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AGROMETEOROLOGY - Article

Energy balance partitioning and evapotranspiration from irrigated Muskmelon under Semi-Arid Conditions

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ABSTRACT: The Mossoró-Assu-Baraúna district, Rio Grande do Norte State (RN), is recognized by the intense production of horticulture, mainly muskmelon for export. However, this region is often devastated by intense droughts. Thus, the muskmelon production is predominantly under irrigated condition and, due to constant threat of water resources collapse on the region, a rigorous irrigation water management in the region is needed. The main objective of this article was to analyze the seasonal pattern of energy balance partitioning and evapotranspiration on irrigated muskmelon crop on the region around Mossoró-RN. The study was carried out in two areas of commercial production of muskmelons in the Mossoró-Assu-Barúna district, during two growth seasons from 2012-Jun to 2012-Nov. The components of energy balance and evapotranspiration were determined by using the Bowen Ratio Energy Balance method. It was observed that more than 60% of the net radiation (*Rn*) was converted into latent heat flux (λE), while 21 and 11% of *Rn* was converted into sensible heat flux (H) and soil heat flux (G), respectively. The ratio λE/Rn varies according to the change of leaf area index (LAI) while the ratios H/Rn and G/*Rn* vary inversely with the LAI. The agreement *λE/Rn* and LAI is also evidenced by similarity between curves of crop evapotranspiration (ETc) and LAI, particularly when the melon crop reaches its maximum vegetative growth (LAI > 3). The muskmelon ETc ranged from 265 to 289 mm, values that are similar to those found by other researcher.

Key words: Mossoró-Assu-Baraúna district, net radiation, latent and sensible heat fluxes, soil heat flux.

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INTRODUCTION

Muskmelon (*Cucumis melo* L.) is a vegetable of great economic importance, which is cultivated in all Brazilian regions and in various parts of the world (Melo et al. 2011; Qi et al. 2015). Its cultivation has been widespread in tropical and/or semiarid regions where environmental conditions, particularly higher temperatures, low relative humidity and high insolation duration have favored its development.

Among the regions with these conditions stands out the Northeast region of Brazil, especially the Mossoró-Assu-Baraúna district, located on the northwest portion of the Rio Grande do Norte State (Medeiros et al. 2012). This district is recognized by the intense production of horticulture under irrigated conditions and it is the largest muskmelon producer in Brazil, accounting for more than half of all domestic production (Medeiros et al. 2011).

However, it is located in the Brazilian Semi-Arid region, which is often devastated by prolonged and intense droughts. The rainy season is limited to the first half of the year and about 80% of the total annual rainfall occurs in four months (from February to May). Therefore, the water deficit in the region can reach up to 800 mm·yr^{-1} (Bezerra et al. 2012). In this scenario, the muskmelon production in this region is predominantly under irrigated conditions, because the irregularity of rainfall does not allow commercial production on rainfed conditions. The groundwater is main source of water for irrigation in the region, which is pumped out from Jandaíra calcareous aquifer through wells of 100 m depth (Bezerra et al. 2012; 2015). However, the expansion of irrigation projects has led to a substantial increase in groundwater demand in the region, leading to sharp downgrades of this aquifer to generate concerns about water security in the region and sustainability of agricultural production under irrigated conditions over long drought periods. Therefore, a careful and rigorous irrigation water management in the region is needed.

The fundamental requirement of scheduling irrigation is the determination of crop evapotranspiration (ETc). The ETc can be determined through numerous systems including lysimeters, micrometeorological methods, soil water balance, sap flow, and scintillometry (Allen et al. 2011; Bezerra et al. 2012; 2015; López-Olivari et al. 2016).

The micrometeorological method based on Bowen ratio energy balance (BREB) is a relatively practical and reliable method. It has often been used to estimate the ETc of different soil-vegetation systems and in different climatic conditions, including the Brazilian Semi-Arid (Bezerra et al. 2012; 2015). The energy balance explains the destination of the energy available to the system, i.e., net radiation (*Rn*) distributed among non-radiative soil surface flows, primarily soil cover, soil water content and the availability of solar energy control energy balance partitioning. In crops on irrigated conditions it has been reported that the portion of *Rn* converted into latent heat flux (or evapotranspiration) is greater than 70% (Bezerra et al. 2012; 2015).

Given the concerns raised, the main objective of this study was to analyze the seasonal behavior of the energy balance partitioning, beyond evapotranspiration of muskmelon crop under irrigated conditions on the region around Mossoró-RN, Brazil.

MATERIAL AND METHODS

The study was conducted on the Mossoró-Assu-Baraúna district, located in the northwest portion of Rio Grande do Norte State (RN), Northeast region of Brazil (Figure 1). The climate of region (1981-2010), according to Thornthwaite (1948), is semi-arid, megathermal with water deficit during the year. The average annual rainfall is 674 mm, of which about 550 mm occur between February and May. The average annual relative humidity is 68.9%, while the average annual temperature is 27.7 °C, ranging from 27.2 °C in June to 28.4 °C in February. The soils of the area in which the experiments were carried out are predominantly red-yellow latosols (Embrapa 1971).

The field experiment was carried out in two farms of commercial production of muskmelons for export on the Mossoró County, during two consecutive cycles in the 2012 year. The mentioned farms and their respective coordinates are: Dinamarca (lat 4°54’28”S, long 37°24’06”W, 17 m asl.) and Norfruit (lat 4°54’10”S, long 37°22’01”W, 36 m asl.), referred as Area 1 and Area 2, respectively.

The experiment was conducted during two consecutives growing seasons: from June 18 to September 05 (1st cycle) and from September 06 to November 13 (2nd cycle) on the two studied areas.

The crop was sown in a greenhouse and 10 days after sowing (DAS) the seedlings were transplanted to the field, where the soil was protected with plastic mulch. At the time of transplanting, the rows were covered with white polypropylene agro-textile blankets (TNT), a procedure that aims to minimize the incidence of pests and diseases. The characteristics of the field experimental plots are described in Table 1.

The crop was irrigated by using drip irrigation system. The emitters have the same plant spacing, so as to have one dripper per plant. The irrigation schedule adopted was the daily.

The growth season of muskmelon crop was identified based on the methodology proposed by FAO-56 (Allen et al. 1998), which are: Initial season = from transplanting to approximately 10% ground cover; Crop development = from 10% ground cover to effective full cover or start of flowering; Middle season = from start of flowering to start of maturity; Late-season = from the start of maturity to harvest or end of water use.

The components of the energy balance were determined by using BREB method. Neglecting the energy stored in the canopy and the photosynthetic energy flows, which represent less than 2% of net radiation (Rn), the energy balance expresses the energy conversion in mass flow and heat on crop (Eq. 1) (Perez et al. 1999; Bezerra et al. 2012; 2015).

$$Rn = \lambda E + H + G \tag{1}$$

where Rn is the surface net radiation, λE the latent heat flux, H the sensible heat flux and G the soil heat flux, all in $W{\cdot}m^{-2}$.

Rn was measured by using a NR-LITE net radiometer (Kipp & Zonen, Delft, The Netherland), installed about 2.5 m above the crop canopy. The values of G, in turn, were measured using two soil heat flux plate model HFP01SC Self-Calibration Soil Heat Flux Plate (Hukseflux Thermal Sensors, Delft, The Netherlands), buried in the soil to 0.02 m depth, one between plants under the mulch and the other between rows.

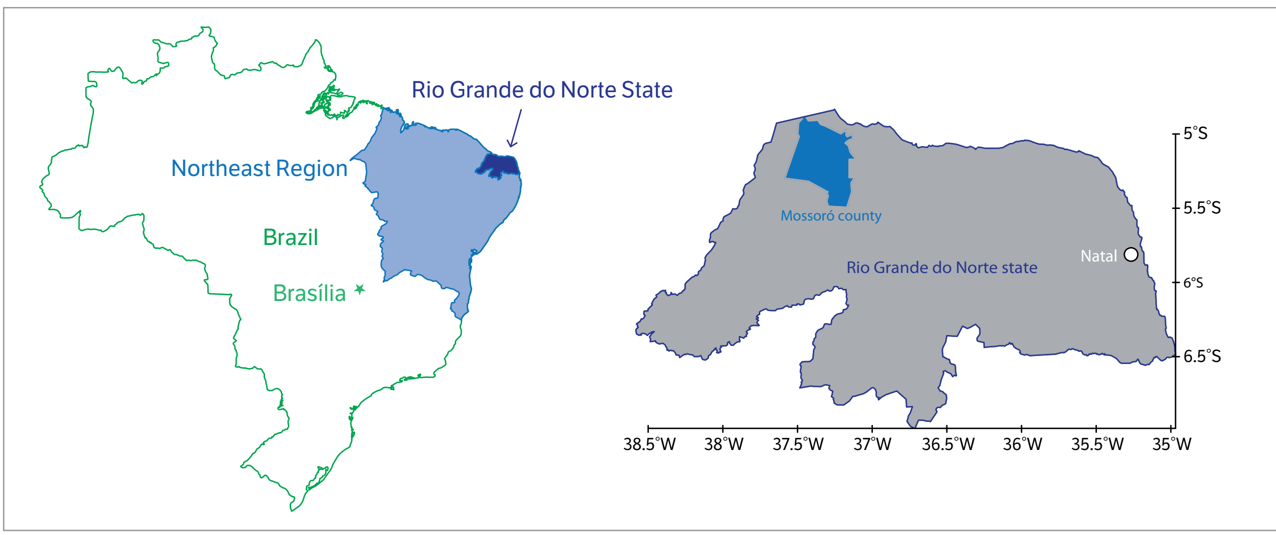

Figure 1. Map of Brazil, Northeast region, Rio Grande do Norte State and Mossoró County.

Table 1. Description of the assessed plots in the two areas studied and the two muskmelon cycles: plot area (ha), cultivated variety, spacing (m), planting dates, placing and removal of blanket and early harvest in Mossoró-RN, 2012.

Area	Cycle	Area (ha)	Variety	Spacing between plants (m)	Transplantation	Blanket placing	Blanket removal	Harvest starting
1	1°	3.0	Amarelo (Goldex)	0,3 × 2,0	Jun-08	Jun-18	Jul-07	Aug-24
	2°	2.5	Amarelo (Iracema)	0,3 × 2,0	Aug-31	Sep-10	Oct-01	Nov-10
2	1°	2.8	Amarelo (Iracema)	0,4 × 1,9	Jun-08	Jun-19	Jul-09	Agu-16
	2°	2.8	Gália	0,4 × 1,9	Agu-27	Sep-06	Sep-24	Oct-29

The values of λE and H were derived from the energy balance equation (Eq.1) and Bowen ratio concept (Bowen 1926; Perez et al. 1999):

$$\lambda E = \frac{Rn - G}{1 + \beta} \quad (2)$$

$$H = \frac{Rn - G}{1 + \beta^{-1}} \quad (3)$$

where β is the Bowen ratio (Bowen 1926), calculated by following equation, only for daytime period with positive available energy ($Rn - G > 0$) (Perez et al. 1999; Bezerra et al. 2015). This equation is derived from empirical relationships between fluxes and vertical gradients, assuming that turbulent diffusion coefficients for the transport of heat and water vapor are equal (Verma et al. 1978; Perez et al. 1999):

$$\beta = \frac{H}{\lambda E} = \gamma \frac{\Delta T}{\Delta e} \quad (4)$$

where $\Delta T = T_2 - T_1$ and $\Delta e = e_2 - e_1$ are above canopy verticals gradients of air temperature (°C) and vapor pressure (kPa), respectively, γ is psychometric constant (kPa·°C^{-1}), which was calculated by using following equation:

$$\gamma = \frac{c_P P_a}{0{,}622\lambda} \quad (5)$$

where c_P is dry air specific heat at constant pressure (J·kg^{-1}·K^{-1}), λ is latent heat of vaporization of the water (MJ·kg^{-1}), which was calculated by using Eq. 6, and P_a is atmospheric pressure (kPa).

$$\lambda = 2{,}501 - 2{,}361 \times 10^{-3} T_a \quad (6)$$

where T_a is air temperature (°C).

The temperature and vapor pressure gradients were obtained from measurements of wet and dry temperatures measured in two levels above the canopy (0.5 and 2.0 m) by using two psychrometers constructed with thermocouple type T (copper-constantan). Electrical signals from the all sensors used in the measurement and/or computation of energy balance components were sampled every 5 s and storage averages every 20 min, through a data acquisition system CR10X (Campbell Sci, Logan, UT, USA) with energy supplied by a solar panel of 20 W. The height of the sensors remained unchanged during the crop growing since the changes on the muskmelon height was insignificant.

The partitioning of the available energy balance can be evaluated by analyzing the dimensionless evaporative fraction (Λ), defined as a ratio of latent heat flux to available energy flux, and it is usually used to characterize the energy partition over the land surface (Shen et al. 2004; Bezerra et al. 2015):

$$\Lambda = \frac{\lambda E}{Rn - G} \quad (7)$$

Daily *ETc* of muskmelon crop was obtained from daily values of λE (MJ·m^{-2}·day^{-1}) (Eq. 2) converted to millimeters (mm) from value of latent heat of vaporization of the water (Eq. 6). Reference evapotranspiration (ET_0) was calculated by the FAO-56 method (Allen et al. 1998), based on meteorological data collected on the weather station of National Institute of Meteorology (INMET), located about 400 m to experimental areas.

The consistency analysis of BREB data was performed according to the criteria established by Perez et al. (1999) and Payero et al. (2003). Extremely inaccurate H and fluxes obtained by the BREB method occur when $\beta \approx -1$, which correspond to the night-time period and to precipitation or irrigation events. Thus, data collected during these events or when $-1.25 < \beta < -0.75$, were eliminated as proposed by Perez et al. (1999), and Payero et al. (2003). Given these criteria, data deemed physically inconsistent were discarded, including cases that are outside the limits of instrumental resolutions.

Leaf Area Index (LAI) was measured weekly from the first Day After Transplanting (DAT) until the end of growing season totalizing eleven measurements during first cycle in the Area 1 and nine measurements during second cycle of Area 1 and first and second cycles of the Area 2. Leaf Area was measured using LI-3100C Area Meter (LI-COR, Lincoln, NE, USA). The LAI was derived from leaf area measurements and crop spacing.

RESULTS AND DISCUSSION

Total irrigation amount applied on the Area 1 was 583.9 and 468.0 mm during the two consecutive cycles, →

respectively. In the Area 2, in turn, total irrigation was 293.7 and 352.9 mm for the first and second muskmelon cycle, respectively.

The mean monthly values of meteorological variables beyond monthly total precipitation observed during growing season of muskmelon on both cycles were showed in Table 2. Note that during 1st cycle T_{air} ranged from 26.7 °C to 26.9 °C while during 2nd cycle T_{air} ranged from 26.9 °C to 27.2 °C. This increase of the T_{air} during 2nd cycle in relation to 1st cycle was due to radiative effect because mean monthly solar radiation during 2nd cycle was almost 1 $MJ·m^{-2}·day^{-1}$ higher than 1st cycle (Table 3). This increase occurred because during transition between two consecutives cycles occurred spring equinox in the Southern Hemisphere, when consequently the Southern hemisphere gets warmer.

The direct effect of T_{air} increase is in establishing the length of the growing season (Bezerra et al. 2012; 2015). Note that during 2nd cycle T_{air} was almost 0.5 °C warmer than 1st cycle. Consequently, 2nd cycle was shorter than 1st in both studied areas, according to Table 3 which shows the dates of the events that marked the changes of physiological stages of the crop and the length thereof in each assessed portion. On Area 2, 2nd cycle was 4 days shorter than 1st cycle, while on Area 1 the 2nd cycle was 15 days shorter than 1st cycle (Table 3). However, excessive extension of the 1st cycle in Area 1 should not only be attributed to air temperature. During the ripening the muskmelon crop was infested by the whitefly pest. So, to minimize the crop yield losses, the producer extended the irrigation and consequently the crop growing season was lengthened. Note that late-season of the 1st cycle of the Area 1 was almost twice late-seasons of others cycles.

Also according to Table 2 the demand atmospheric water during the 2nd cycle was greater than during the 1st cycle, since ET_0 was almost 1 mm higher. It is also noted that the wind speed during the 2nd cycle is greater than during the first cycle. The VPD, in turn, during the 1st cycle (Figure 2a) ranged from 1.01 kPa (Jul-27) to 2.42 kPa in August17. During 2nd cycle (Figure 2b) VPD ranged from 1.40 kPa (September 21) to 2.41 kPa recorded in October 5.

Table 2. Mean monthly solar radiation, air temperature, relative humidity, wind speed, vapor pressure deficit, reference evapotranspiration, and total monthly rainfall observed during muskmelon growing season on Mossoró, 2012.

Month	Solar radiation ($MJ·m^{-2}·day^{-1}$)	Air temperature (°C)	Relative humidity (%)	Wind speed at 2 m ($m·s^{-1}$)	Vapor pressure deficit (kPa)	Evapotranspiration ($mm·d^{-1}$)	Rainfall (mm)
Jun-2012	208	26.7	69.1	3.1	1.66	5.7	0.2
Jul-2012	22.6	26.9	63.6	3.6	1.84	6.5	27.2
Aug-2012	22.6	26.9	58.8	3.9	2.10	7.2	26.8
Sep-2012	22.6	26.9	60.9	4.4	1.96	7.4	12.2
Oct-2012	22.6	27.2	63.2	4.8	1.88	7.5	24.2
Nov-2012	23.1	27.2	65.9	4.5	1.61	6.9	0.2

Table 3. The growing season length of muskmelon in Mossoró-RN, 2012.

Area	Growing season	1st cycle		2nd cycle	
		Period	Length (days)	Period	Length (days)
1	Initial	From Jun-18 to Jul-02	14	From Sep-10 to Sep-24	14
	Development	From Jul-03 to Jul-24	22	From Sep-25 to Oct-19	25
	Mid-season	From Jul-25 to Agu-23	30	From Oct-20 to Nov-06	18
	Late-season	From Agu-24 to Sep-05	13	From Nov-07 to Nov-13	7
	Full-season	From Jun-18 to Sep-05	79	From Sep-10 to Nov-13	64
2	Initial	From Jun-19 to Jun-30	11	From Sep-06 to Sep-19	13
	Development	From Jul-01 to Jul-22	22	From Sep-20 to Oct-12	23
	Mid-season	From Jul-23 to Agu-15	24	From Oct-13 to Oct-29	17
	Late-season	From Agu-16 to Agu-22	7	From Oct-30 to Nov-05	7
	Full-Season	From Jun-18 to Agu-22	64	From Sep-06 to Nov-05	60

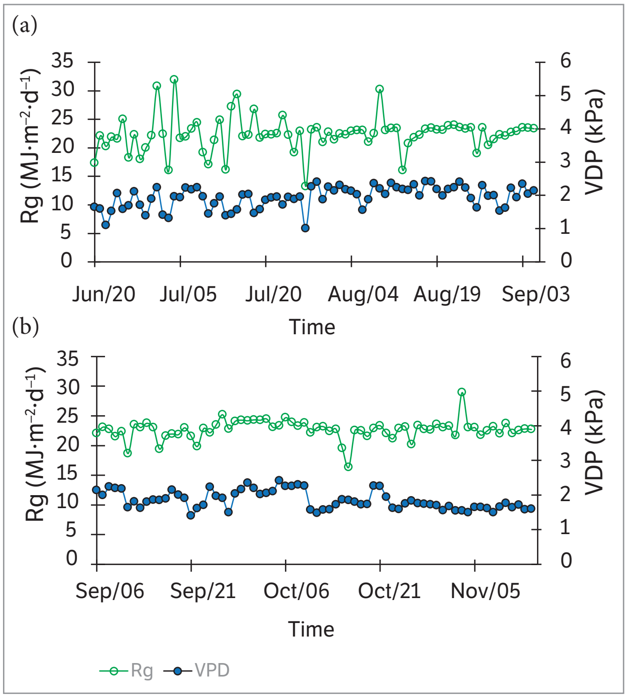

Figure 2. Daily values of the Vapor Pressure Deficit (VPD) and global daily solar radiation (Rg) recorded during the first (a); and second (b) Muskmelon cycle in Mossoró (RN), 2012.

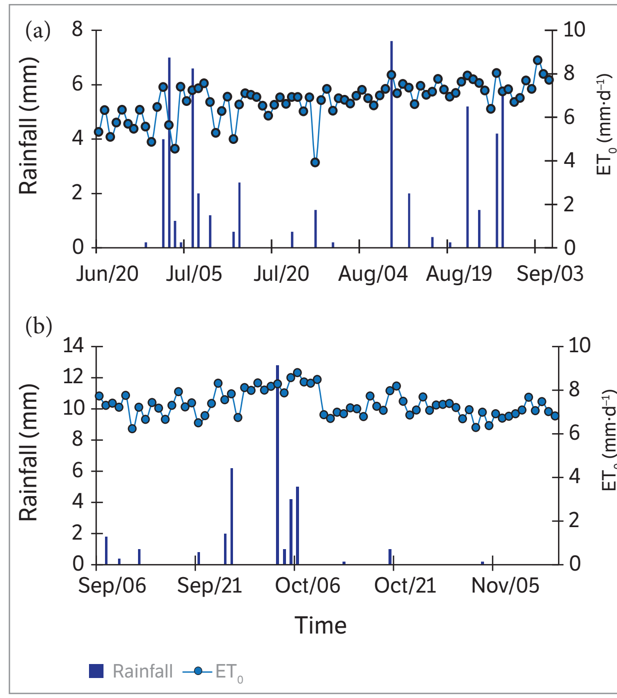

Figure 3. Daily values of the reference evapotranspiration (ET_0) and rainfall recorded during first (a); and second (b) cycle of muskmelon on Mossoró(RN).

Figure 2 shows the behavior of the daily solar radiation (*Rg*) and VPD values during growing season of muskmelon crop. During first cycle (Figure 2a) the highest Rg values occurred on July 4 (32 $MJ \cdot m^{-2} \cdot day^{-1}$), while on July 27 was registered the lowest *Rg* value, 13.2 $MJ \cdot m^{-2} \cdot day^{-1}$. During second cycle (Figure 2b) the highest *Rg* value occurred on November 2 (29.8 $MJ \cdot m^{-2} \cdot day^{-1}$), while on October 15 was recorded the lowest value, 16.32 $MJ \cdot m^{-2} \cdot day^{-1}$.

The rainfall was small, totaling 54.2 mm and 36.6 mm during 1st (Figure 3a) and 2nd (Figure 3b) cycles, respectively. About 85% of total observed was concentrated in July (27.2 mm), August (26.8 mm), and October (24.2 mm) (Figure 3).

The accumulated ET_0 was 527.7 mm and 514.34 mm during 1st (Figure 3a) and 2nd (Figure 3b) cycles, respectively, showing the high atmospheric water demand of the local. The behavior of the daily ET_0 was similar to daily global solar radiation as well as VPD. The months of maximum water demand were August (1st cycle) and October (2nd cycle), whose daily mean values of ET_0 were of 7.2 mm and 7.5 mm, respectively. The minimum and maximum values of ET_0 recorded during 1st muskmelon cycle were 3.9 $mm \cdot day^{-1}$ on July 27 and 8.6 $mm \cdot day^{-1}$ on September 03. During 2nd cycle daily values of the ET_0 ranged from 6.2 mm on September 11 to 8.8 mm on October 6.

The applied irrigation on muskmelon crop in the two studied areas during two consecutive cycles in 2012 is shown in Table 4. Still in the Table 4 we can see the changes of the energy balance partitioning and of the leaf area index (LAI) during growing season of muskmelon crop.

Analyzing the data related to Area 1 in the Table 4, one can see that from Initial to Middle season the LAI increased from 0.01 $cm^2 \cdot cm^{-2}$ to 4.23 $cm^2 \cdot cm^{-2}$ during first cycle and from 0.05 $cm^2 \cdot cm^{-2}$ to 4.22 cm2·cm^{-2} during 2nd cycle. In turn, the percentage of converted to λE increased from 58% to 73% and from 67% to 72% during 1st and 2nd cycles, respectively. On the other hand, the LAI decreased from 4.23 to 2.49 $cm^2 \cdot cm^{-2}$ during first cycle and from 4.22 $cm^2 \cdot cm^{-2}$ to 2.34 $cm^2 \cdot cm^{-2}$ during second cycle, from Middle to Late season, while λE decreased from 73% to 71% during first cycle, and from 72% to 62% in the second cycle.

In Area 2, also according to Table 4, the same behavior is observed on this account LAI increased from 0.01 to 3.54 $cm^2 \cdot cm^{-2}$ from Initial to Middle season, during 1st cycle and from 0.18 $cm^2 \cdot cm^{-2}$ to 4.57 $cm^2 \cdot cm^{-2}$ during the 2nd cycle. There was also an increase of the values λE from →

Table 4. Rainfall, irrigation, average values of energy balance partition, evaporative fraction and leaf area index for each growing season in each muskmelon crop cycle in Mossoró- RN, 2012.

Area	Cycle	Growing season	Energy Balance Partitioning						
			Rainfall (mm)	irrigation (mm)	$\lambda E/Rn$ (%)	H/Rn (%)	G/Rn (%)	Evaporative fraction	Leaf area index ($cm^2 \cdot cm^{-2}$)
1	1º	Initial	11.2	39.0	58	25	17	0.71	0.01
		Development	14.6	158.2	62	26	12	0.71	1.65
		Middle	17.0	289.2	73	20	7	0.80	4.23
		Late	11.4	84.5	71	19	10	0.78	2.49
	2°	Initial	1.8	53.1	67	21	12	0.75	0.05
		Development	31.4	197.2	71	19	10	0.81	1.89
		Middle	1.2	172.2	72	18	10	0.82	4.22
		Late	0.0	45.5	62	22	16	0.73	2.34
2	1º	Initial	11.20	65.13	58	30	12	0.66	0.01
		Development	14.60	86.45	59	27	14	0.68	1.16
		Middle	17.00	108.95	66	26	8	0.71	3.54
		Late	11.40	28.42	64	27	9	0.69	2.51
	2º	Initial	1.80	87.63	72	15	13	0.87	0.18
		Development	31.40	142.11	76	13	11	0.87	1.48
		Middle	1.20	106.58	79	12	9	0.84	4.57
		Late	0.00	16.58	66	22	12	0.74	3.41

58% to 66% (1st cycle) and from 72% to 79% (second cycle). In contrast, there was a decrease in the LAI values from Middle to Late season (from 3.54 $cm^2 \cdot cm^{-2}$ to 2.51 $cm^2 \cdot cm^{-2}$) during 1st cycle and from 4.57 $cm^2 \cdot cm^{-2}$ to 3.41 $cm^2 \cdot cm^{-2}$ during 2nd cycle, while the $\lambda E/Rn$ decreased from 66% to 64% (1st cycle) and from 79% to 66% (second cycle).

The increase $\lambda E/Rn$ from initial to middle season, in accordance with the increase of the LAI, is expected since in this period the muskmelon crop has high growth and development changing from seedlings (very low LAI) to middle season when it reaches the apex of its development during only about 50 days (Table 3). During middle season (from flowering to start of fruit maturity) the crop reaches the prime of their photosynthetic, physiological and metabolic activities and requires maximum water use (Bezerra et al. 2015).

Note that during Mid-season λE/Rn values were greater than 70%, except during the first cycle of the Area 2. This value is slightly higher than the values found in other studies in which was used drip irrigation system such as López-Olivari et al. (2016) on olive orchard located in the Pencahue Valley, Región del Maule, Chile, and Kool et al. (2016) in a desert vineyard located central Negev highlands, Israel. However, it should be considered that the muskmelon crop provided greater ground cover than olive orchard. In this study, muskmelon crop reached LAI mean values of 2.0 and maximum values of 4.5 (Table 3), while López-Olivari et al. (2016) obtained the mean value of 1.32 and Kool et al. (2016) found maximum values of 1.71. According to Zhou et al. (2012), the similar behavior of the change on the λE/Rn and LAI values during full season is expected because a higher LAI considerably increases crop transpiration so contributing to higher values of λE/Rn and vice versa. The agreement between the λE/Rn and LAI curves were also observed in cotton crops at oasis Shihezi in northern Xinjing, China (Zhou et al. 2012). Compared with other studies in muskmelon crop, such as Borges et al. (2015), Mossoró region, Brazilian Semi-Arid, it appears that the portions of Rn converted into λE found in this study were lower. Borges et al. (2015) reported that during Mid-season λE values corresponding to almost all available energy, reaching values higher than net radiation during the daytime. During late season Borges et al. (2015) found λE values ranging from 77 to 89% of the available energy (Rn), while those found in this study ranged from 62 to 71%.

The values of λE/Rn about 70% during mid-season are within range reported in literature for irrigated crops. Hernandez-Ramirez et al. (2010) found a ratio of 0.86

between λE and *Rn* for the full growing season of the soybean and corn crops near Ames, Iowa, Midwestern US. Teixeira et al. (2008) reported an average of 89% of the *Rn* was converted into λE and 11% was converted into *H* during flowering season of the mango crop in the semi-arid region of the São Francisco River basin, Northeast Brazil. In cultivation of crotalaria, near to Tottori City, Southwest part of Japan, Takagi et al. (2009) recorded partition 80% of the available energy (*Rn* – *G*) for *ETc* and only 20% for *H*. However, in this study the muskmelon crop was mulched and irrigated by using drip irrigation system whose dripper is located below mulch. Thus, the water loss is reduced and considerable portion of *Rn* is converted into *H*, which is almost double that the *G*/*Rn* (Table 4). Moreover, the reduction of LAI and the LE/*Rn* values during Late season occurs due to decreased water irrigation supply and muskmelon crop senescence.

In contrast, percentages of converted into *G* (*G*/Rn) and *H* (*H*/Rn) varied inversely with the LAI, i.e., decreased from Initial to Mid-season and increased from Middle to Late seasons. This behavior is physically expected since the values of *G* and *H* are controlled by the soil water availability and soil cover (Shen et al. 2004; Bezerra et al. 2015). Note that when the LAI values increased (from Initial to Mid-Season) *G* and *H* values decreases. During Late season the muskmelon crop is senescence, the leaves age and fall, and strongly decreases the ground cover. In this period *H* and *G* values increases. The lower *G* values occurred during Middle season, when LAI > 3.

The mean values of *G*/*Rn* values observed during two cycles in each area were 11%, ranging from 8% (Mid-season) to 17% (Initial season). Borges et al. (2015), studying the muskmelon crop under irrigated conditions, reported that the portion of *Rn* converted in to *G* ranged from 20% (Initial season) to less than 10% (Mid-season), whose average was 14%.

Values of Λ reflect the condition of soil moisture in the root-zone, so that there is a direct relationship between them (Bezerra et al. 2013). According to Table 4 higher values of Λ was observed during Mid-season, period in which the crop requires maximum water supply, consequently maximum soil water content.

Figures 4 and 5 show the daily behavior of the energy components on the muskmelon crop during growth season. The maximum value of *Rn* and LE for Area 1 (Figure 4) takes place between 11:20 am and 12:20 pm local time on the 1st cycle, and between 11:00 a.m. and 12:00 p.m., local time, during 2nd cycle. In the area 2 (Figure 5) the maximum value of Rn and LE takes place between 11:40 am and 12:40 pm in the first cycle and between 11h00 am local times and 12:20 pm local time during second cycle. Similar behavior was found by Bezerra et al. (2015) on the cotton crop under irrigated conditions on the western region of Rio Grande do Norte State.

The maximum values of G occurred between 10:00 a.m. and 13:00 p.m. local time (Figures 4 and 5). The peak of the *G* values ranged in comparison with the other components, which may be explained by irrigation because despite being performed always in the morning period there was no standardization of times: sometimes occurred at the beginning, middle, or late in the morning. The influence of irrigation on *G* has been reported in the literature (for example, Abu-Hamdeh and Reeder 2000; Bezerra et al. 2012; 2015). As the irrigation events occurred in the morning, soil water content in this period has always been higher than in the afternoon. According Abu-Hamdeh and Reeder (2000) increasing soil water content increases thermal conductivity and thus increases *G*. At about 12:30 pm local time, the soil water content decreased because of soil evaporation resulting in a decline in the *G*.

ETc of muskmelon crop was 362.2 mm and 289 mm on the Area 1 during first and second cycles, respectively, and 265 mm and 279 mm on the Area 2, during 1st and 2nd cycles, respectively. However, there was difference more than 70 mm between the first and second cycles of the Area 1. The reason for this high difference was the late-season lengthening due to extension of the irrigation and consequently extension of late-season of the Area 1 first cycle. The effect of irrigation extension is evidenced by LAI extension from eighth to ninth measurement (Figure 6a).

Except the *ETc* value of 1st cycle of the Area 1, the other results are similar to values reported by Borges et al. (2015) (273.3 mm) and Sousa et al. (2000) (281 mm).

However, a comparison of these values with other studies is difficult because *ETc* values are influenced by many local factors such as climate, soil characteristics, cultural practices, water management, growing season length , and responds strongly to the magnitude of solar radiation received (Alberto et al. 2011; Bezerra et al. 2012).

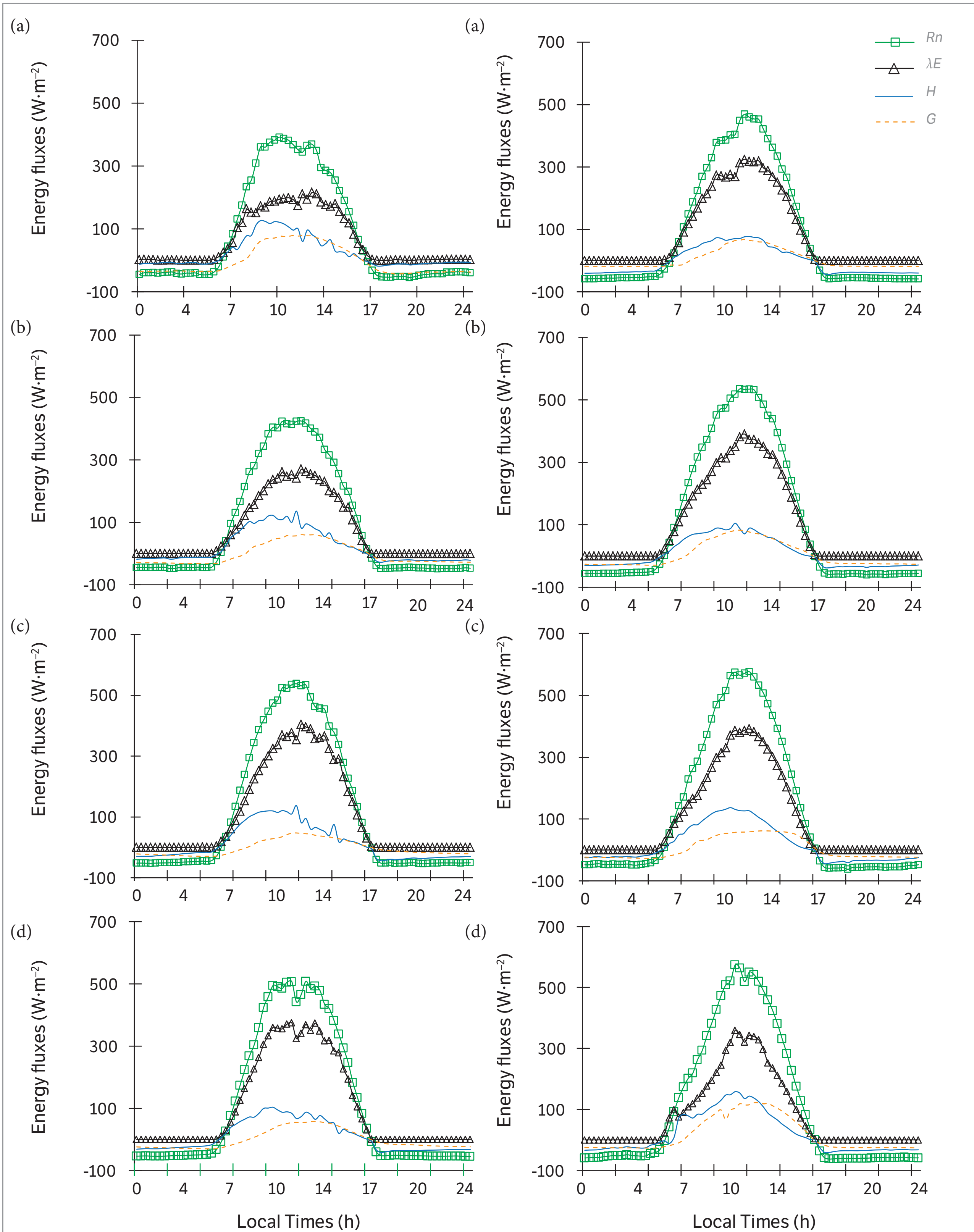

Figure 4. Mean daily of the energy balance fluxes determined by BREB method in the first (left panel) and second cycles (right panel), on Area 1, during the growing season of the muskmelon crop: (a) Initial season; (b) Crop development; (c) Mid-season and (d) Late-season in Mossoró (RN).

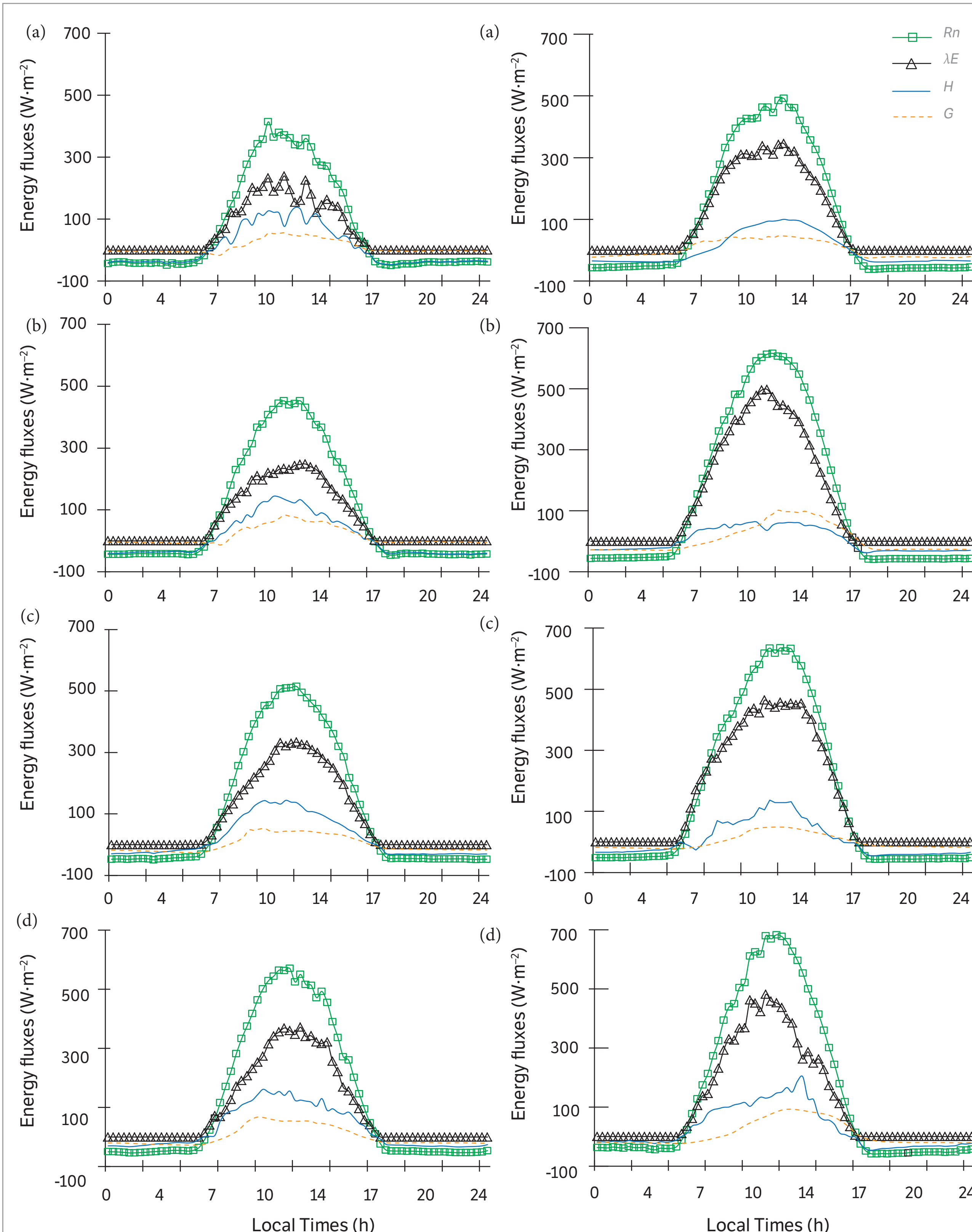

Figure 5. Mean daily of the energy balance components determined by BREB method in the first (left panel) and second (right panel) cycles, on Area 2, during the growing season of the muskmelon crop: (a) Initial season; (b) Crop development; (c) Mid-season and (d) Late-season in Mossoró (RN).

According to Figure 6, which shows the daily *ETc*, the maximum daily values were 6.7 and 6.2 mm·d^{-1} during two consecutive cycles on the Area 1 (Figures 6a and 6c), respectively, and 6.2 mm·d^{-1} and 7.1 mm·d^{-1} on the Area 2 during first and second cycle (Figures 6b,d), respectively. Such daily amounts of *ETc* corroborate to results obtained by Borges et al. (2015) in the same region of Mossoro-RN. Melo et al. (2011), in order to determine the evapotranspiration and production of irrigated muskmelon Gália also in Mossoró-RN, found values of 6.5 mm·d^{-1}, while Oliveira et al. (2010) reported values of 5.2 mm·d^{-1} in the Juazeiro, north of Bahia State. Both studies were conducted in the Brazilian Semi-Arid region. The differences between the *ETc* daily maximum values in the current study and the values found in other areas of Semi-Arid region may be associated with several factors such as the high spatial variability and climate parameters (relative humidity, wind speed, and the air temperature) in the region.

Note that daily *ETc* values varied considerably. The maximum daily *ETc* values occurred due to increased soil evaporation, especially during the Initial season and Crop-development - when crop does not provide complete ground cover (LAI < 3, Table 4 and Figure 6).

From transplanting until about 50 days after transplanting (DAT), *ETc* continuously increased its daily values. This increase was due to high crop growth during this period, as evidenced by the LAI, which increased from 0.01 cm^2·cm^{-2} (9 DAT) to 5.24 cm^2·cm^{-2} (45 DAT) and from 0.05 cm^2·cm^{-2} (10 DAT) to 4.61 cm^2·cm^{-2} (50 days) during 1st and 2nd cycles, respectively, on the Area 1 (Figures 5a,c). In Area 2 LAI increased from 0.01 cm^2·cm^{-2} (8 DAT) to 3.79 cm^2·cm^{-2} (37 DAT) and 0.18 cm^2·cm^{-2} (15 DAT) to 4.60 cm^2·cm^{-2} (48 DAT), during first and second cycles, respectively, (Figures 5b,d). Around 45 DAT until the end of the growing season the LAI and *ET* decreased due to crop senescence. This ETc variation during each muskmelon growing season is comparable with the values proposed by FAO-56 (Allen et al. 1998).

CONCLUSION

The energy balance partitioning and evapotranspiration over the muskmelon crop under irrigated conditions on the Brazilian Semi-Arid region was observed for during two consecutive growing seasons and in two distinct areas. The seasonal variations and its relations throughout the

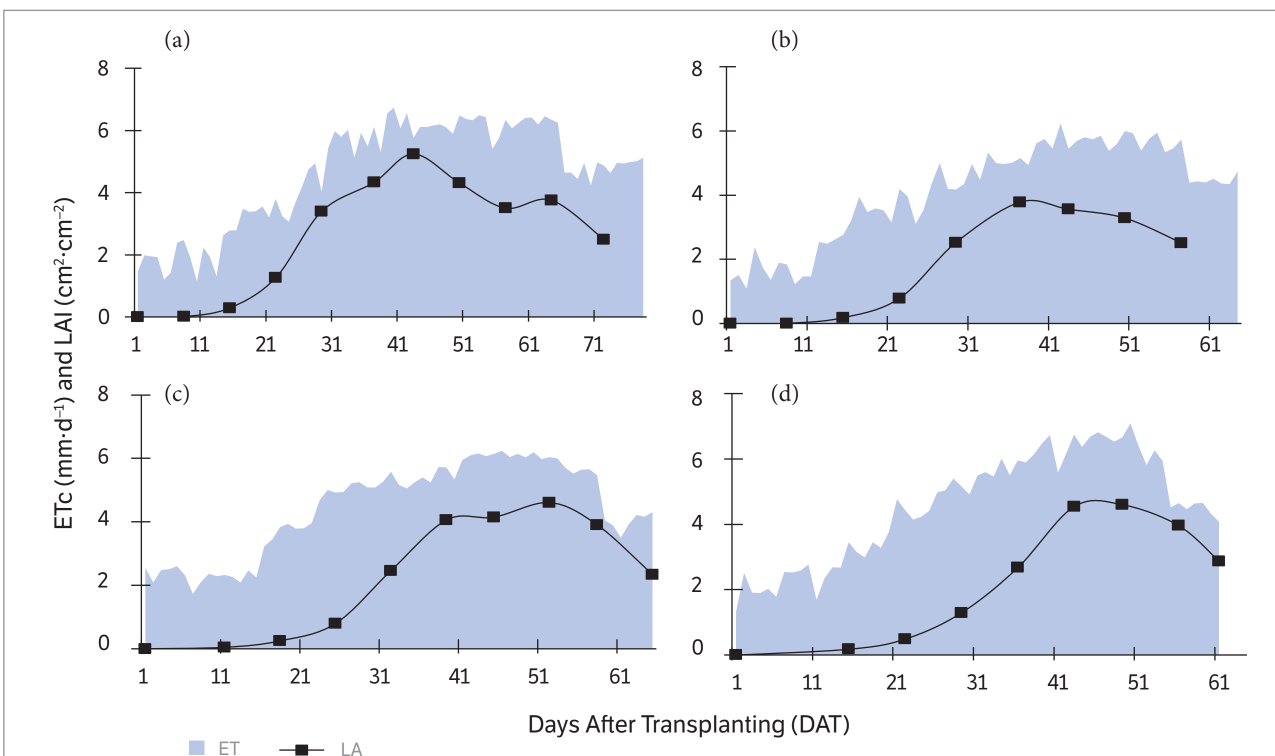

Figure 6. Seasonal variations of the ETc and LAI observed in the first cycle of Area 1 (a) and Area 2 (b) and the second cycle of Area 1 (c) and Area 2 (d) in Mossoró (RN).

vegetative growth were discussed for reaching the following conclusions: approximately 60% of the net radiation was used as latent heat (λE), 21% as sensible heat (H) and 11% as soil heat flux (G). The values vary according to the variations of the leaf area index (LAI), while and varied inversely to LAI. These results reveal important role of the muskmelon crop vegetative growth in the partitioning of the energy balance. The muskmelon ETc obtained from BREB on the climatic conditions of Mossoró-RN ranged from 265 to 289 mm, excluding the value of first cycle of Area 1, due to reason previously discussed. The values range is similar to values found by other researchers on the region.

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