INOVAGRI International Meeting
XXVIII CONIRD
I Simpósio Latino Americano de Salinidade

ASSESSING MODELS TO ESTIMATE K_{cb} FROM NDVI: A STUDY FOR MELON IRRIGATED CROPS IN BRAZILIAN SEMIARID REGION

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ABSTRACT: The world population increasing in the last decades demands efficient use of water, mainly in agriculture, that uses the most of fresh water. Remote sensing techniques for irrigation management are very useful in the study of large areas, making possible the planning of water resources. The crop water needs can be obtained from estimates of the crop coefficients from vegetation indexes. This work aimed to assess the accuracy of Kcb estimation models from NDVI, for the irrigated melon crop. The study area is located in the municipality of Mossoró-RN (4°59'52 "S, 37°23'09" W). Three TM Landsat 5 satellite images, free of clouds, were obtained and processed from the path/row 216/63 for the dates: 09/01/2009, 09/17/2009 and 10/03/2009. The images were applied to calculate NDVI and Kcb. Four different models were evaluated which were developed for distinct annual and perennial crops. The Bowen Ratio Energy Balance method was used to validate the models. Three of the models underestimated melon basal evapotranspiration by a maximum of 7.5% and the other one overestimated by 9.7%, proving the efficiency and generality of the spectral models to determine the crop water requirements.

KEY WORDS: vegetation indices, evapotranspiration, *Cucumis melo* (L).

AVALIAÇÃO DE MODELOS DE ESTIMATIVA DO KC_B COM NDVI: ANÁLISE PARA O MELOEIRO IRRIGADO NO SEMIÁRIDO BRASILEIRO

RESUMO: O aumento da população mundial nas últimas décadas exige o uso eficiente da água, principalmente na agricultura, a atividade que mais utiliza esse insumo. As técnicas de sensoriamento remoto para o manejo da irrigação são muito úteis no estudo de grandes áreas,

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possibilitando o planejamento dos recursos hídricos. A demanda hídrica das culturas pode ser obtida a partir da estimativa dos coeficientes de cultivo, determinados com índices de vegetação. O objetivo deste trabalho foi avaliar a acurácia de modelos de estimativa do Kc_b a partir do NDVI, para a cultura do meloeiro irrigado. A área de estudo está localizada no município de Mossoró-RN (4°59'52" S, 37°23'09" W). Foram obtidas e processadas três imagens geradas pelo satélite Landsat 5 TM, livres de nuvens, da orbita 216 e ponto 63 nas datas: 01/09/2009, 17/09/2009 e 03/10/2009. As imagens foram utilizadas para o cálculo do NDVI e Kc_b. Foram avaliados quatro diferentes modelos, desenvolvidos para diversas culturas, anuais e perenes. Utilizou-se o método do Balanço de energia pela Razão de Bowen para a validação das equações. Três dos modelos subestimaram a evapotranspiração basal do meloeiro em no máximo 7.5% e o outro superestimou-se em 9.7%, comprovando a eficiência e generalidade do uso de modelos espectrais para a determinação das necessidades hídricas das culturas.

PALAVRAS-CHAVE: índice de vegetação, evapotranspiração, *Cucumis melo* (L).

INTRODUCTION

The world population has increased in the last decades, promoting a competition for water use in industrial, agricultural and household sectors. Water scarcity affects more than 40% of the world population, a figure that will reach 66% by 2050 (FAO, 2015). Irrigated crops use most of the water resources, accounting for 46% of the water bodies withdrawals and 67% of total consumption in Brazil (ANA, 2018). Melon (*Cucumis melo L.)* is one of the most exported fresh fruits from Brazil. The Rio Grande do Norte state (RN) participates with 64% of these exports, due to the special crop management and the availability of groundwater for irrigation. However, irregular rainfalls and groundwater quality issues are limiting aspects for assuring long term crop production in that region. In this scenario, improving the water use efficiency is essential for maintaining the water supply to crop irrigation, as well as increasing farmers' awareness of the adequate management of water during the crop cycle.

Crop water needs can be estimated based on the crop evapotranspiration (ETc), which includes weather conditions and crop aspects, such as: species, variety, stage of development and crop management (Borges et al., 2015). The ETc can be determined by the product between the crop coefficient (Kc) and the reference evapotranspiration (ETo). ETo represents the effect of climate on the evaporative power of the atmosphere and the Kc represents the crop peculiarities (Johnson and Trout, 2012). The basal crop coefficient – Kcb – is one of the biophysical parameters linked to crop transpiration that can be derived from vegetation indices (Rocha et al., 2010). The Normalized Difference Vegetation Index – NDVI is the most used in vegetation studies and is obtained by contrasting red and near infrared canopy reflectances. Empirical equations with NDVI data for Kcb estimation have already been developed for several crops (Toureiro et al., 2017). This method is a viable alternative for ETc estimation, since field methods have disadvantages in equipment acquisitions, installation and maintenance. In this study, we aimed to evaluate Kcb models from NDVI data, for melon crops in the Brazilian semiarid region.

MATERIAL AND METHODS

The field experiment was conducted in a melon farm in the municipality of Mossoró, RN, Brazil (4°59'52" S, 37°23'09" W, and 54 m elevation). According to Koppen, the climate classification of the region is BSwh, with an average temperature of 27.2 °C, total annual rainfall of 766 mm and average relative humidity of 69% (Borges et al., 2015). The crop area (5.74 ha) were cultivated with the 'Sancho' variety, with planting on Aug 12, 2009 and harvest on Oct 19, 2009. The plants were grown in rows in the center of beds that were 0.6 m wide and covered with light gray polyethylene film. The beds were placed 1.4 m apart (bare soil), totaling 2.0 m spacing between the plant rows. Plants were separated by 0.5 m resulting in a plant population of 1 plant m^{-1}. From seedling emergence to the beginning of flowering, it was installed the agrotextiles (tunnel of polypropylene woven above the crop bed) to minimize pest incidence. The crop was drip irrigated, with emitters located below the plastic cover.

The orbital images (TM - Landsat 5) from the melon crop area corresponded to path/row 216/63 and were obtained from the Brazilian National Institute for Space Research. The images, free of clouds in the interest area, were from the following dates: 09/01/2009, 09/17/2009 and 10/03/2009, referring, respectively, to the initial, development and mid-season crop stages (Table 1).

Table 1. Length of the phenological stages of melon crop from field experiment (Borges et al; 2015).

Stage	Events	Dates	DAS
1 – Initial	Planting	08/12/2009	0
2 – Development	10 % ground cover	09/04/2009	23
3 – Mid-Season	80 % ground cover	09/23/2009	42
4 – Late Season	Fruit maturing	10/11/2009	58
	Harvest	10/19/2009	68
Total crop cycle (days)			68

DAS: days after sowing

NDVI is computed from the crop reflectance of red (ρ_{RED}) and near infrared (ρ_{NIR}) radiation (Eq. 1). The Landsat images were processed following the steps reported in Allen et al. (2002). With the NDVI maps, the basal crop coefficients (Kcb) were determined by the models present in Table 2.

$$NDVI = (\rho_{NIR} - \rho_{RED})/ (\rho_{NIR} + \rho_{RED}) \quad (1)$$

Table 2. Models to determining basal crop coefficients, from NDVI data.

Crop	Models	Reference
Cotton	$1.5625 \times NDVI - 0.1$	Dercas et al., 2017
Citrus	$1.1875 \times NDVI + 0.05$	Sawant et al., 2016
Lettuce	–0.11×NDVI^2 + 1.39×NDVI + 0.01	Johnson e Trout, 2012
Wheat	$1.07\ [1- (NDVI_{max} - NDVI/NDVI_{max} - NDVI_{min})^{0.84/0.54}]$	Er-Raki et al., 2007

Due to the crop characteristics (use of plastic cover and drip irrigation below this cover), the water transfer to the atmosphere was only by plant transpiration. In addition, there were no rainfall during the crop cycle period. So, melon ETc_b (basal evapotranspiration) was computed by the FAO 56 method (Allen et al., 1998):

$$Etc_b = Et_0 \cdot Kcb \quad (2)$$

ET_0 was calculated using the data collected at the weather station belonging to the Brazilian Meteorology National Institute (INMET), which is located 10 km from the experiment site (5°4'54" S, 37°22'7" W, and 36 m elevation).

The Bowen Ratio Energy Balance - BREB method was applied to assess the Kcb-NDVI models. Micrometeorological data were measured during the total crop cycle, with the following sensors: a net radiometer (KippZonen, model CNR1, Delft, The Netherlands) installed at a 2.20 m height and two soil heat flux plates (Hukseflux HFP01-L, Delft, The Netherlands) buried at 0.02 m, one under the mulch in the planting row and the other between rows. Fan-aspirated psychrometers with wet and dry copper-constantan thermocouples were applied to measure the vertical gradients of temperature and water vapor pressure. The data were stored on a CR1000 data acquisition system (Campbell Scientific, Logan, UT, USA) programmed to collect measurements every 5 s with averages every 30 min. For more BREB experimental details, see Borges et al. (2015).

RESULTS AND DISCUSSION

NDVI evolution in crop cycle

The monitoring of melon crop development through NDVI is shown in Table 3. The lowest NDVI values were found on the date corresponding to the initial crop phase (Sep 01, 2009), due to the short soil cover and the use of agrotextile. In the next dates, corresponding to crop stages 2 and 3, there was an increase in NDVI values due to the development of the plant and consequent increase of the soil cover fraction, since these two parameters have a positive correlation with NDVI (Rocha et al., 2010; Johnson e Trout, 2012).

Table 3. Minimum, maximum and average NDVI values for experimental area cultivated with melon.

Date	Phenological stage	NDVI min	NDVI max	NDVI average
09/01/2009	1 - Initial	0.08	0.22	0.11
09/17/2009	2 – Development	0.44	0.58	0.53
10/03/2009	3 – Mid-Season	0.62	0.73	0.69

Assessing the Kcb-NDVI models in each phenological crop phase

The maps of basal crop coefficients determined by the spectral models, for the experimental field, are presented in the following figures 1, 2, 3, for each phenological stage. At the first stage, the Er-Raki model performed a high spatial variability from the Kcb data, with negative values in some pixels. This result is probably due the variable $NDVI_{min}$ present in Er-Raki model. Because of the agrotextile, the spectral surface reflectance is quite different from the same crop without this cover. This large contrast between maximum and minimum values of NDVI conduced to a poor performance of the model. Drerup et al. (2017), when estimating wheat evapotranspiration from this model, obtained Kcb values close to 0 in the NDVI range from 0 to 0.4, corroborating the effect attributed to agrotextile in the Kcb estimate. At the next phenological stages, the Kcb values are similar among the models, with spatial homogeneity in the crop field.

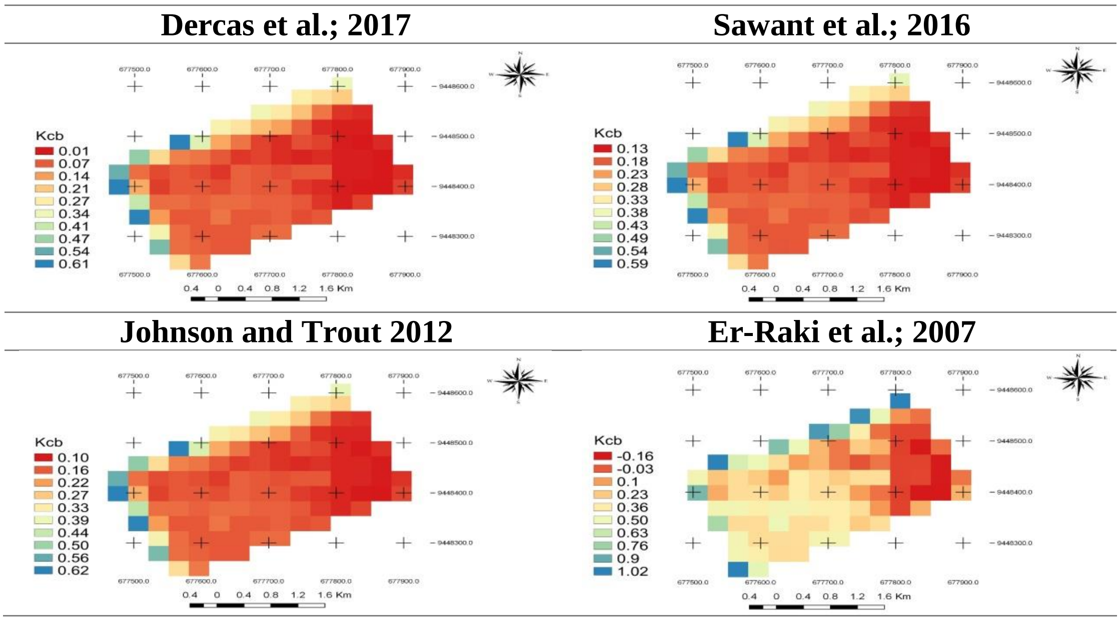

Figure 1. Thematic maps of Kcb estimated by the NDVI models, from Initial crop stage (09/01/2009).

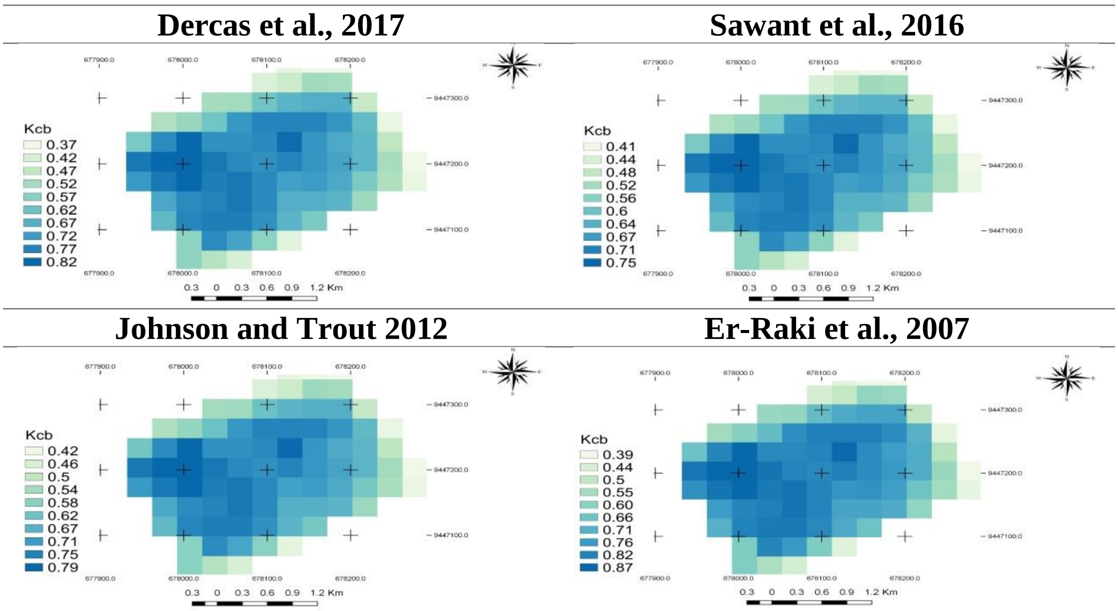

Figure 2. Thematic maps of Kcb estimated by the NDVI models from Development crop stage (09/17/2009).

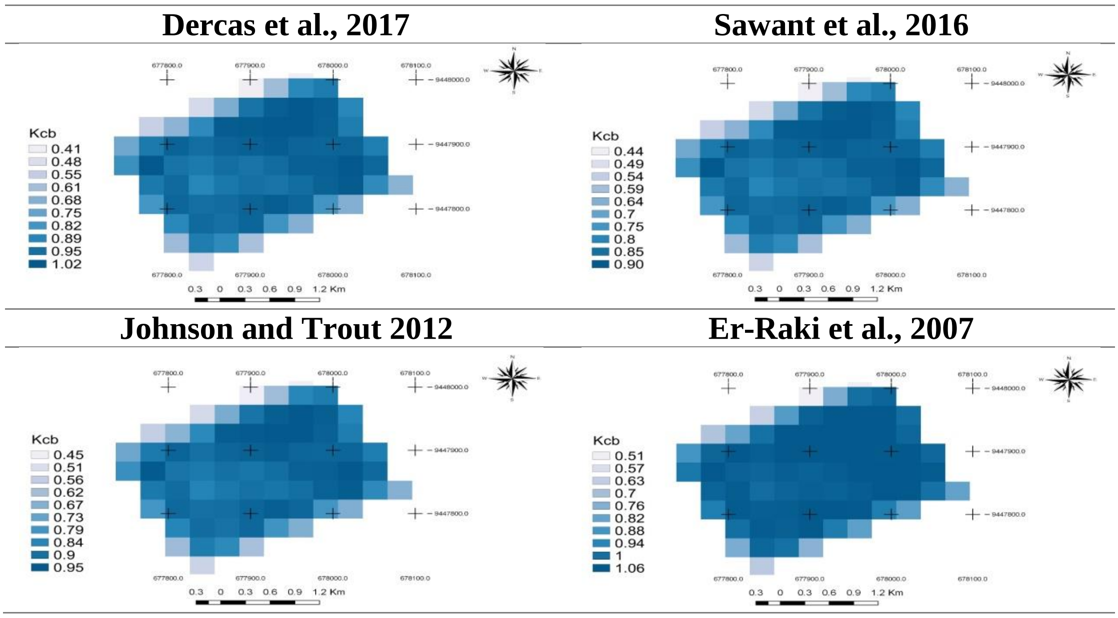

Figure 3. Thematic maps of Kcb estimated by the NDVI models from Mid-Season crop stage (10/03/2009).

At the 1st crop phenological stage, the poor performance observed in three of the four evaluated spectral models, in comparison to the BREB model, may be due to the agrotextile, causing an atypical reflectance of the vegetation (Table 4). The Kcb values from the model proposed by Swant et al. (2016) were closer to the BREB data, underestimating the field measurement by 10%. For phenological stages 2 and 3, the estimated Kcb data had a better agreement with the field-based values. With increasing ground cover, NDVI was able to better represent the crop surface, therefore model more accurately the transpiration.

Table 4. Kcb values from the Kcb-NDVI spectral models and Bowen Ration Energy Balance (BREB) method.

Date	K_{cb1}	K_{cb2}	K_{cb3}	K_{cb4}	Kcb_{BREB}
09/01/2009	0.07	0.18	0.16	0.31	0.20
09/17/2009	0.77	0.71	0.75	0.83	0.75
10/03/2009	0.96	0.85	0.91	0.94	1.01

Kc_{b1}: Dercas et al., 2017; Kc_{b2}: Swant et al., 2016; Kc_{b3}: Johnson & Trout, 2012; Kc_{b4}: Er-Raki et al., 2007.

The Johnson and Trout model provide Kcb value equal BREB model result (date for Stage 2). This great performance is due the characteristics of lettuce crop, more similar to melon field than the crops from the other models, in terms of development and soil fraction cover. At the Late stage, which presents de higher water needs because of the fruiting season, all the models underestimated the Kcb. Dercas equation retrieved the best result, although with 4,9% of underestimation. The Swant model, originally proposed for citrus crops, had the poorest performance in this study. Probably, since citrus has not full ground cover, its relation between NDVI and transpiration is not adequate for melon crops in maximum development.

Comparison of ETc retrieved from the spectral models and field experiment

The results in Table 5 are the accumulate basal evapotranspiration (ETc_b) for each phenological stage. The Initial stage corresponding to the period of lower water requirement, which increased along the crop cycle, reaching the maximum at Stage 2 for the Kcb-NDVI models, although the higher ETc_b occurred at Stage 3 for BREB model. This divergent result between spectral and field methods is due to the date of the only Landsat image that represents Stage 2 (09/17/2009). The Development Stage has a large variation of soil ground cover, in comparison with the Initial and Late Stages. Because the Landsat image date was from the end of Stage 2, the spectral models could not detect the crop development and overestimated the water requirement for this whole phase. On the other hand, during fruiting and fruit maturation period, all the spectral models underestimated the accumulated ETc_b. Again, the only available image to represent this crop stage affect the results for ETc_b. The Oct 03, 2009 corresponded to begging of fruiting, and not characterized the days of maximum water consumption by the melon crop, reducing the ability of spectral models to estimate accurately the season Etc_b. So, satellite images with better temporal resolution would improve the spectral method application, aiming the irrigations schedules.

Table 5. Accumulated ETc_b (mm) during each phenological phase from melon crops, obtained from Kcb-NDVI models and field measurements (Bowen Ratio Energy Balance method).

Phenological Phase	ETcb1	ETcb2	ETcb3	ETcb4	ET BREB
1	8.5	21.9	19.5	37.8	35.2
2	110.8	102.2	107.9	119.5	93.1
3	108.5	96.1	102.9	106.3	112.0
Total	227.8	220.2	230.3	263.6	240.3

ETcb1: Dercas et al., 2017; ETcb2: Swant et al., 2016; ETcb3: Johnson e Trout. (2012); ETcb4: Er-Raki et al., 2007; ET_{BREB}: Borges et al., 2015.

The better performance to estimate ETc_b for entire crop cycle was by Johnson e Trout (2012) model, which underestimated the ET_{BREB} by 4.2% only. The equation of Er-Raki et al. (2007) overestimated the total ETc_b in 9.7%, while the Dercas et al. (2017) and the Swant et al. (2016) models presented total ETc_b 5.2% and 8.4% lower than ET_{BREB}, respectively. Toureiro et al. (2017) obtained differences of 8.3%, 3.9%, 8.9% and 2.1% in ETc estimates by NDVI model with respect to field measurements in four maize crops experimental plots.

CONCLUSION

The use of agrotextile, at the beginning of the crop, influenced the performance of the spectral models, with at least 10% difference between Kcb estimates and the measurements in the experimental field.

The four Kcb-NDVI models performed well in estimating the total melon evapotranspiration, differing by a maximum of 10% with $ET_{c_{BREB}}$. The model developed by Johnson & Trout (2012) presented a better agreement with the field data. The results proved the efficiency and generality of the NDVI models to determine the evapotranspiration of melon cultivated with plastic mulch and agrotextile.

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