Revista Brasileira de Agrometeorologia, Santa Maria, v. 9, n. 2, p. 169-179, 2001
Recebido para publicação em 22/02/2001. Aprovado em 06/12/2001.

ISSN 0104-1347

Estimate of the radiation balance components on greenhouse lettuce based on outside radiation measurements and structure orientation

Estimativa dos componentes do balanço de radiação sobre cultura de alface em estufas com diferentes orientações

Emerson Galvani[1], João Francisco Escobedo[1] e André Belmont Pereira[2]

Abstract – *Estimate equations of radiation balance components, such as global solar irradiance (G), net radiation (Rn) and shortwave balance (SWB) as a function of measurements obtained in greenhouses with polythylene cover with east-west (G_{E-W}, Rn_{E-W} and SWB_{E-W}) and north-south (G_{N-S}, Rn_{N-S} and SWB_{N-S}) orientations are presented in this manuscript. The crop used was lettuce, cultivar Elisa, throughout a period of 2,816 observations. The equations obtained for both greenhouses and its respective determination coefficients were: $G_{E-W} = 0.78\,Gext$ ($r^2 = 0.93$) and $G_{N-S} = 0.74\,Gext$ ($r^2 = 0.96$); $Rn_{E-W} = 0.85\,Rn_{ext}$ ($r^2 = 0.93$) and $Rn_{N-S} = 0.83\,Rn_{ext}$ ($r^2 = 0.98$); $SWB_{E-W} = 0.86\,SWB_{ext}$ ($r^2 = 0.94$) and $SWB_{N-S} = 0.84\,SWB_{ext}$ ($r^2 = 0.92$).*

Key words: *Solar radiometry, protected environment, greenhouse orientation, lettuce, radiation balance components.*

Resumo *- Neste trabalho são apresentadas equações de estimativa da irradiância solar global (G), saldo de radiação (Rn) e balanço de radiação de ondas curtas (SWB) obtidas em estufas com cobertura de polietileno orientadas no sentido leste-oeste (G_{E-W}, Rn_{E-W} e SWB_{E-W}) e norte-sul (G_{N-S}, Rn_{N-S} e SWB_{N-S}). A cultura utilizada foi a alface, cultivar Elisa, durante um período de 2.816 observações. As equações obtidas para as duas estufas e seus coeficiente de determinação foram: $G_{E-W} = 0{,}78\,Gext$ ($r^2 = 0{,}93$) e $G_{N-S} = 0{,}74\,Gext$ ($r^2 = 0{,}96$); $Rn_{E-W} = 0{,}85\,Rn_{ext}$ ($r^2 = 0{,}93$) e $Rn_{N-S} = 0{,}83\,Rn_{ext}$ ($r^2 = 0{,}98$); $SWB_{E-W} = 0{,}86\,SWB_{ext}$ ($r^2 = 0{,}94$) e $SWB_{N-S} = 0{,}84\,SWB_{ext}$ ($r^2 = 0{,}92$).*

Palavras-chave: *Radiometria solar, ambiente protegido, orientação de casas de vegetação, alface, componentes do balanço de radiação.*

Introduction

Throughout the last decades, the cultivation in protected environments, which aims agricultural yield of better quality and with no sazonal variation on the production, has been increasing considerably not only in developed countries but also in those ones in development, such as Brazil. Considering the geographic localization of the national territory, the use of protected environments covered with plastic films or half shadow structure presents double function. The first one of them is worth for the south and north regions, actuating as a regulator of the temperature, reducing the harmful effect caused by low temperatures in some crops, assuring the production at between harvest periods. For other regions of Brazil, such environments provide an efficient control of the amount of water on the crop,

[1]Department of Environmental Sciences, State University of São Paulo - UNESP, Botucatu, SP, Brazil. Corresponding author e-mail: galvani@fca.unesp.br, escobedo@fca.unesp.br
[2]Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa – UEPG, Ponta Grossa, PR, Brazil. e-mail: abelmont@uepg.br

as well as protect against strong rainfalls, hails and stress caused by the direct action of the winds. In both situations, the phytosanitary control is usually more effective inside these enviroments. In synthesis, protected environment provides a great thermal comfort to the plants, allowing them to reach its yield optimum level and, consequently, for the most situations a relation cost-benefit more favourable to the farmers.

Knowledge about physical and agrometeorological parameters at protected environments is still incipient. The researches related to such environments set bounds to Universities and researches' organizations, and even at such institutions the monitoring of climatic elements has been made by equipments of high cost, being usually imported and with strait comercial range. Faced with this reality, many researchers from Brazil and from all over the world proposed estimate equations to evaluate the internal parameters from external measurements which revealed good correlations, being able to be used with considerable precision as it is not possible to proceed the measurements to be obtained.

OLIVER and SENE (1992), analyzing the net radiation and global solar irradiance on grapevine crops in south of Spain have found the relation $Rn(W.m^{-2}) = 0.57\ G - 59$, with a determination coefficient of 0.986. According to the same authors, for the same region in tilled bare soil, it was obtained the following equation: $Rn(W.m^{-2}) = 0.59\ G - 60$ ($r^2 = 0.950$). Other researchers also obtained similar results: DAVIES & BUTTIMOR (1969), MATTHIAS & COATES (1986), IMPENS et al. (1970), ANDRÉ and VISWANADHAN (1983) and NKEMDIRIM (1973). In the Brazilian literature we found the following papers: FIGUEIREDO & ESCOBEDO (1995), RICIERI et al. (1994), ESCOBEDO et al. (1994a, 1994b, 1994c), CUNHA et al (1989), AZEVEDO at al. (1990), AZEVEDO et al (1997) and PRATES et al. (1988).

As the aim is the monitoring of some physical and agrometeorological elements in protected environments, it is indispensable to consider the orientation of such enviroments. It is known that the global solar irradiance flux density is a function, among other factors, of the incidence angle of the solar radiation on the surface. Thus, the greenhouses differently orientated have shown different irradiance flux densities throughout the year depending on the apparent movement of the sun in east-west direction, the fluctuation of the solar declination throughout the year and also the structure aspects of these greenhouses. Such a fluctuation of the irradiance flux density on a given surface will promote alterations on the net radiation and energy balance, influencing other elements, such as air and soil temperature and humidity.

The purpose of this work was to quantify the global, net radiation and short waves balance components throughout the lettuce crop cycle at both external environment and greenhouse conditions, orientated to east-west and north-south directions, and from such measurements to propose estimate models which lead to the knowledge of studied components from the external measurements, for the case in which there is only one set of available equipments.

Material and methods

The experiment was conducted at the experimental area of the Department of Physics and Biophysics in the Biosciences Institute from the State University of São Paulo (UNESP), Campus of Botucatu, located at 22°54'S, 48°27'W and 850m of altitude. The experimental area consisted of 3 plots with identical dimensions of 7.0 x 5.0m, from which 2 of them were located at greenhouses, type tunnel, with a polyethylene film of 100μm, orientated to east-west (E-W) and north-south (N-S) directions. The third plot was located outside the greenhouse. Figure 1 shows the schematic representation of the experimental area.

Lettuce was transplanted 40 days after correcting the soil with $160 g.m^{-2}$ of dolomitic calcareous rock applied at a minimum depth of 20cm. The cultivar of lettuce used was Elisa, belonging to Lisa group. The adopted spacing was 0.25 x 0.25m in both environmental conditions. The planting date was on 6 November 1995 and the harvest one on 16 January 1996, having the crop cycle lasted 6 weeks.

The sensors for the global and reflected fractions were installed at 2.0m above the dossel and the sensors for the net radiation at 1.0m, in both experiments.

From the measurements of reflected and global solar irradiance flux densities, the shortwave balance (SWB) was determined by means of the following expression:

$$SWB = G - Gr \qquad (1)$$

Rev. Bras. Agrometeorologia, v. 9, n. 2, p. 169-179, 2001

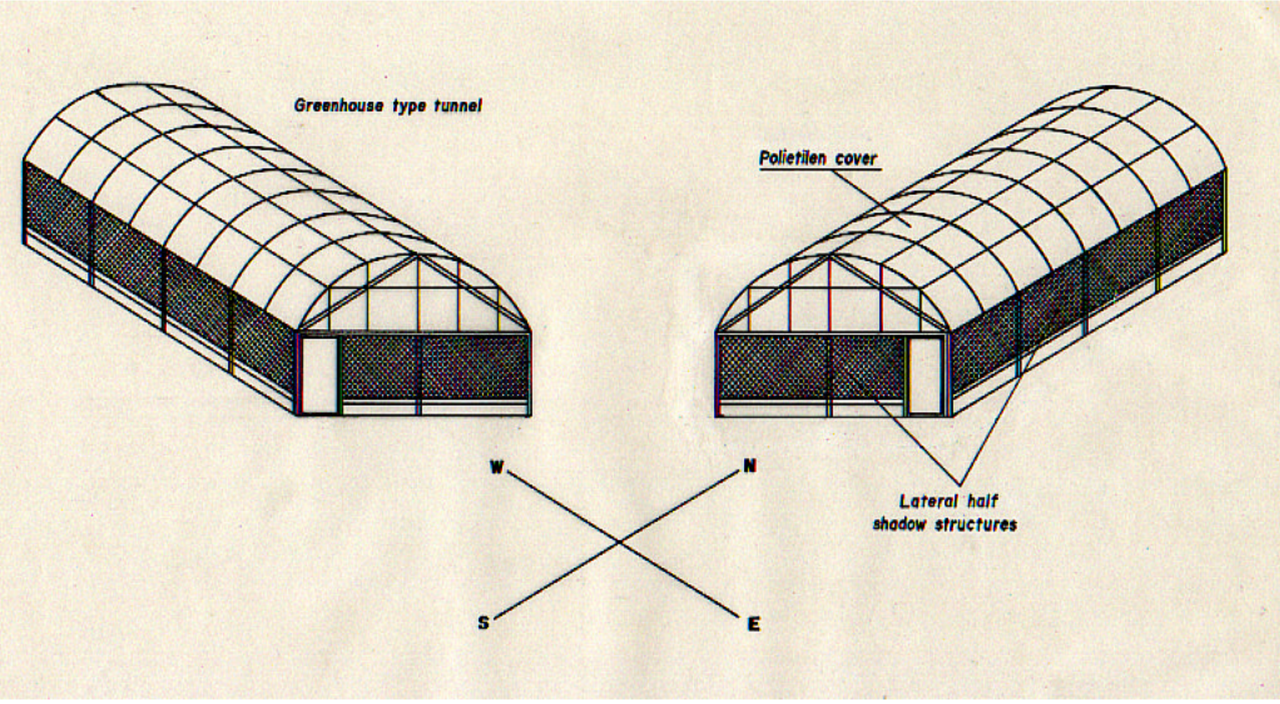


Figure 1. Schematic representation of the experimental area showing greenhouse arrangements with E-W and N-S orientations.

where G is the global solar irradiance and Gr is the reflected irradiance.

The data acquisition system consisted of a datalogger (Model 21X Micrologger, Campbell Scientific Inc., Logan, UT), which was connected to a microcomputer 486 by means of a SC32A interface. Data was acquired at the frequency of 1 Hz, but only average values were stored at 5 minutes intervals.

The sensors for the global and reflected fractions were manufactured and calibrated at the Solar Radiometry Laboratory of the Department of Natural Resources of the State University of São Paulo. The sensors for the net radiation used were from REBS (Radiation Energy Balance System, Seatle, USA).

Results and discussion

Taking into account that it is available only one set of sensors to measure the global and reflected irradiance flux densities and the net radiation at external environment and also that the aim of this work is to estimate the same elements at greenhouses orientated to E-W and N-S conditions, the results obtained from such a correlation study can be observed in Figures 2 through 5.

Values of **a** and **b** coefficients of the simple linear regression equations and its respective determination coefficients can be seen on Table 1.

Table 1 indicates that 78.3% of external irradiance passed through the polyethylene film when the greenhouse was oriented in the East-West direction. In contrast, 73.6% was transmitted by the cover for $GH_{(N-S)}$. Such a difference of transmissivity between these greenhouses is due to the incidence angle of radiation on the structures and also the shade pattern caused by the structure itself. These factors resulted in different conditions for net radiation and energy balance which affected other elements, such as air and soil temperature and humidity.

Net radiations rated in $Rn_{(E-W)}$ and $Rn_{(N-S)}$ were represented by 85.3% and 82.8% of that one measured at external condition, respectively. The shortwave balance evaluated in $SWB_{(E-W)}$ and $SWB_{(N-S)}$ represented 85.6% and 83.9%, respectively. Concerning the monitoring of those elements at external condition, the net radiation component corresponded to 87.4% of the shortwave balance

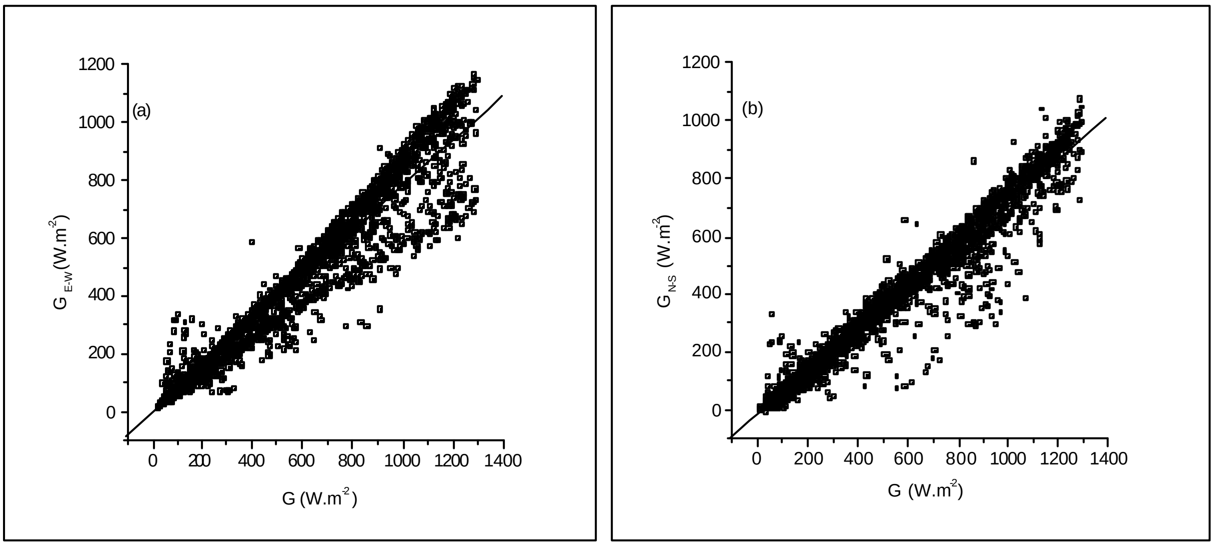


Figure 2. Comparison of outside global solar irradiance and global irradiance measured in greenhouses with E-W (a) and N-S (b) orientations in Botucatu, SP, Brazil.

(Figure 5, Table 1). AZEVEDO et al. (1997) have found for grapevine crop in northeastern Brazil that the shortwave balance represented 78.0% of the net radiation.

The determination coefficients obtained evidence good correlation among the components that generated all estimate models. Thus, by means of such models found on Table 1, it is possible to analyse with a high precision the response of all components studied at the greenhouses orientated to east-west and north-south directions.

Figures 6 through 9 show for the date 15 December 1995 the curves of the measured and estimated values through the models presented on Table 1 as a function of the time. By the analysis of such figures, a good correlation between measured and estimated values has been found, however standing out that the curves obtained with estimated

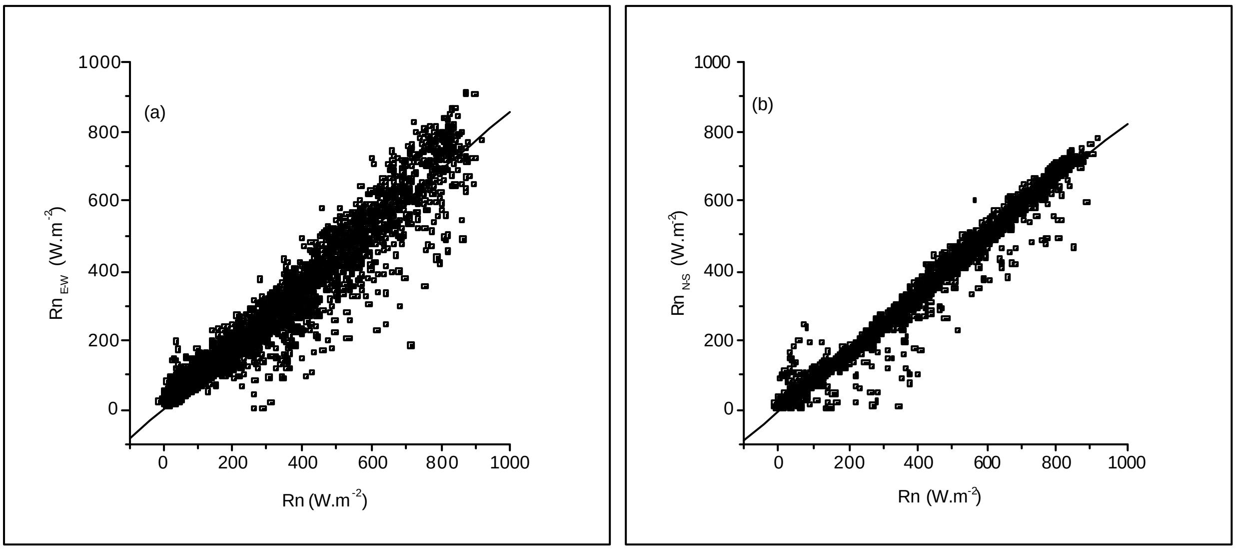


Figure 3. Comparison of outside net radiation and net radiation measured in greenhouses with E-W (a) and N-S (b) orientations in Botucatu, SP, Brazil.

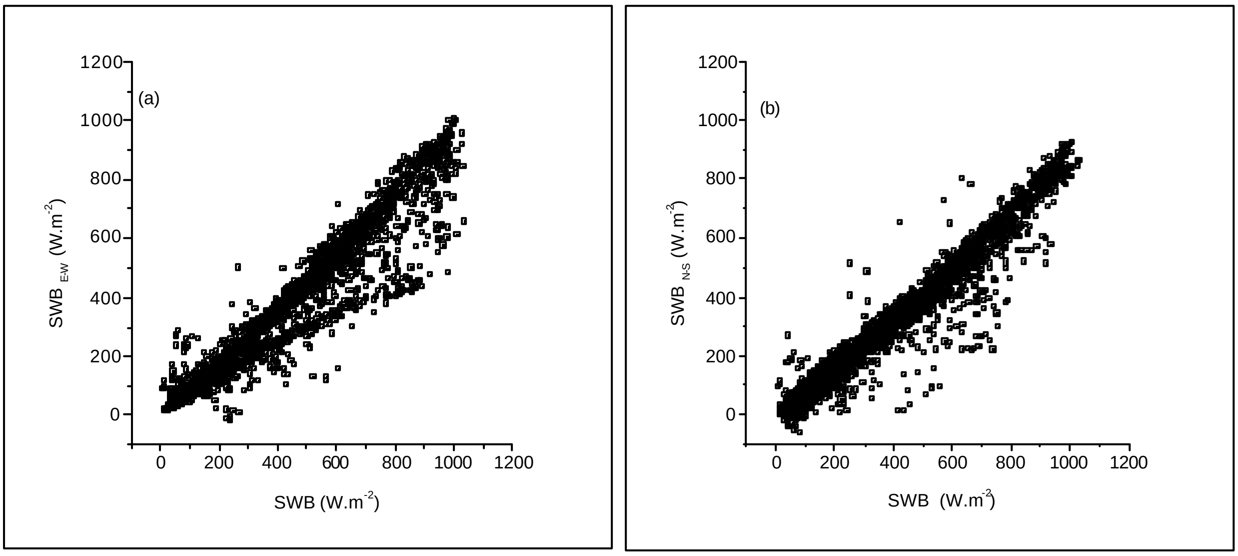


Figure 4. Comparison of outside shortwave balance and shortwave balance measured in greenhouses with E-W (a) and N-S (b) orientations in Botucatu, SP, Brazil.

values have presented a shape more uniform, mainly on cloudless day condition. The curves using measured values inside the greenhouses have shown peaks of energy fall as a result of the shadiness of sensors promoted by metalic archs of the greenhouse structure, a fact which has not been observed at external condition.

Table 2 shows the integrated values of measured and estimated energy flux densities on 15 December 1995 with its respective deviations in relation to the measured values. Results presented in this table indicate that even with high determination coefficients (r^2>0.92), the difference between measured and estimated values might reach about –10.47%, just in case of proceeding to the estimate of net radiation at greenhouses from measurements obtained at external condition. However, other equations have shown deviations lower than 6.5% and can be successfully used to estimate the internal radiation components.

A regression analysis was performed on measured data to provide insight into the relation

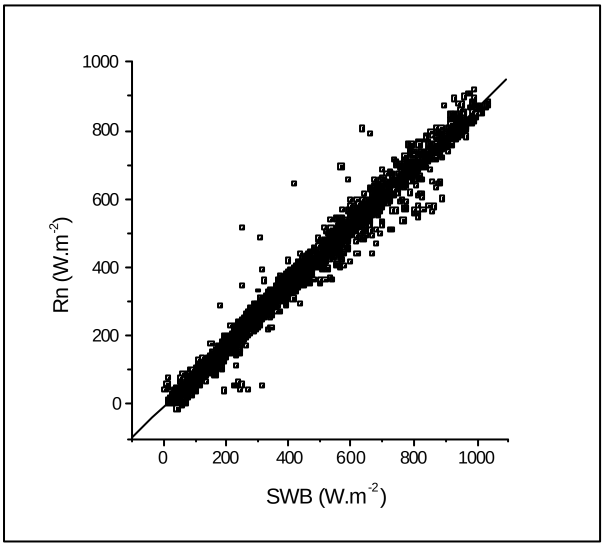


Figure 5. Comparison of outside shortwave balance and outside net radiation in Botucatu, SP, Brazil.

Table 1. Results of regression analysis between components of radiation balance (G, Rn and SWB) measured in greenhouses with E-W and N-S orientations and components of radiation balance measured in the external environment.

Equation	R^2	n *
$G_{E\text{-}W} = 0.783\ G_{ext} - 7.560$	0.93	2,816
$G_{N\text{-}S} = 0.736\ G_{ext} - 21.838$	0.96	2,816
$Rn_{E\text{-}W} = 0.853\ Rn_{ext} + 3.890$	0.93	2,816
$Rn_{N\text{-}S} = 0.828\ Rn_{ext} - 5.689$	0.98	2,816
$SWB_{E\text{-}W} = 0.856\ SWB_{ext} - 10.708$	0.94	2,816
$SWB_{N\text{-}S} = 0.839\ SWB_{ext} - 23.280$	0.92	2,816
$Rn_{ext} = 0.874\ SWB_{ext} - 11.170$	0.98	2,816

* Total number of observations.

Rev. Bras. Agrometeorologia, v. 9, n. 2, p. 169-179, 2001

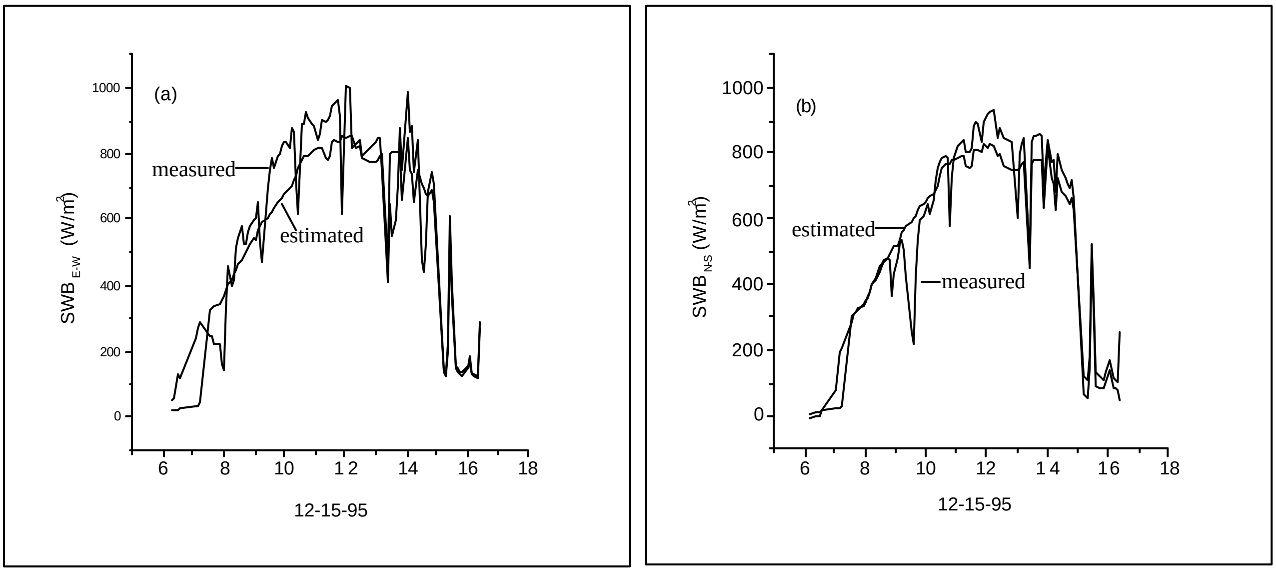


Figure 8. Curves of instantaneous values of shortwave balance measured in greenhouses with E-W (a) and N-S (b) orientations, as a function of outside measured values of shortwave balance in Botucatu, SP, Brazil.

resulting in differences of reflection and emission of incident energy on that surface. AZEVEDO et al. (1997) have found for the grapevine crop a quotient of 64% for the northeastern Brazil.

The shortwave balance in greenhouses with E-W and N-S orientations represented 64.6% and 64.9% of the external global irradiances, respectively. The relationship between the external global and the external net radiation was 57.6% and between the external global and the net radiation in the greenhouse N-S oriented was 55.8%.

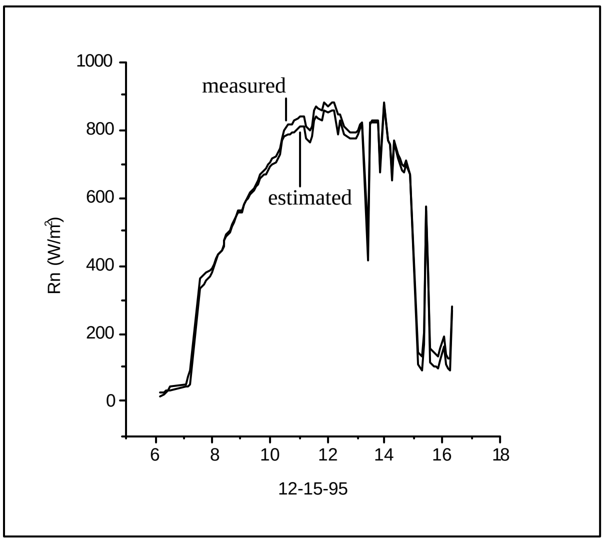


Figure 9. Comparison between the curves of net radiation measured in external condition and net radiation estimated from the measurements of outside shortwave balance throughout the time in Botucatu, SP, Brazil.

Figures 13 through 15 show for the studied date measured and estimated values of outside shortwave balance, outside net radiation, shortwave balance in greenhouses with E-W and N-S orientations, net radiation in greenhouses with E-W and N-S orientations, as a function of outside measured values of global solar irradiances. Such figures show a good agreement between measured and estimated values, making evident once more the shadiness effect of the sensors promoted by the structure of the greenhouses.

Table 4 reveals the deviations between measured and estimated values of 10.56% for shortwave balance with E-W greenhouse orientation. However, considering the error source for the measurements obtained with bimetalic actinographs, it is possible to estimate with a remarkable reliability the internal components at greenhouse conditions from measurements of external global solar irradiances.

Conclusions

By the results presented in this manuscript it is possible to conclude that:

- The radiation balance components, such as global solar radiation flux density, shortwave balance and net radiation on the lettuce crop in greenhouses with east-west and north-south orientations in Botucatu, SP, Brazil, can be estimated with a very high reliability as a function of outside measurements of such components.

- The radiation balance components, such as, shortwave balance and net radiation on the lettuce crop in greenhouses with east-west and north-south orientations in the site above mentioned, can be estimated with a very high reliability as a function of outside measurements of the global solar radiation flux density.

Table 2. Estimated and measured values of global solar irradiance (G), net radiation (Rn) and shortwave balance (SWB) at protected environment (G_{W-E} and G_{N-S}) and external conditions on 15 Dec 1995 in Botucatu, SP, Brazil.

Equation	Measured ($MJ.m^{-2}$)	Estimated ($MJ.m^{2}$)	Deviation %
$G_{E-W} = 0.783\ G_{ext} – 7.560$	24.02	22.50	-6.32
$G_{N-S} = 0.736\ G_{ext} – 21.838$	20.16	20.61	+2.23
$Rn_{E-W} = 0.853\ Rn_{ext} + 3.890$	16.57	16.82	+1.51
$Rn_{N-S} = 0.828\ Rn_{ext} – 5.689$	17.86	15.99	-10.47
$SWB_{E-w} = 0.856\ SWB_{ext} – 10.708$	20.97	19.66	-6.24
$SWB_{N-S} = 0.839\ SWB_{ext} – 23.280$	19.03	18.70	-1.73
$Rn_{ext} = 0.874\ SWB_{ext} –11.170$	19.56	19.94	+1.94

References

ANDRÉ, R.G.B., VISWANADHAN, Y. Radiation balance of soybeans grown in Brazil. **Agricultural Meteorology**, Amsterdam, v. 30, p. 157-173, 1983.

AZEVEDO, P.V. de., LEITÃO, M.M.V.B.R., SOUZA, I.F. de. Balanço de radiação sobre culturas irrigadas no semi-árido do nordeste do Brasil. **Revista Brasileira de Meteorologia,** São Paulo, v.5 , n. 1, p. 403-410, 1990.

AZEVEDO, P.V., TEIXEIRA, A.H. de C., SILVA, B.B. da. et al. Avaliação da reflectância e do saldo de radiação sobre um cultivo de videira européia. **Revista Brasileira de Agrometeorologia,** Santa Maria, v. 5, n. 1, p. 1-7, 1997.

CUNHA, R.G., BERGAMASCHI, H., BERLATO, M.A. Balanço de radiação em cultura de milho. In: CONGRESSO BRASILEIRO DE AGROMETEOROLOGIA, 6, 1989, Macéio. **Anais**..., Macéio : Sociedade Brasileira de Agrometeorologia, 1994. p. 389-393.

DAVIES, J.A., BUTTIMOR, P.H. Reflection coefficients, heating coefficients and net radiation at Sincoe, Southern Ontario. **Agricultural Meteorology**, Amsterdam, v. 6, p. 373-386, 1969.

ESCOBEDO, J.F., FRISINA, V.A., RICIEIRI, R.P.Estimativa de radiação fotossinteticamente ativa através da radiação global em estufa de polietileno. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 8., 1994, Belo Horizonte. **Anais**..., Belo Horizonte : Sociedade Brasileira de Meteorologia, 1994a. p. 385-389.

ESCOBEDO, J.F., RICIERI, R.P., OLIVEIRA, A.P. Radiação solar em câmara nebulizadora. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 8., 1994.. **Anais**..., Belo Horizonte : Sociedade Brasileira de Meteorologia, 1994b. p. 389-393.

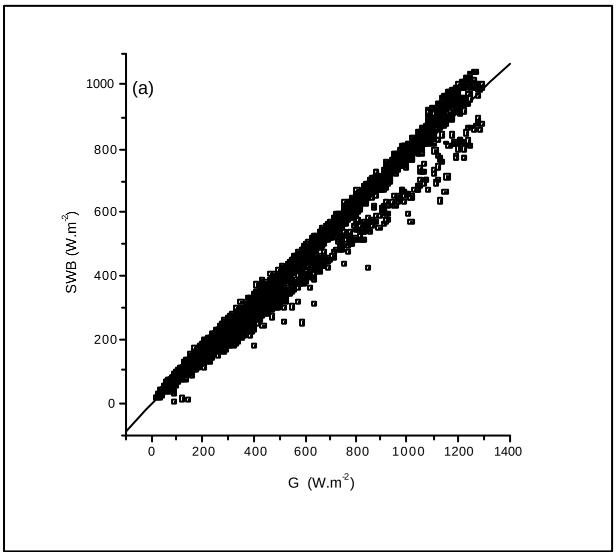
ESCOBEDO, J.F., MELO, J.M.D., FRISINA, V.A. Radiação solar global e fração da global refletida em estufa tipo túnel com cobertura de polietileno. In: CONGRESSO IBÉRICO DE ENERGIA SOLAR, 7., 1994, Vigo. **Anais**..., Vigo : Associaion Española de Energia Solar/ International Solar Energy Society, 1994. p. 53-58.

FIGUEIREDO, D., ESCOBEDO, J.F. Correlações entre o saldo de radiação e a radiação solar global em cultura de alface na estufa de polietileno. In: CONGRESSO BRASILEIRO DE BIOMETEOROLOGIA, 1., 1995, Jaboticabal. **Anais**..., Jaboticabal : Faculdade de Ciências Agronômicas e Vaterinárias, Universidade Estadual Paulista, 1995, p. 215-225.

IMPENS, I., LEMEUR, R., MOERMANS, B.L. Spacial and temporal variation in crop canopies. **Agricultural Meteorology**, Amsterdam, v. 7, p. 335-337, 1970.

Table 3. Constants a and b, and determination coefficients for the relationships between external global irradiance (G_{ext}) and external shortwave balance (SWB_{ext}), shortwave balance at greenhouse E-W (SWB_{E-W}) and at greenhouse N-S (SWB_{N-S}), external net radiation (Rn_{ext}), net radiation at greenhouse E-W (Rn_{E-W}) and at greenhouse N-S (Rn_{N-S}) in Botucatu, SP, Brazil.

Equation	R^2	n
$SWB_{ext} = 0.769\ G_{ext} - 8.660$	0.98	2,816
$Rn_{ext} = 0.673\ G_{ext} - 19.126$	0.97	2,816
$SWB_{E-W} = 0.646\ G_{ext} - 11.876$	0.88	2,816
$SWB_{N-S} = 0.649\ G_{ext} - 32.006$	0.93	2,816
$Rn_{E-W} = 0.576\ G_{ext} - 13.209$	0.90	2,816
$Rn_{N-S} = 0.558\ G_{ext} - 22.158$	0.95	2,816



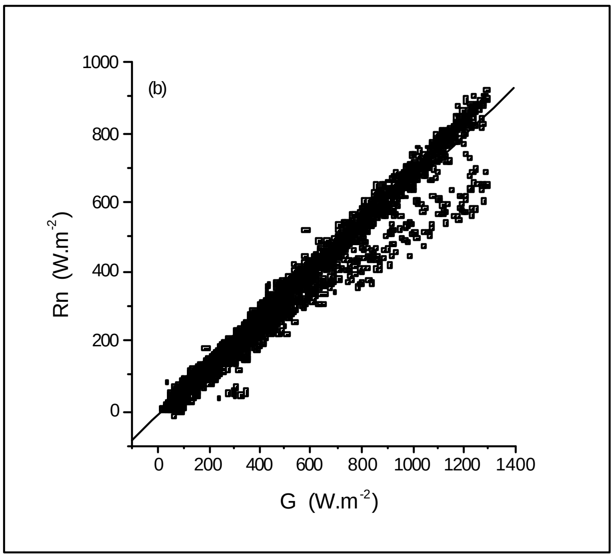


Figure 10. Comparison of outside values of the global solar irradiance to shortwave balance (a) and to net radiation (b). Instantaneous values were measured in Botucatu, SP, Brazil.

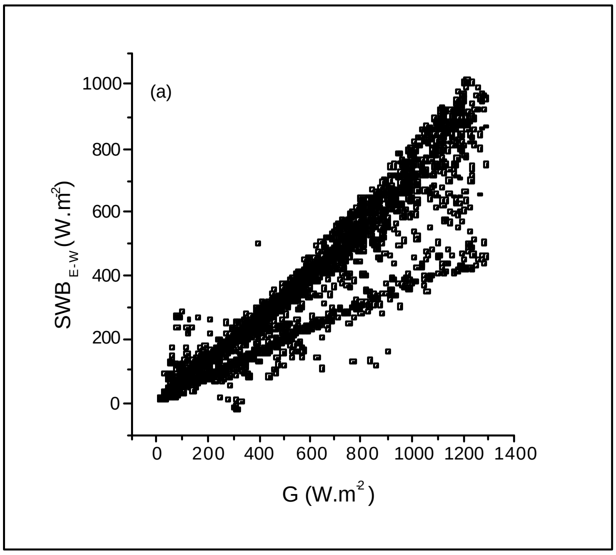
MATTHIAS, A.D., COATES, W.E. Wine Grape vine radiation balance and temperature modification with fine-mist nozzles. **Horticultural Science**, Alexandria, v. 21, n. 6, 1453-1455, 1986.

NKENDIRIM, L.C. Radiative flux relations over crops. **Agricultural Meteorology**, Amsterdam, v. 11, p. 229-242, 1986.

OLIVER, H.R., SENE, K.J. Energy and water balances of developing vines. **Agricultural and Forest Meteorology**, Amsterdam, v. 62, p. 167-85, 1992.

PRATES, J.E., COELHO, D.T., STEINMETZ, S. Análise da variação temporal dos componentes do balanço de radiação em cultura de arroz (*Oryza sativa* L.) de sequeiro. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 5., 1988, Rio de Janeiro. **Anais**..., Rio de Janeiro : Sociedade Brasileira de Meteorologia, Rio de Janeiro, 1988, p. 29-33.

RICIERI, R.P., ESCOBEDO, J.F., MELLO, J.L. de. Trasmissividade das radiações solar global e difusa em estufas de polietileno. In: CONGRESSO BRASILEIRO DE METEOROLOGIA, 8., 1994, Belo Horizonte. **Anais**..., Belo Horizonte : Sociedade Brasileira de Meteorologia, 1994, p. 381-385.



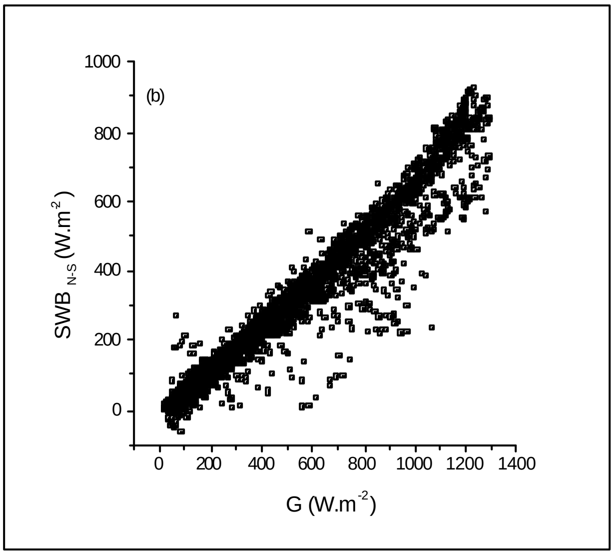


Figure 11. Comparison of outside global solar irradiance and shortwave balance measured in greenhouses with E-W (a) and N-S (b) orientations in Botucatu, SP, Brazil.

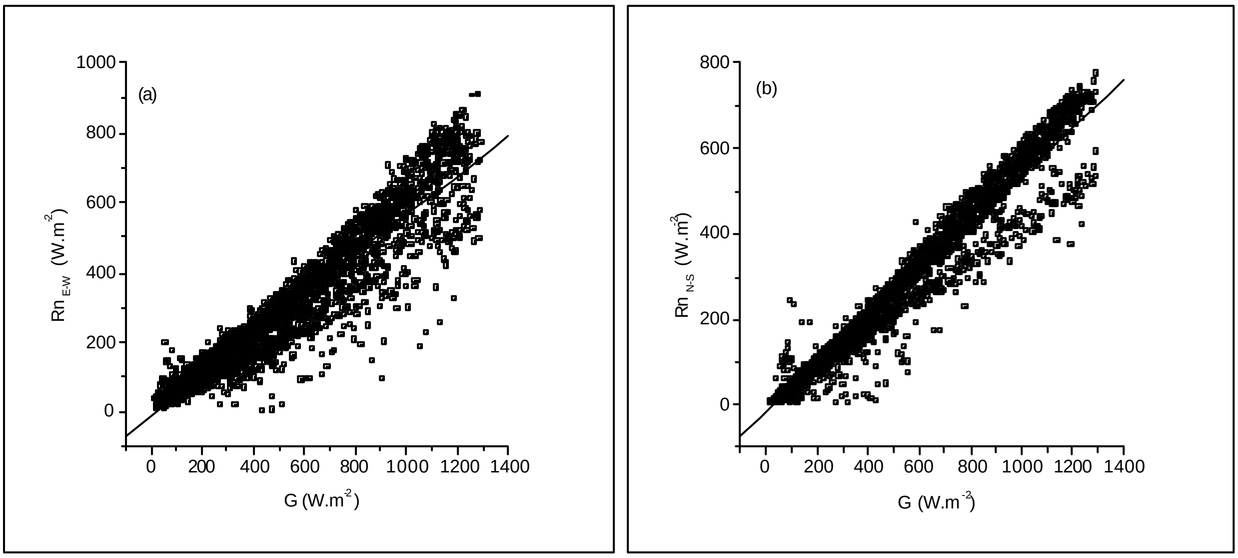


Figure 12. Comparison of outside global solar irradiance and net radiation measured in greenhouses with E-W (a) and N-S (b) orientations in Botucatu, SP, Brazil.

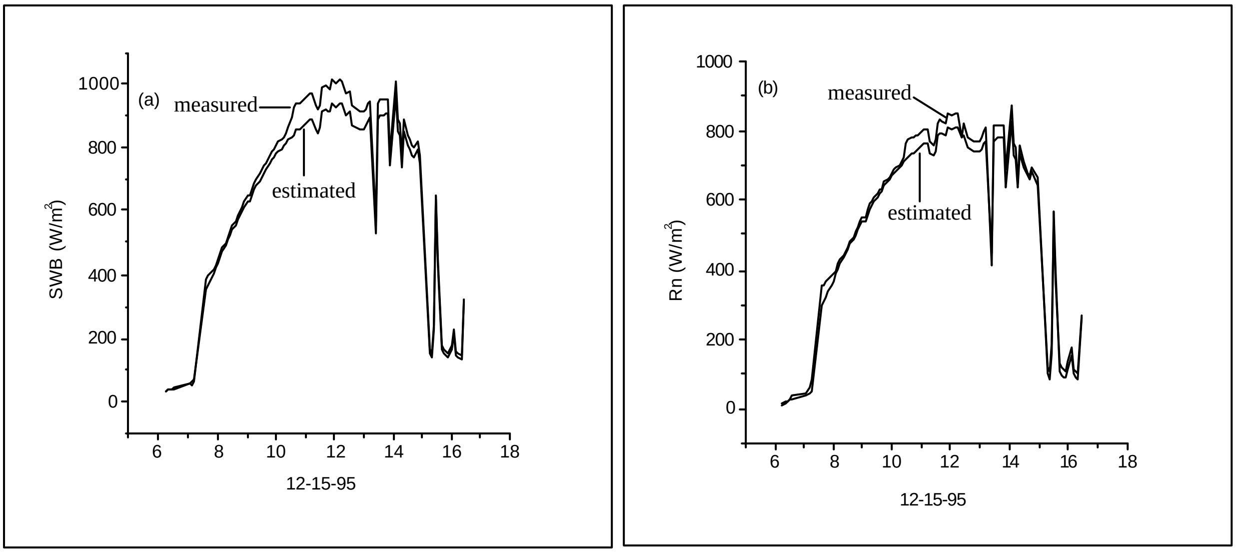


Figure 13. Comparison between the curves of outside shortwave balance (a) and outside net radiation (b) measured throughout the time and estimated from the outside global irradiance in Botucatu, SP, Brazil.

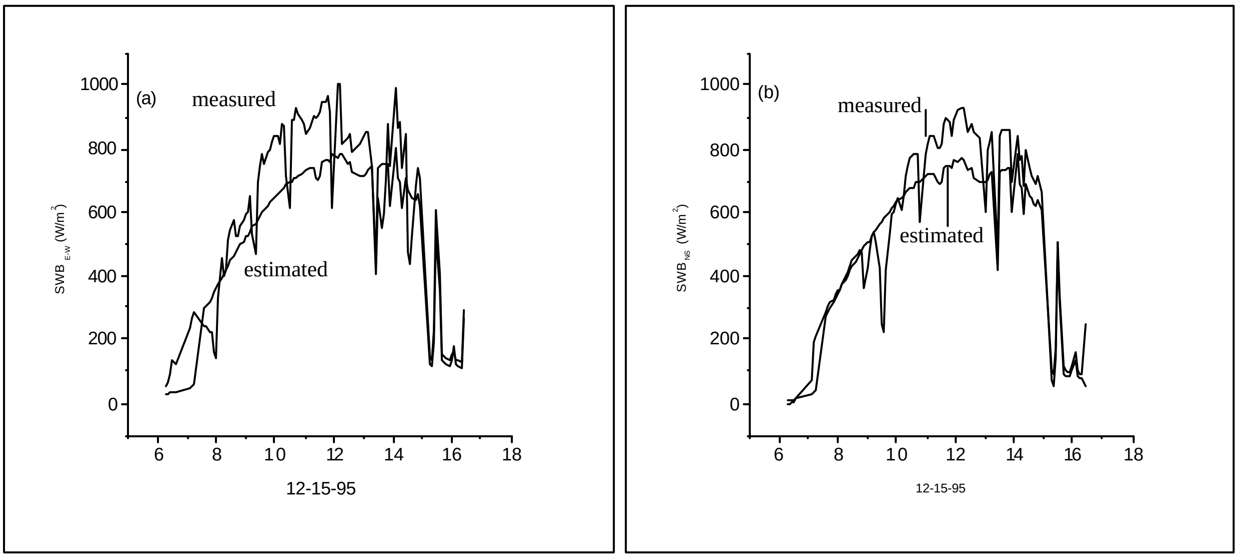


Figure 14. Comparison between the curves of shortwave balance measured in greenhouses with E-W (a) and N-S (b) orientations throughout the time and estimated from the outside global irradiance in Botucatu, SP, Brazil.

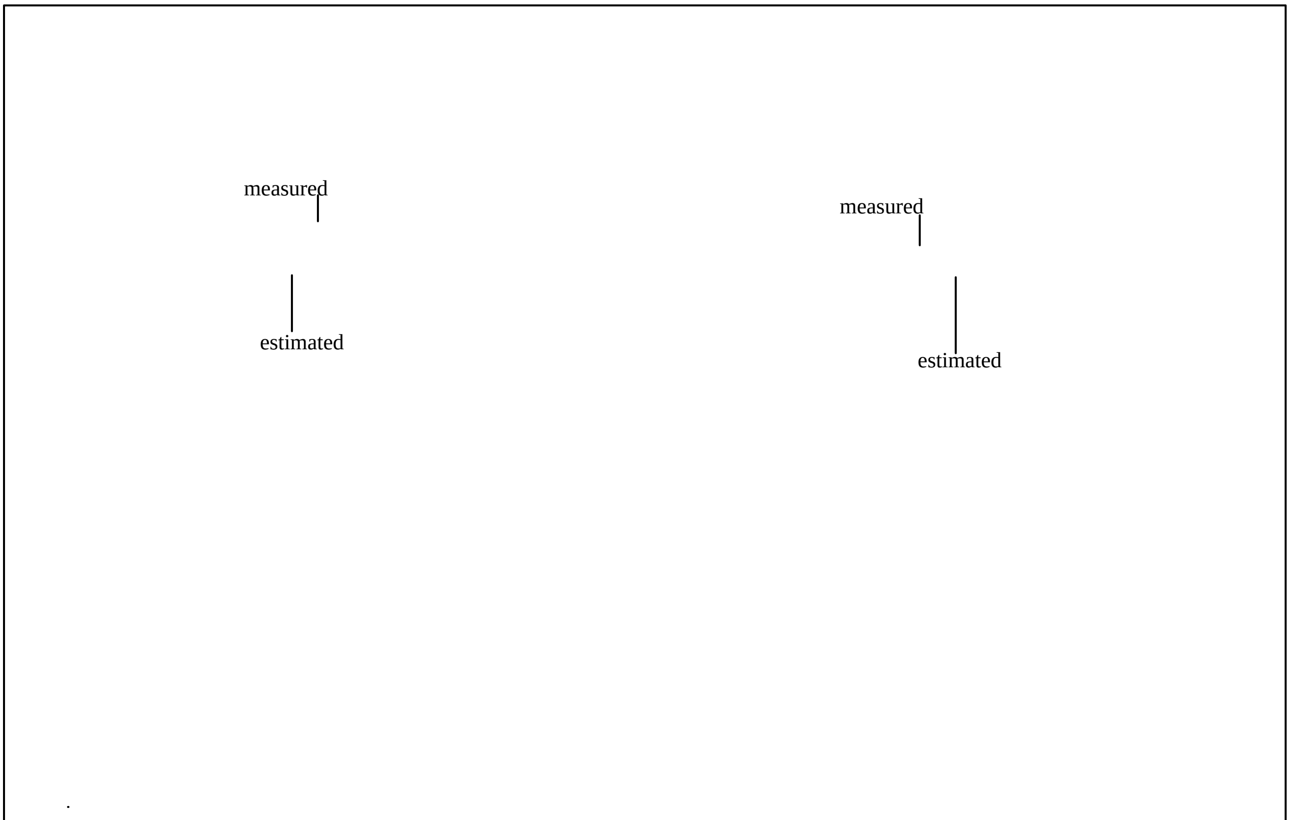


Table 4. Estimated and measured daily values of short waves balance (SWB) and net radiation (Rn) at protected environment (G_{E-W} and G_{N-S}) and external conditions on 15 Dec 1995 in Botucatu, SP, Brazil.

Equation	Measured ($MJ.m^{-2}$)	Estimated ($MJ.m^{-2}$)	Deviation (%)
$SWB_{ext} = 0.769\ G_{ext} - 8.660$	23.30	22.40	-3.86
$Rn_{ext} = 0.673\ G_{ext} - 19.126$	19.56	18.97	-3.02
$SWB_{E-W} = 0.646\ G_{ext} - 11.876$	20.97	18.75	-10.56
$SWB_{N-S} = 0.649\ G_{ext} - 32.006$	19.03	17.86	-6.14
$Rn_{E-W} = 0.576\ G_{ext} - 13.209$	16.57	16.27	-1.81
$Rn_{N-S} = 0.558\ G_{ext} - 22.158$	17.86	16.51	-7.55