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Temporal variation of normalized difference vegetation index (NDVI) and calculation of the crop coefficient (K_c) from NDVI in areas cultivated with irrigated soybean

Variação temporal do Índice de Vegetação por Diferença Normalizada (NDVI) e obtenção do coeficiente de cultura (K_c) a partir do NDVI em áreas cultivadas com soja irrigada

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ABSTRACT

Vegetation indices obtained by remote sensing products have various applications in agriculture. An important application of the Normalized Difference Vegetation Index (NDVI) is obtaining the crop coefficient (K_c). The aims of this study were to analyze NDVI temporal profiles and to obtain K_c from the NDVI vegetation index product MOD13Q1. The analysis is based on the phenological stages of irrigated soybean crops in the municipality of Planura/MG during the 2010/2011 growing season. Areas planted with irrigated soybean were identified through fieldwork. Temporal series of the MOD13Q1 products were used to analyze NDVI, allowing the extraction of NDVI values for all points in the period studied. The NDVI temporal profiles showed a similar pattern to each other and corresponded to the crop cycle. The K_{cNDVI} values for the MOD13Q1 products were well correlated to the FAO K_c values (r^2=0.72). Thus, NDVI can be used as an alternative for obtaining crop coefficient (K_c).

Key words: *MOD13Q1, phenological stages, temporal profiles.*

RESUMO

Os índices de vegetação obtidos a partir de produtos de sensoriamento remoto apresentam várias aplicações na agricultura. Uma importante aplicação do índice de vegetação Normalized Difference Vegetation Index (NDVI) está relacionada à obtenção do coeficiente de cultura (K_c). Assim, o objetivo deste trabalho foi analisar os perfis temporais de NDVI e obter o K_c a partir do produto de índice de vegetação NDVI (MOD13Q1), baseado na análise dos estádios fenológicos da cultura de soja irrigada, no município de Planura/MG, safra 2010/2011. A identificação das áreas plantadas com soja irrigada foi feita através de pesquisa de campo. As séries temporais do produto MOD13Q1 foram utilizadas para analisar o NDVI, permitindo a extração dos valores de NDVI para todos os pontos no período estudado. Os perfis temporais de NDVI apresentaram um padrão semelhante entre si e quanto ao ciclo da cultura. Os valores de K_{cNDVI} variaram, em média, de acordo com os valores de K_c FAO, representando uma correlação linear (r^2) de 0,72 para o produto MOD13Q1. Assim, o NDVI pode ser usado como uma alternativa na obtenção do K_c.

Palavras-chave: *MOD13Q1, estádios fenológicos, perfis temporais.*

INTRODUCTION

Agricultural surveys are conducted mainly by using conventional methods and information available from government agencies. However, with advances in remote sensing devices, including vegetation index-based sensors such as TERRA/MODIS, the data thus obtained can be used to monitor agricultural areas.

For agricultural applications, the high periodicity provided by these vegetation indices products is of fundamental importance for analysis and monitoring of the phenological cycle of crops such as soybean over large areas (ESQUERDO & ZULLO, 2007; RUDORFF et al., 2007; WARDLOW et al., 2007; EPIPHANIO et al., 2010; PENG et al., 2013), which could vary from 75 to 210 days depending on the cultivar (GARCIA et al., 2007). Nevertheless, because the images are produced with different spatial and temporal resolutions, further studies are needed to assess the influence of these resolutions in the behavior of indexes from planting to harvest.

The Brazilian Agricultural Research Corporation (Embrapa) makes available the

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vegetation index product called Normalized Difference Vegetation Index (NDVI) with the purpose of facilitating and disseminating the use of TERRA/MODIS products() (ESQUERDO et al., 2010).

An important application of NDVI is that it helps determine the crop coefficient (K_c). Thus, determination of the crop's evapotranspiration (ET_c), which is based on Kc, on a daily basis is a key requirement for the adoption of agricultural management and for irrigation (BEZERRA et al., 2010).

K_c is related to phenological crop cycles and when it is associated to NDVI products, it provides an alternative in obtaining new K_c values (DUCHEMIN et al., 2006; SINGH & IRMAK, 2009; BERGSON et al., 2010; KAMBLE et al., 2013).

Therefore, the present study aimed to analyze the temporal NDVI profiles and obtain K_c values from the NDVI vegetation index product (MOD13Q1), based on analysis of the growth stages of irrigated soybean in the Municipality of Planura/MG, during the 2010/2011 harvest.

MATERIALS AND METHODS

The study area selected was the municipality of Planura, located in the "Mineiro" Triangle region (19° 57′ 22″ and 20° 10′ 10″ S, 48° 44′ 39″ and 48° 30′ 45″ W; total area: 318 km²). The municipality has a plateau relief, covered by a savannah-like vegetation (Brazilian "cerrado") and irrigated agriculture is common. Climate is humid (B2) with a moisture index of 32.8, which is attributable to the aridity index (la) of 13.7, according to the climatic classification of Thornthwaite (CARVALHO et al., 2008).

Areas cultivated with irrigated soybean by center-pivot sprinkler have been previously identified by PEREIRA et al. (2011), who conducted field work for the identification and collection of 11 points (punctual geographic coordinates) by using a GNSS receiver (Table 1), in farms located within the study area. Each point represented data including dates of planting and harvesting, and duration of different crop cycles. This information was then compared with NDVI data obtained from the MODIS sensor.

MOD13Q1 products were obtained from September 2010 to April 2011 (i.e., the 2010/2011 harvest season). These products were obtained from the Bank of MODIS Products supplied by Embrapa, in the Brazilian state basis, for Minas Gerais (ESQUERDO et al., 2010). Technical specifications of the MOD13Q1 products are presented in table 2.

The software Environment for Visualizing Images (ENVI), version 4.8 *(VISUAL INFORMATION SOLUTIONS, 2008)*, was used to import the MOD13Q1 products. A time series of MOD13Q1 products was constructed for comprehensive description and analysis of NDVI, thereby allowing determination of NDVI values, for a 16-day composite.

The relationship between K_c and NDVI values was evaluated by analysis of K_{cNDVI} and K_c FAO values obtained in the FAO56 manual (ALLEN et al., 1998). Thus, using the simple linear regression model (Equation 1) created by KAMBLE et al. (2013), it was obtained K_{cNDVI} values, which were subsequently compared to K_c FAO data for the analysis of phenological stages of irrigated soybean crop. In addition, according to KAMBLE et al. (2013), the procedure for quantifying crop coefficients from NDVI data (Equation 1) could find applications in other

Table 1 - Specifications of points regarding areas cultivated with irrigated soybeans in the municipality of Planura/MG.

Points	----------Irrigated Soybean----------		Area (ha)	Cultivar
	Latitude	Longitude		
1	-20.1324	-48.6960	40	'Gloriosa'
2	-20.0381	-48.5523	62.23	'RR 7211'
3	-20.0493	-48.5500	71.76	'RR 7211'
4	-20.0493	-48.5568	41.33	'RR 7211'
5	-20.0448	-48.5635	77.09	'Embrapa 48'
6	-20.0875	-48.5613	61.03	'Embrapa 48'
7	-20.1167	-48.6354	120.88	'BRS 232'
8	-20.1144	-48.6600	116	'Embrapa 48'
9	-20.1257	-48.6578	134.96	'BRS 232'
10	-20.1077	-48.6354	42	'BRS 232'
11	-20.1055	-48.5837	59.77	'Embrapa 48'

Table 2 - Technical specifications of the product MOD13Q1.

Satellite/sensor	Imaged range (km)	Spatial resolution (m)	Spectral resolution (nm)	Temporal resolution (days)	Radiometric resolution (bits)
TERRA/MODIS	2330	250	Red (620-670) NIR (841-876)	16	16

Source: Adapted from SHIMABUKURO & RUDORFF (2006).

regions worldwide to understand the regional consumption of water for irrigation.

$$K_{cNDVI} = 1.457\ NDVI - 0.1725 \quad (1)$$

To evaluate the comparison between calculated (K_{cNDVI}) and tabulated (K_c FAO) data, a simple linear regression was carried out to NDVI and K_c FAO. Statistical analyses involved using the *t*-test, at a 5% significance level (relative standard error, estimate, standard error, t-value, and p-value) for the parameters β_0 and β_1 of the regression equation, as well as for the coefficient determination (r^2) analysis.

RESULTS AND DISCUSSION

The NDVI temporal profiles of MOD13Q1 products for the irrigated soybean crop during the 2010/2011 harvest were grouped according to cycle duration (Figure 1). The soybean development period continued until November 17 for plots harvested on February 02, 2011, and February 18, 2011, with mean NDVI values of 0.77 and 0.84, respectively. As for the plot harvested on March 06, 2011, the mean NDVI value in the crop development period was 0.85, as on December 03, 2010. The maturation period started on January 01, 2011, for the plot harvested on February 02, 2011; and on January 17, 2011 for plots harvested on February 18, 2011 and March 06, 2011.

With regard to NDVI analysis of the MOD13Q1 products (Figure 1), it was reported that the duration of the soybean cycle was 109, 125, and 141 days, respectively, for the plots harvested on February 02, 2011; February 18, 2011; and March 06, 2011. According to GARCIA et al. (2007) the soybean cycles can range from 75 to 210 days depending on the crop, which indicated that the variation of soybean cycle observed in this study was within the expected period.

The dates of planting and harvest, and duration of the irrigated soybean cycle, based on the NDVI analysis of MOD13Q1 products were compared to field data collected by Pereira (2011), for the 2010/2011 harvest (Table 3). Thus, the field data analysis showed that planting occurred for most points at the end of the second fortnight of October, and NDVI/MOD13Q1 analysis revealed that planting occurred early in the second fortnight of October. The harvest occurred, for most points in February. However, even with the difference between the dates

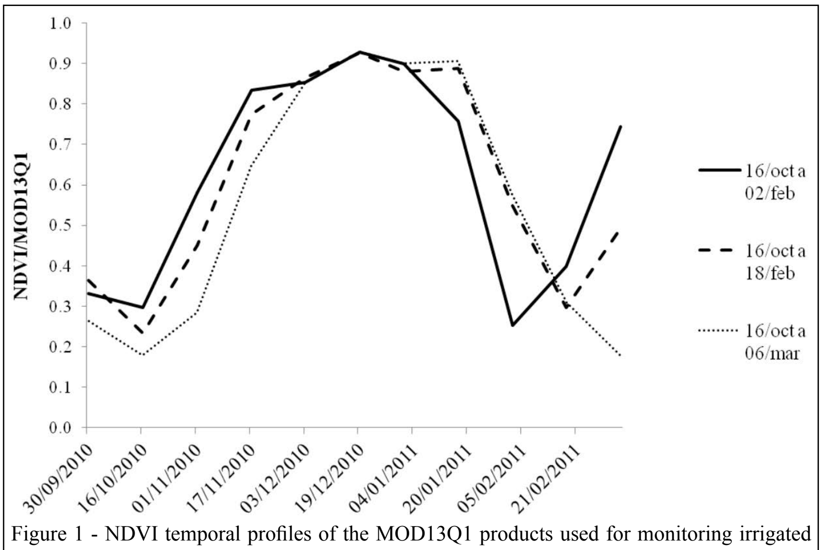

Figure 1 - NDVI temporal profiles of the MOD13Q1 products used for monitoring irrigated soybean crop during the 2010/2011 harvest season.

Table 3 - Comparison among dates of planting and harvesting, and duration of the irrigated soybean cycle in the analysis of field data and NDVI of the MOD13Q1 products.

Points	Field Data			Analysis of NDVI/MOD13Q1		
	Planting	Harvest	Cycle duration	Planting	Harvest	Cycle duration
1	10/10/2010	27/02/2011	140	16/10/2010	18/02/2011	125
2	21/10/2010	17/02/2011	119	16/10/2010	18/02/2011	125
3	21/10/2010	16/02/2011	118	16/10/2010	18/02/2011	125
4	12/10/2010	05/02/2011	116	16/10/2010	02/02/2011	109
5	14/10/2010	31/01/2011	109	16/10/2010	02/02/2011	109
6	22/10/2010	06/02/2011	107	16/10/2010	18/02/2011	125
7	27/10/2010	21/02/2011	117	16/10/2010	06/03/2011	141
8	22/10/2010	10/02/2011	111	16/10/2010	18/02/2011	125
9	27/10/2010	19/02/2011	115	16/10/2010	06/03/2011	141
10	27/10/2010	24/02/2011	120	16/10/2010	18/02/2011	125
11	24/10/2010	18/02/2011	117	16/10/2010	18/02/2011	125

of planting and harvesting, the duration of the cycle was similar in both analyses.

Analyses of NDVI temporal profiles of MOD13Q1 products (Figure 1) revealed little variation among the crops, which possibly indicates that the temporal profiles of the respective plantations showed a similar pattern with each other regardless of the difference between the harvest dates and type of crop adopted. This was observed by ESQUERDO & ZULLO (2007) in their analysis of NDVI temporal profiles that were generated using remote sensing data for the soybean crop in western Paraná.

Comparisons were made between K_{cNDVI} and K_c FAO in the analysis of phenological stages of irrigated soybean crop for the MOD13Q1 products. Thus, the NDVI, K_{cNDVI} and K_c FAO values (Table 4) are associated with the respective phenological stages of the irrigated soybean crop, based on the analysis of the MOD13Q1 product temporal profile, considering the planting from October 16, 2010 to February 02, 2011 (Figure 1). The stages were characterized on the basis of methodology proposed in the FAO-56 report (ALLEN et al., 1998). During the growth stage (stage II), K_c varied between 0.6 and 1.1, increasing up to stage III. After maturation (stage IV), K_c decreased until harvest (stage V), with values of 0.2 and 0.4, respectively, for K_{cNDVI}, and K_c FAO. When NDVI showed high values, K_c values ranged between 1 and 1.2 on average, which showed that the maximum evaporation (ET_c) can be higher than the reference

Table 4 - Phenological stages of irrigated soybean and their values of NDVI, K_{cNDVI} and K_c FAO, for the planting from October 16, 2010 to February 02, 2011, of the MOD13Q1 products.

Stages		Period			NDVI	K_{cNDVI}	K_c FAO
		Initial	Intermediary	Final			
I	Planting	16/10/2010	-	-	0.30	0.26	0.30
II	10 to 80% do VD*	-	01/11/2010	-	0.58	0.68	0.70
		-	17/11/2010	-	0.84	1.04	0.70
III	80 to 100% of VD*	-	03/12/2010	-	0.85	1.07	1.00
		-	19/12/2010	-	0.93	1.18	1.00
IV	Maturation	-	01/01/2011	-	0.90	1.14	0.70
		-	17/01/2011	-	0.76	0.93	0.70
V	Harvest	-	-	02/02/2011	0.25	0.20	0.40

*VD: Vegetative Development.

Table 5 - Statistics of the linear regression fit to NDVI and K_c FAO data, for the MOD13Q1 products.

----------MOD13Q1 (Relative Standard Error = 13.02%)----------				
Parameter	Estimate	Standard Error	t-value	P-value
β_0	0.1453	0.1318	1.102	<0.005
β_1	0.8024	0.1828	4.391	<0.005

evapotranspiration (ET_0), defining the well irrigated crop condition. This was observed by KAMBLE et al. (2013) in the analysis of K_c for irrigated crops in the state of Nebraska-USA.

Table 5 shows the statistics of the linear regression fit to NDVI and, K_c FAO, for the MOD13Q1 products.

Analyses by the *t*-test revealed that all parameters were statistically significant P<0.05), although the standard deviation was relatively high. This can be explained by the existence of several factors that directly affect the determination of K_c, such as relative humidity, wind speed, type of cultivar used, as well as the conditions that affect soil evaporation (ALLEN et al., 1998).

The coefficient of determination (r^2) was 0.79. This result corroborated those obtained by SINGH & IRMAK (2009) and KAMBLE et al. (2013), in the correlation between NDVI and K_c values for irrigated soybean with an r^2 value of 0.9 and 0.81, respectively, which highlighted the adequacy of the method to represent NDVI variation in the K_c data set.

CONCLUSION

These results showed that despite the low spatial resolution of the MODIS sensor, it was possible to follow the phenological cycle of the irrigated soybean crop, based on the analysis of the NDVI temporal profiles of the vegetation index. Thus, the NDVI temporal profiles of the MOD13Q1 products showed similar patterns to each other and regarding crop cycle.

Comparing K_{cNDVI} and K_c FAO values in the analysis of the phenological stages of the irrigated soybean crop, we reported that the calculated K_c values (K_{cNDVI}) varied, on average, according to the tabulated values of K_c (K_c FAO) and the coefficient of determination (r^2) has showed that variations in the K_c data set are explained by variations in NDVI. Therefore, NDVI may be used as an alternative tool for obtaining the crop coefficient (K_c).

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