with another orientation of the planting lines (Figure 5). Net radiometers positioned between the median and upper crown extracts indicate positive values during the daytime period, while those positioned between the median height and the lower crown extracts show negative ones. A distinct behavior is observed between seasons. On summer day (Figure 6a), when the solar declination is larger (more negative) than the local latitude, the southern face of the hedgerow is sunnier as visualized by the values of NR5 and NR6. In the following seasons, with solar declination varying from zero to 23.45°N, the face of the hedgerow exposed to north becomes sunnier, determining higher values of NR7, NR8 and NR9.

Unlike the measurements carried out during daylight, with the device constantly in motion, we chosen some

Figure 6. Diurnal course global solar radiation (SR) and net radiation (NR) measured in the acid lime cv IAC 5. Leaf area (LA) expressed per unit of row length in the planting line.



nocturnal days to assess measurements done with moving (Figure 7a) and stationary (Figure 7b) device. In order for the measurements to be comparable, the interval between them was only 2 days. Measurements with the system on were carried out between April 29 to 30, 2004 (119-120/04), and with the system stopped from May 01 to 02, 2004 (121-122/04).

With the same measurement standard (Figure 7) the net-radiometers positioned in the lower hemisphere show positive values, due to the greater proximity and energy gain of the soil surface and vegetated lower layers, while those of the upper hemisphere show negative values because the radiant energy loss due to their higher exposure to the free atmosphere.

The NR recordings of the four-bottom net-radiometers indicate little difference between them and little time variation throughout the period, being less than 10W m^{-2} most part of the night. For the radiometers of the upper hemisphere, it is observed a little difference between the radiometers of the pair NR3 and NR6 and those of pairs NR4 and NR5, being the last pair more negative, following grass net radiation (NRgrass) at least until about 1:30 a.m in the first day and 10:00 p.m in the second. After that both sensors recorded data less negative than NRgrass, closer to NR3 and NR6 data.

Sensor data collected from 00:15 a.m. on 04/120 (Figure 7a) and at 9:45 p.m on 04/121 (Figure 7b) clearly reflects the impact of dewfall, most strongly influencing the sensors of the upper portion of the frame, but also interfering with the sensors of the lower portion (Figure 1). According to our weather station dataset, the relative humidity over grass surface from those times was nearly 90%. Thus, considering normal measurement errors of capacitive sensors in this situation of high humidity, dew deposit certainly already occurred in the experimental field.

For the acid lime orchard (Figure 8), the nocturnal course of the radiometers measurement shows a pattern not very different from that of the coffee plantation (Figure 7).

Discussion

As pointed out by McNaughton et al., (1992), it is difficult to have a direct evaluation of the consistency and the error degree of the measurements obtained with the mobile systems used in this kind of measurement. A possibility is to compare their measurements to the results of modeling radiation absorbed by the hedgerows, but this procedure reverses the rationale normally used, i.e., to make direct measurements of radiation absorption by the canopy for evaluating the performance of the modeling. So, the discussion about the performance of the devices and the reliability of the measurements will be based more on indirect evaluation.

The devices performance and reliability may depend on several error sources, associated with both the sensors used and device metallic structure used interferences. Field et al., (1992) described the "double-dome" net radiometers calibration, as the Q-7.1 net radiometers used. According to the authors, after careful sun/shade calibration tests done with side-by-side sensors revealed daytime differences as large as 5 to 7% for instruments of the same manufacture.

The research carried out by Field et al., (1992) and also Michel et al., (2008) emphasizes that plastic double-dome design type of sensor, as the Q-7.1 net radiometers used, has substantially lower sensitivity to longwave (thermal) net radiation than to shortwave (solar) net radiation. The magnitude of the sensitivity is greater when the sky is clear than when cloudy. Furthermore, according to sensor manufacture, external condensation (dew) on the plastic dome (windshields) causes incorrect measurements

Figure 7. Overnight course of net radiation measured by the sensors at adult coffee plants (Days 119-120/04 and 121/121/04) and acid lime trees (day 174-175/09).

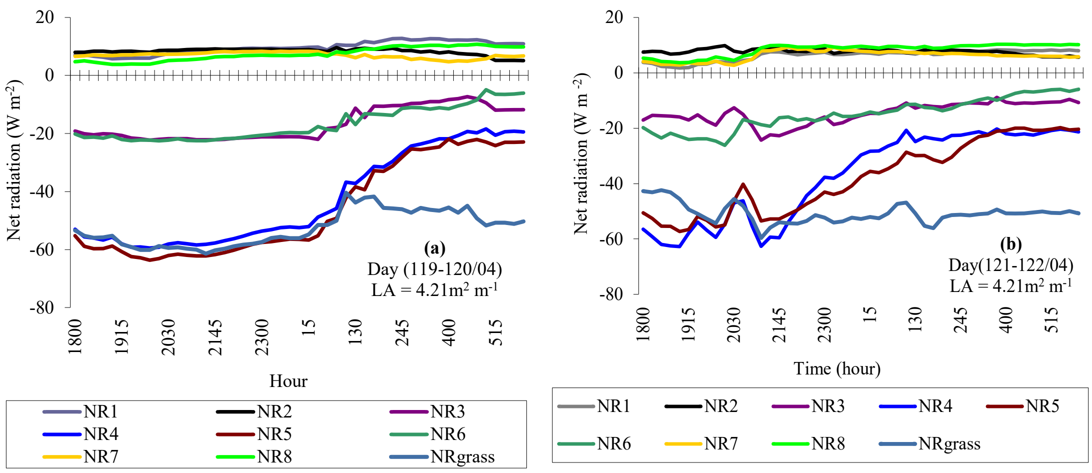
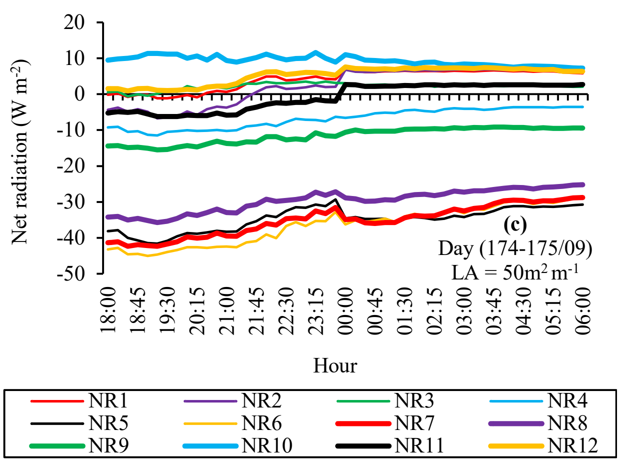


Figure 8. Overnight course of net radiation measured by the sensors at acid lime orchard.



(Campbell Scientific Inc. Instruction manual., Q-7.1 Net radiometer 1996; Malek, 2008).

It was noticed during night-time measurements (Figure 7). Dew generates smaller negative net radiation measurements (Figure 7) presented by the sensors fixed at the upper portion of frame/hedgerow, as NR3, NR4, NR5 and NR6 (Figure 1). All these negative aspects in relation to the type of sensor used make measurements more susceptible to errors and this type of sensor nowadays is no longer the first choice.

Some of the first mobile system results may be related to errors due to the type of sensor used and device metallic structure (Figures 2 and 3). The negative deviation close to sunrise (Figures 2 and 3) seems to be continuously most likely related to external condensation (dew) on the net radiometer windshields. It is important to highlight that the position of the NR4 and NR5 sensors (Figure 1) is almost as recommended by the manufacturer for installation. NR4 and NR5 are with the lower thermopiles facing the surface (hedgerow) and the upper ones facing the sky. In this case the dew deposit intensifies on the upper thermopile/dome. Thus, the thermopile is measuring the temperature of the water droplets on the window rather than the temperature of the sky or even the first sun rays. The NR1 and NR8 sensors (Figure 1), as opposed to the NR4 and NR5, have the upper thermopile facing the surface (soil + grass) and the lower one facing the sky. When installed in the opposite way, the dew ends up deposited on the dome of the lower thermopile, with the opposite effect on the measurements.

After that, some brief deviations up to 15 W m^{-2} were observed (Figs. 2 and 3). It was maybe related to the delay of dew evaporation, in relation to the sensors of the upper and lower parts of the device, and the influence triggered by the device metallic structure. This is caused by the interposing of the frame between the solar beam and the net-radiometers (NR5, NR6 and NR7) and this resulted in an increase of the positive signal and the consequent peak.

A similar explanation is applicable to the acid lime orchard device, with the difference in this case that the test was carried out with the device positioned of some distance to west of the acid lime orchard, in a manner that to about a little after 7:00 a.m. the lower positioned radiometers were partially shaded by the hedgerows, accentuating the negative signals (see the first step of the increase in Figure 4). Subsequently, this increase of negative values was reinforced by the interference of the frame attenuating the positive signal of the radiometers NR7, NR8, NR9 and NR10, with different magnitude and duration between them. From 10:00 to 12:00 a.m. the effect of the frame presence was inverted, occurring on the lower radiometers, attenuating their negative signals, and promoting the increase of the positive values.

Peaks do not appear in the afternoon, either in the coffee plantation (Figure 2 and 3) or in the acid lime orchard devices (Figure 4), because there was no interposition of obstacles between the radiation beam and radiometers. Reflection effects of solar radiation by the metal structure were observed during the preliminary tests of null deviation (Marin, 2003; Angelocci et al., 2008), but painting it with matte black minimized satisfactorily the problem.

We used eight net radiometers for the coffee plantations, the same number used by the authors introducing the technique (Landsberg et al., 1975; Thorpe 1978; McNaughton et al., 1992), and twelve in the acid lime orchard experiment, considering the larger dimension of the frame in this case. In addition to the justification of McNaughton et al., (1992) that eight radiometers represent a compromise between the cost of these instruments and the closer approach to a true integral surface, it is necessary to remember that greater the number of sensors, greater is the interference in the measurement itself, as much by the fraction of the foliage cover of the foliage, as well as the effect of the frame presence on the sensors. In our opinion, even the twelve radiometers in the acid lime orchard also is a reasonable number in complying with the aforementioned commitments.

In addition to these results, indirect evidence also indicated that measurements of radiation absorption of all wavelengths by the crown are reliable and sufficiently accurate in their use in hedgerows of coffee and acid lime with the used sizes. Measuring the sap flow as indicative of the 24-h transpiration flux of the four coffee plants used in the first experiment here described and comparing it with the net radiation of the hedgerow stretch, Angelocci et al., (2008) found a direct linear relation between these two variables, with the latent heat flux expressed by sap flow representing 73% of the absorbed radiation measured by the moving system. Considering that the plants were irrigated, the latent heat predominates over the sensible heat and part of the radiation absorbed is by the little or non-transpiring fraction (example: branches) of the crown, the proportion between the two fluxes seems very reasonable.

An end point in this discussion is about the speed of the moving part. We choose a speed of 12.8 m min^{-1} for the device of the coffee plantations and 18 m min^{-1} for that of the acid lime orchard, corresponding to respective round trips of 41.2 and 80 s, higher than the time constant of the net radiometers. In future studies, it would be interesting to study the effect of other speeds, since as indicated by McNaughton et al., (1992), the performance of the instrument can be affected when cloudiness causes rapid fluctuation of the radiation values.

Conclusion

The devices showed to be operationally reliable and the results here described allow us to conclude that the sampling of the radiation absorption by trees in hedgerows was improved in relation to the use of static sensors. Their results might be applied to measure the integrated photosynthetic active radiation or combined with the measurements with other ecophysiological and physical-mathematical studies.

Author contributions

L. R. ANGELOCCI conceptualization, data collection and organization, data analysis, writing and editing. J. SIMON data collection, data analysis, writing. F. G. PILAU and F. R. MARIN data collection, data analysis, writing and editing.

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Desempenho e incerteza de um integrador espaço-temporal de saldo de radiação de copas de árvores

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INFORMAÇÕES

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RESUMO

A quantificação da energia eletromagnética trocada entre plantas e seu ambiente é importante para estudos ecofisiológicos. Técnicas de medição foram desenvolvidas para a determinação desse balanço em diferentes escalas espaciais. Na literatura são encontrados alguns trabalhos descrevendo a utilização de dispositivos em torno de uma árvore isolada, gerando uma geometria esférica de medição que permite a integração da radiação absorvida pela árvore. Quando se trata de plantações com arranjo espacial de árvores em renques, é mais conveniente usar uma geometria de medição cilíndrica fictícia. Neste artigo descreve-se detalhes técnicos da montagem de dispositivos movendo-se ao longo da linha de plantio, gerando uma geometria cilíndrica nocional para integração espaço-temporal da radiação absorvida pelas copas das árvores. Ao longo dos experimentos verificou-se a necessidade de pequenas modificações que levaram ao aperfeiçoamento dos sistemas móveis de medição. Testes com o dispositivo sem plantas indicaram que os erros decorrentes do desvio nulo nesta condição foram suficientemente pequenos. Análises das medições de cada saldo-radiômetro e a comparação com a medição do calor latente diário calculado a partir do fluxo de seiva indicaram que o sistema proposto fornece medições acuradas, sendo confiável para testar os resultados de modelos físico-matemáticos.

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