RELATIONS BETWEEN SURFACE TEMPERATURE, ALBEDO, AND EVAPOTRANSPIRATION OF MELON GROWN WITH PLASTIC MULCH

V. P. Borges[1], R. S. Nascimento[2], R. da C. Ferreira[3], J. E. Sobrinho[4], B. B. da Silva[5]

ABSTRACT: Surface albedo (α) and surface temperature (T_S) are associated with crop development, energy balance, and evapotranspiration (ET). Melon, an important fruit in Brazilian exportations, has been cultivated on plastic mulch and in tunnels of agrotextiles. This work aimed to study the relationships between surface albedo and surface temperature with ET of melon grown in plastic mulch. Two field experiments were carried out during the 2009/2010 melon season to determine the ET by the Bowen Ratio Energy Balance method. α data were taken by a net radiometer and T_S data were obtained with an infrared radiometer. Values of α reached up to 0.29 due to the use of agrotextile, which is white. After removing the agrotextile α values stabilized around 0.22. There was no statistical correlation between α and ET. T_S varied inversely to ET, with a strong negative correlation between them in both experiments (-0.916 and -0.74). In experiment 2, the relationship of these two variables presented $R^2 = 0.55$, probably due to increased cloudiness in this period. However, for days with atmospheric transmissivity > 0.6, t the equation that relates T_S and ET had $R^2 \geq 0.8$. Therefore, it is possible to estimate ET under clear sky days conditions based on T_S.

KEYWORDS: water needs, *Cucumis melo* L., biophysical parameters

RELAÇÕES ENTRE TEMPERATURA DA SUPERFÍCIE, ALBEDO E EVAPOTRANSPIRAÇÃO DO MELOEIRO CULTIVADO COM MULCH

RESUMO: Albedo (α) e temperatura da superfície (T_S) são associados ao desenvolvimento da planta, ao balanço de energia e à evapotranspiração. O meloeiro, uma das principais frutas exportadas pelo Brasil, é cultivado sobre mulch plástico e em túneis de agrotêxtil. O presente trabalho teve por objetivo estudar as relações entre os albedo e temperatura da superfície com a ET do meloeiro cultivado em mulch plástico. Foram realizados dois experimentos de

[1] Doutora, Professora, Departamento de Solos e Engenharia Rural/CCA/UFCG, Rod PB 079 – Km 12, CEP: 58.397-000, Areia – Paraíba. Fone: (83) 33621715, email: valeria@cca.ufpb.br
[2] Doutor, Professor, DSER/CCA/UFCG, Areia – Paraíba. Email: rnascimento@cca.ufpb.br
[3] Doutor, Professor, DCETH/UFERSA, Angicos – Rio Grande do Norte. Email: rafael@ufersa.edu.br
[4] Doutor, Professor, DCAT/UFERSA, Mossoró – Rio Grande do Norte. Email: jespinola@ufersa.edu.br
[5] Doutor, Professor, UACA/UFCG, Campina Grande – Paraíba. Email: bernardo.silva@ufcg.edu.br

campo, na safra 2009/2010 para determinar a ET pelo método do Balanço de Energia pela Razão de Bowen. α foi medido com um saldo radiômetro e a T_S obtida com um radiômetro infravermelho. Valores de α alcançaram até 0,29, devido ao emprego do agrotêxtil, que é branco. Após a retirada do agrotêxtil, α estabilizou em torno de 0,22. Não houve correlação entre α e ET. A T_S variou inversamente à ET, com forte correlação negativa obtida nos dois experimentos (-0,916 e -0,74). No experimento 2, a relação ET x T_S apresentou R^2 de 0,55, provavelmente devido ao aumento da nebulosidade neste período. Entretanto, para dias com transmissividade atmosférica > 0,6 a equação de ET em função de T_S teve $R^2 \geq 0,8$. Portanto, é possível estimar a ET a partir de T_S, nestas condições, para dias de céu claro.

PALAVRAS-CHAVE: demanda hídrica, *Cucumis melo* L., parâmetros biofísicos

INTRODUCTION

The quantification of crop evapotranspiration (ET) improve irrigation scheduling and the water use efficiency, which can provide better harvests with less water applications. Water loss by the crop surfaces is a result of the surface energy balance and the atmosphere water demand. Therefore, besides the weather conditions, surface characteristics such as albedo, temperature, vegetation cover and emissivity are important to determine the rate of ET (Allen et al., 2011).

Surface temperature is related to sensible and latent heat fluxes in the atmosphere boundary layer (Maes and Steppe, 2012), and these fluxes are also influenced by the surface albedo. The infrared canopy temperature is used to obtain crop water stress indices and crop transpiration in stress conditions (Kullberg et al., 2016). Several models have applied the difference between surface and air temperatures during the crop canopy evolution to determine ET, including parameterizations that use satellite images data such as SEBAL, METRIC, and TSEB models (Bastianssen et al., 1998; Allen et al., 2007; Colaizzi, 2017).

Melon is one of the most important crops in Rio Grande do Norte State, with production primarily aimed at the foreign market. Studies on the water needs of melon crops in this region are important due not only to the local climatic conditions but also to the specific cultural practices. Similar to other melon-producing regions worldwide, the plants are cultivated on plastic mulch (polyethylene film). In addition, polypropylene webs – agrotextiles – are installed over the plant rows to minimize insect attacks. Both plastic mulch and agrotextile influence the microclimate near plants, including temperature, net radiation, relative humidity, wind speed and accumulated degree-days (Diaz-Perez, 2009). Therefore, these techniques cause changes in the evapotranspiration and water use by plants (Qin et al., 2014).

The present work aims to study the variations of the biophysical parameters albedo and surface temperature, as well the relationships between them and the evapotranspiration of melon crop cultivated with plastic mulch and agrotextile.

MATERIALS AND METHODS

This work was conducted in the municipality of Mossoró, state of Rio Grande do Norte, Brazil (4°59'52"S, 37°23'09"W, and 54 m elevation). According to Koppen, the climate classification of the region is BSwh (very hot and dry, with rainfall in the summer and early autumn), with an average temperature of 27.4 °C, average rainfall of 673.9 mm per year and average relative humidity of 68.9%.

Two field experiments were carried out at different times to determine the ET by the Bowen Ratio Energy Balance (BREB): Experiment 1 (Exp. 1), with planting on Aug. 12, 2009 and harvest on Oct. 19, 2009, and Experiment 2 (Exp. 2), with planting on Nov. 3, 2009 and harvest on Jan. 11, 2010. Both experimental fields were cultivated with the 'Sancho' variety, in drip irrigation. The plants were grown in beds that were 0.6 m wide and covered with light gray polyethylene film. Plants were separated by 0.5 m and the plant rows are 2.0 m distant from each other. More details are presented in Borges et al. (2015).

The growth stages of the melon plant were divided into four phases: 1) initial stage, 2) vegetative growth stage, 3) midseason stage (fruit growth) and 4) late season stage (maturity) according to Miranda et al. (2008). Table 1 shows the dates and lengths of the crop physiological phases. Plant emergence occurred seven days after sowing (DAS), when the agrotextiles (white color) were installed on the rows. The agrotextile is used from the time of emergence to flowering, therefore, in Exp. 1 from Aug 19 to Sept 10 and in Exp. 2 from Nov 17 to Dec 1, in the period. Crop development was monitored by growth analysis with weekly samples beginning 15 DAS. The leaf area index (LAI) was determined using a leaf area integrator (LI-COR, model 3100, Lincoln, NE, USA).

Micrometeorological data were measured during the whole crop cycle in both experiments. A net radiometer sensor was installed at 2.0 m height to obtain net radiation and surface albedo (KippZonen, model CNR1, Delft, The Netherlands), as well as two soil heat flux plates sensors (Hukseflux HFP01-L, Delft, The Netherlands) buried at 0.02 m, one under the mulch in the planting row and other between rows. Vertical temperature and water vapor pressure gradients were determined from wet and dry copper-constantan thermocouples measurements in fan-aspirated psychrometers. The psychrometers were installed 0.3 m (z1) and 1.8 m (z2) above the plant canopy and were elevated as the crop developed. Surface temperature (Ts) was measured using an infrared radiometer (Apogee SI-111) installed at 2.20 m height and inclined at 45° to the surface. All data were recorded at 5-s intervals and stored as 30-min averages using a CR1000 datalogger (Campbell Scientific, Logan, UT, USA).

The BREB method, applied to determine ET, is present in the Equations 1 and 2.

$$LE = \frac{(R_n - G)}{1+\beta} \qquad (1)$$

Where LE is the latent heat flux, Rn is the net surface radiation, G is the soil heat flux (both in W m^{-2}), and β is the ratio between sensible heat flux and latent heat flux (Bowen Ratio)

$$\beta = \gamma \frac{\Delta T}{\Delta e} \qquad (2)$$

where γ is the psychrometric factor (kPa °C^{-1}), ΔT is the vertical temperature gradient (°C), and Δe is the vertical water vapor pressure gradient (kPa), both determined above the crop canopy using psychrometers.

RESULTS AND DISCUSSION

The surface albedo (α) variation is present in Figure 1A. At the first week after sowing, the mean value of α in Exp. 1 was 0.16, due to the reflectance of bare soil with plastic cover. For the same period, α were high in Exp. 2, with an average of 0.24. The soil of the first experimental area was sandy, however with dark red color, probably due to the presence of iron oxides. This characteristic is the reason of its lower reflectance, while sandy soils of lighter color, as in the Exp. 2 area, tend to present greater value of α (Demattê et al., 2004; Dalmolin et al., 2005).

After placing the agrotextile occurred an increase in α values, reaching 0.23 in Exp. 1 and 0.29 in Exp. 2, because of the white color of the material. On this occasion, net radiation dropped down 9% and 12% in Exp. 1 and Exp. 2, respectively. Mean values of α decreased to 0.19 and 0.22 after removing the agrotextile, and increased again as from 37 DAS, when the plants reached 80% of the ground cover. Thus, the α values, 0.22 (Exp. 1) and 0,23 (Exp. 2), remained unchanged until the harvest.

T_S had similar variation during the melon season in the two experiments (Figure 1B). On the first week after sowing the mean daily T_S during daytime was 41 ºC in Exp. 1 and 40 °C in

Exp. 2. The average daytime values dropped down one degree in each experiment during the period of agrotextile application, which it was observed on the next day after placing the agrotextile. The maximum value of T_S in Exp. 1 was 55 °C, recorded at 12:30 h (i.e., the mean of the interval between 12:00 and 12:30 h) on August 20. In Exp. 2 the maximum T_S (52°C) also occurred in the first week after sowing, on November 06 at 12:00 h.

In the crop mid-season stage, where vegetative growth and water demand reached the highest values, mean diurnal temperatures were 30 °C and 29°C in Exp. 1 and in Exp. 2, respectively, maintaining this pattern until harvest. During this phase, was found that the air temperature, recorded by the psychrometer, next to crop canopy were very close to the surface temperature measured by the infrared radiometer (data not shown). In this stage, the highest T_S values were 36 °C in Exp. 1 (October 05 at 12:00 h) and 35 °C in Exp. 2 (December 29, at 13:00 h). T_S tends to raise up with air temperature and solar radiation increases, also with air relative humidity and wind speed decreases. At vegetated surfaces, T_S has a strong relation with the surface roughness length, thus, with the structure and development of the vegetative canopy (Maes and Steppe, 2012).

The evolution of ET data for each experiment are presented in Figure 2. The total crop evapotranspiration was 256 mm in Exp. 1 and 273.3 mm in Exp. 2. The maximum ET values were 7.9 mm (53 DAS) and 7.0 mm (47 DAS) for Exp. 1 and Exp. 2, respectively. Up to 30 DAS the ET remained practically unchanged despite the plant continues growing. This can be explained by the agrotextile using, because of its white color, which contributed to the decreasing the net radiation and, consequently, the ET.

Only data collected after removing the agrotextile (about 30 DAS) were used to correlate ET and α. Nevertheless, the relationship presented low coefficient of determination (R^2) in experiment 1 and there was no correlation in experiment 2 (Table 2). Values of α presented little variation having been stabilized again after 40 DAS (Figure 1). Meanwhile, the ET increased reaching its peak at around 50 DAS and decreased in the last 10 days before harvest (Figure 2), following the crop phenology. Melon crop has a fast horizontal grow, so its reflectance quickly reaches a constant value, while the water needs still continue increasing with fruit development.

The relationship of T_S and ET was inversely proportional (Table 2), as also reported by Szilagyi (2015) and Sun et al (2016), in the latter even under energy limited and water stress conditions. The highest value of T_S was recorded in the first week of the crop, just when there was the lowest ET. The surface water losses were due solely to the plant transpiration, because it was a drip irrigated crop whose emitters were covered by the plastic mulch. Therefore, the contribution of dry bare soil was important at T_S up to about 25 DAS. Thereafter T_S decreased due to the fast growth of the crop canopy. Maes and Steppe (2012) reported that the difference between crop canopy temperature (T_S) and air temperature just above the plants (T_a) reduced linearly with the increase of ET. The same was verified by the authors when increasing the leaf area and the plant height. These results show clearly the relation of T_S and ET, since a high value of (T_S – T_a) infers a high sensible heat flux too.

In both experiments, the coefficient of correlation (ρ) indicated a strong negative relation between T_S and ET, with values of -0.916 e -0.74 for Exp. 1 and Exp. 2, respectively. It was verified that the most distant points of the linear trend chart ET x T_S refer to the days with low atmospheric transmissivity (τ). τ was computed by the simple ratio R_S/R_0, (R_S is the solar radiation and R_0 is the extraterrestrial radiation, both for 24 h). These occurrences were mainly in Exp. 2, at the end of crop mid-season and crop late season stages (from December 15), when the cloudiness increased. Between December 31, 2009 and January 1, 2010, for example, τ dropped down from 0.6 to 0.4; ET varied 14%, whereas T_S varied only 6%. In this phase, when the ground cover reach about 80%, T_S remained stable, whereas the weather conditions readily affected ET.

To evaluate the impact of τ on the ET x T_S relationship, new regressions were made, this time only for days with $\tau \geq 0.6$, i.e. little or no cloudiness. In Exp. 1, only 13 days were excluded according to this criterion, so in the new regression there were no significant changes in R^2 (Figure 3). In Exp. 2, 23 days had τ less than 0.6, so the new relation between T_S and ET had $R^2 = 0.8$. Therefore, for clear sky days, the ET parametrizations that consider T_S are still more reliable. This is even more relevant for determinations via remote sensing, since these are only possible in cloudless conditions.

CONCLUSIONS

Agrotextile and plastic mulch influenced the albedo and the surface temperature in melon crop fields. During agrotextil period, the albedo reached high values (up to 0.29) and the temperature fell by 1 °C in both experiments. There was no statistic correlation between albedo and evapotranspiration, however there was a strong negative correlation (ρ = -0.916) between evapotranspiration and surface temperature. The linear regression between these variables presented better R^2 for days of atmospheric transmissivity > 0.6. Therefore, it is possible to estimate ET under clear sky days conditions based on T_S.

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TABLES AND FIGURES

Table 1. Length of the phenological stages of melon plants from Experiment 1 and Experiment 2 (Borges et al., 2015). Mossoró, RN, Brazil. DAS: days after sowing.

Stage	Events	Exp. 1 (2009)		Exp. 2 (2009/2010)	
		Dates	DAS	Dates	DAS
Initial	Planting	12/08	0	03/11	0
Development	10% ground cover	04/09	23	25/11	22
Mid-season	80% ground cover	23/09	42	13/12	40
Late season	Fruit maturing	11/10	56	04/01/2010	62
	Harvest	19/10	68	11/01/2010	69
Total crop cycle (days)			68		69

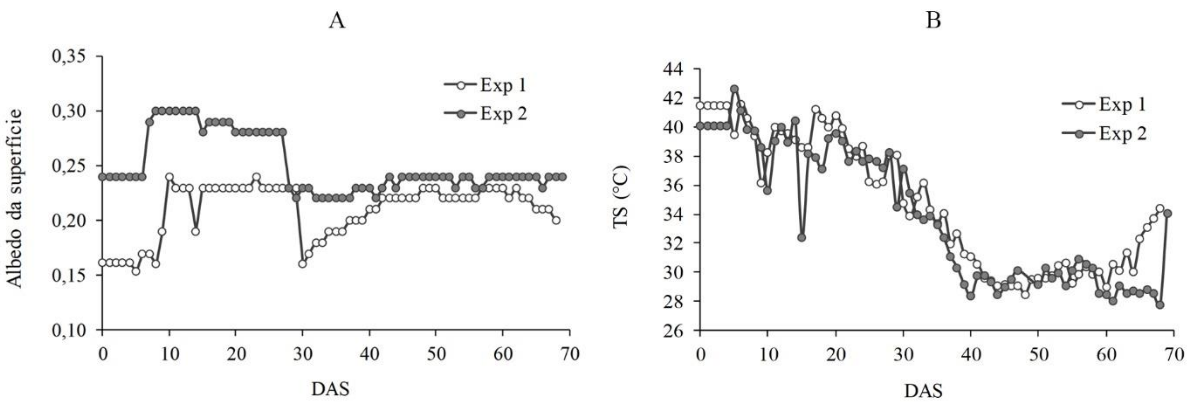

Figure 1. A: Surface albedo and B: surface temperature (°C) for melon crops in two different seasons. Experiment 1: Aug 12 to Oct 19, 2009, Experiment 2: Nov 4, 2009 to Jan 11, 2010, DAS: days after sowing. Mossoró, RN, Brazil.

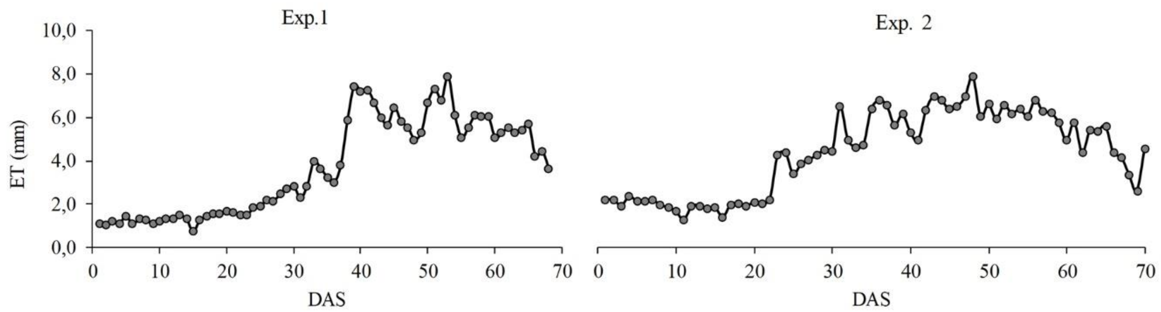

Figure 2. Melon evapotranspiration (mm) in two different seasons. Experiment 1: Aug 12 to Oct 19, 2009, Experiment 2: Nov 4, 2009 to Jan 11, 2010, DAS: days after sowing. Mossoró, RN, Brazil.

Table 2. Equations and respective coefficients of determination (R^2) for the relations between evapotranspiration (ET), albedo (α), and surface temperature (T_S). Experiment 1: Aug 12 to Oct 19, 2009, Experiment 2: Nov 4, 2009 to Jan 11, 2010. Mossoró, RN, Brazil.

Relation	Experiment 1		Experiment 2	
	Equation	R²	Equation	R²
ET x α	49.558α – 5.0945	0.42	-6.6775α + 6.6348	0,00
ET x TS	-0.447TS + 19.244	0.84	-0.2719TS + 13.098	0.55

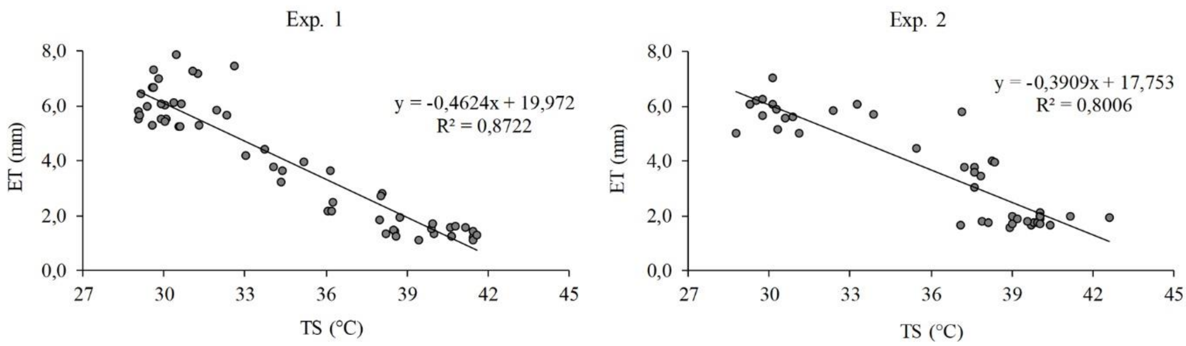

Figure 3. Relation ET x TS for days with atmosphere transmittivity > 0,6. Experiment 1: Aug 12 to Oct 19, 2009, Experiment 2: Nov 4, 2009 to Jan 11, 2010, DAS: days after sowing. Mossoró, RN, Brazil.