DETERMINATION OF WINTER WHEAT CROP COEFFICIENT USING MODIS-DERIVED VEGETATION INDICES: A CASE STUDY OF THE AZADEGAN PLAIN, IRAN

DETERMINATION DU COEFFICIENT CULTURAL DU BLE HIVERNAL EN UTILISANT LES INDICES DE VEGETATION DERIVES PAR MODIS : ETUDE DE CAS DE LA PLAINE D'AZADEGAN EN IRAN

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ABSTRACT

The goal of this study is to investigate the relationships between adjusted crop coefficient values, recommended by FAO-56, and MODIS-derived vegetation indices for winter wheat. Different regression models are developed and validated over two study sites in the Azadegan Plain, located in the Western Iran. Among all of the studied models, those that were based on SAVI, MSAVI and PVI had the least RMSE. As Red and NIR portions of the spectrum are the key formative features of these indices, another simple equation was introduced for estimation of wheat K_c for the studied region. This equation also was successfully tested for a different location and a different cropping season, separately.

Key words: *Crop coefficient, Vegetation indices, MODIS, Winter wheat, Azadegan Plain (Iran).*

RESUME

L'objectif de cette étude est d'étudier les relations entre les valeurs ajustées du coefficient cultural, recommandées par la FAO-56, et les indices de végétation dérivés par MODIS pour le blé hivernal. Différents modèles de régression sont élaborés et validés sur deux sites d'étude dans la plaine d'Azadegan, située en Iran occidentale. Parmi tous les modèles étudiés, ceux qui étaient basés sur SAVI, MSAVI et PVI avaient le moindre RMSE. Les parties

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rouges et proche infrarouge du spectre étant les principales caractéristiques de formation de ces indices, une autre équation simple a été introduite pour l'estimation de Kc de blé de la région étudiée. Cette équation a également été testée séparément avec succès dans un site différent et dans une saison différente de culture.

Mots clés : *Coefficient cultural, indices de végétation, MODIS, blé hivernal, Plaine d'Azadegan (Iran).*

1. INTRODUCTION

Crop evapotranspiration (ET_c) is calculated by multiplying a crop coefficient (K_c) by the reference crop evapotranspiration, ET_o (Allen et al., 1998):

$$ET_c = K_c Et_o$$

Calculation method for K_c has been described by Doorenbos and Pruitt (1977). In this method, the growing season is separated into initial, rapid, midseason and late season growth stages. The values of Kc_{ini}, Kc_{mid} and Kc_{end} have been tabulated by FAO for various crops (Doorenbos & Pruitt 1977; Wright 1982; Allen et al. 1998). However, recommended FAO values for Kc_{mid} and Kc_{end} need some modifications when the average daytime minimum relative humidity is more or less than 45% and also the wind speed is not equal to $2 m.s^{-1}$. These tabulated K_c values are also discrete averages that belong to three points of a continuous growing period (namely initial, mid and end of growing season) and therefore, determination of daily crop coefficients needs interpolation from these K_c values. In addition, constant K_c values are generally used for a large command area such as a plain or a large irrigation district. Therefore, site specific designation of crop coefficients and consequently mapping of crop water requirement (ET_c) would be impossible due to lack of field or point wise K_c values. On the other hand, seasonal and local environmental conditions such as cold (chilling) and heat stresses can alter physiology of the crops and shift the growing stages forward or backward in the region. Also crop species and cultivars differ in their characteristics and sensitivities to environmental conditions (Hall, 2000) and therefore can affect the crop coefficient value and change it locally from one field to another field. In addition it is difficult to predict the correct crop growth stage dates for large population of crops and fields (Allen et al., 2007). These limitations force incorporation of novel advanced technologies for estimation and improvement of crop coefficients via monitoring of crop features in a proper spatio-temporal scale. In this regard, satellite remotely sensed (RS) technique would represent a strong, economical and efficient tool for monitoring of different crop features as like as K_c. Successful estimation of RS based K_c values would be attainable with the help of vegetation indices (Bhaskar et al, 1994; Hunsaker, 2005). Vegetation indices (VI) represent different combinations between red (R) and near infrared (NIR) portions of the spectrum (bands). Different researchers used RS based vegetation indices for estimation of crop coefficient (Gontia and Tiwari 2004; Jayanthi et al. 2007; Attarod et al., 2009; Bashir et al, 2006) and also crop water requirement for different scales (Ray and Dadhwal 2000; Mishra et al., 2005). This paper is aimed at estimation of winter wheat crop coefficient using different vegetation indices that have been derived from MODerate-resolution Imaging Spectroradiometer (MODIS) sensor.

2. MATERIALS AND METHODS

The study area is Dasht-e-Azadegan (DA) plain located at downstream part of KRB in Khuzestan province, west of Iran. The total area of DA is 334,000 ha, of which about 250,000 ha have been cultivated and used for agricultural purposes. Figure 1 shows the geographical setting of Dasht-e-Azadegan on basin, province and country maps. In this study, two sites were selected for observation and validation purposes, respectively. As shown in this figure, observation site (A) is located at the right side of the plain, while the validation site (B) is at the left. At each site, 15 wheat fields were selected with a relatively good spatial distribution.

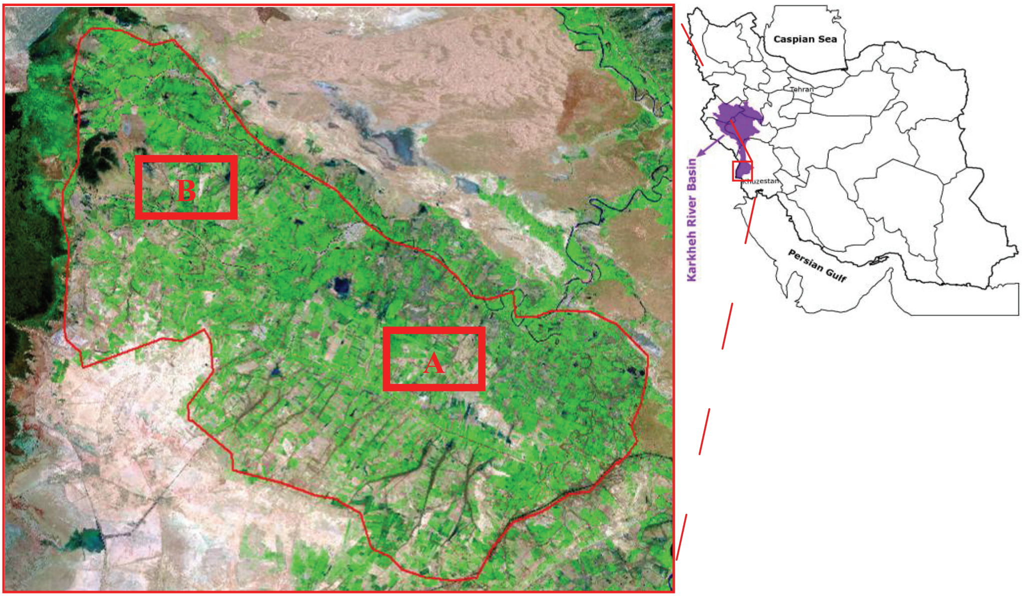

Fig. 1. The study area, Azadegan Plain in Khuzestan province, west of Iran and setting of two studied sites

In this study 13 cloud free images were taken for study area for derivation of nine well-known vegetation indices. These images were acquired from the MODIS sensor of Terra satellite and corresponded to a complete growing season of winter wheat in 2007-2008. Additionally, a time series including 12 cloud free images of same MODIS products were selected and pre-processed from 2006-2007 cropping season as validation dataset (Table 1).

Table 1. List of acquired MODIS images that were used in this study

Image number	Observation dataset (2007-2008)	Validation dataset (2006-2007)
1	26-Nov-07	18-Nov-06
2	12-Dec-07	04-Dec-06
3	23-Dec-07	29-Dec-06
4	03-Jan-08	04-Jan-07
5	17-Jan-08	25-Jan-07
6	02-Feb-08	15-Feb-07
7	09-Feb-08	05-Mar-07
8	14-Feb-08	10-Mar-07
9	05-Mar-08	19-Mar-07
10	14-Mar-08	04-Apr-07
11	21-Mar-08	13-Apr-07
12	25-Mar-08	17-Apr-07
13	02-Apr-08	-

After preparation of corrected reflectance bands (R and NIR), different vegetation indices (VI) were employed for description of winter wheat crop coefficient. Afterwards, corresponding VI values of all fields were extracted via crossing operation. Mean VI of fields was accounted as that VI of site 1 for each image acquisition time. Accordingly, a dataset including mean values of different vegetation indices for different time intervals was generated. Also winter wheat crop coefficients (K_c) were extracted from tabulated FAO 56 paper book recommends for initial, mid and end of cropping season. A correction for humidity also was performed to correct the K_c values to the environmental conditions of Azadegan plain (Allen et al, 1998). The new K_c values were linearly extrapolated for whole the cropping season days and therefore, corresponding K_c values of all image acquisition days were determined. Finally relationships between these adjusted K_c values and MODIS derived vegetation indices were investigated and the best fitted models were identified and evaluated.

All the generated models (adjusted FAO K_c versus MODIS VIs) were statistically evaluated via R^2, RMSE and MAE, as most frequently used statistical parameters. Validation of the models also was successfully performed for different spatial location as well as different growing season. For the first case, the generated models were tested on RS data of site number 2, located inside the DA, about 35 km far from the site number 1 (see figure 1). Cropping season in this procedure was as same as the model generation stage (2007-2008). In the latter procedure, the models were evaluated using data of 2006-2007 cropping season. In this stage a time series of MODIS data including twelve cloud-free images during wheat growing period were acquired and used.

3. RESULTS AND DISCUSSION

Table 2 shows linear correlation matrix (R^2) between adjusted FAO K_c and MODIS derived vegetation indices. As shown in this table, good significant correlations exist between crop coefficient and remotely sensed vegetation indices.

Table 2. Linear correlation matrix (R^2) between K_c and different MODIS derived vegetation indices

Index	DVI	IPVI	MSAVI	$MSAVI_2$	PVI	RVI	SAVI	WDVI	NDVI	Kc
DVI	1.00	0.80	0.99	0.86	0.99	0.81	0.98	0.99	0.80	0.89
IPVI		1.00	0.85	0.97	0.84	0.99	0.88	0.78	1.00	0.88
MSAVI			1.00	0.90	0.99	0.86	0.99	0.99	0.85	0.91
$MSAVI_2$				1.00	0.89	0.98	0.92	0.84	0.97	0.88
PVI					1.00	0.84	0.99	0.99	0.84	0.91
RVI						1.00	0.88	0.79	0.99	0.88
SAVI							1.00	0.98	0.88	0.92
WDVI								1.00	0.78	0.88
NDVI									1.00	0.88
Kc										1.00

Table 3 also shows the best fitted polynomial models for estimation of K_c via different vegetation indices. This table shows high correlation coefficients between K_c and MODIS derived vegetation indices in addition to low RMSE and MAE values. However, SAVI, MSAVI (modified version of SAVI) and PVI seem to be the best vegetation indices for estimation of crop coefficient in the studied site.

Table 3. Polynomial equations for calculation of winter wheat crop coefficient (Kc) using MODIS data (2007-2008 cropping season)

No.	Equation	RMSE	MAE	R^2
1	$K_c = -99.323*DVI^2 + 21.975*DVI + 0.1752$	0.11	0.09	0.92
2	$K_c = -73.856*IPVI^2 + 101.17*IPVI - 33.242$	0.12	0.09	0.90
3	$K_c = -37.148*MSAVI^2 + 13.926*MSAVI + 0.1259$	**0.10**	**0.08**	**0.93**
4	$K_c = -80.239*MSAVI_2^2 + 15.489*MSAVI_2 + 0.573$	0.11	0.08	0.91
5	$K_c = -349.82*PVI^2 + 24.605*PVI + 0.9488$	**0.10**	**0.08**	**0.93**
6	$K_c = -2.1172*RVI^2 + 8.3833*RVI - 6.9638$	0.12	0.09	0.90
7	$K_c = -23.325*SAVI^2 + 11.5*SAVI + 0.0769$	**0.10**	**0.08**	**0.93**
8	$K_c = -78.66*WDVI^2 + 20.103*WDVI + 0.111$	0.11	0.09	0.91
9	$K_c = -18.37*NDVI^2 + 13.615*NDVI - 1.117$	0.12	0.09	0.90

Interrelationships between vegetation indices (table 2) invest opportunities for integration of similarities and promise introduction of a novel and simpler indicator for description of crop K_c. Refer to table 1, main interrelated operators of these indicators are Red and NIR portions of the spectrum. However, data of these two bands were employed for generation of a simple remotely sensed based K_c equation. Following relationship shows the proposed simple equation for estimation of winter wheat coefficient instead of recommended FAO K_c:

$$Kc = 16 * NIR - 21 * Red + 0.5 \qquad (R^2_{adj} = 0.93,\ RMSE = 0.11,\ MAE = 0.09)$$

Figure 2 also shows overall trends of the proposed equation results and adjusted K_c values (FAO K_c) for 2007-2008 growing season at the site 1.

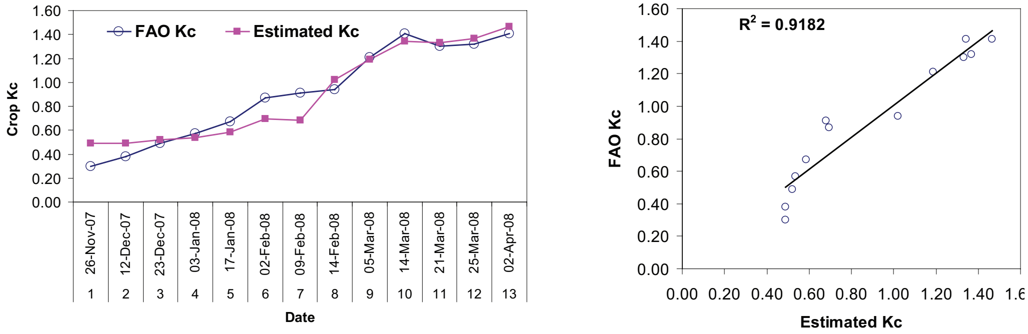

Fig. 2. Overall trend of estimated winter wheat crop coefficient (Kc) and also its correlation with recommended FAO Kc during the studied period (2007-2008 cropping season)

As it was mentioned before, validation of the models were accomplished for a different spatial location (site 2) and also a different period of time (2006-2007 cropping season). Table 4 shows results of these two validation procedures.

Table 4. Results of model validation for a different spatial location (site 2) and also a different cropping season (2006-2007)

Model	site 2			2006-2007 season		
	RMSE	MAE	R^2	RMSE	MAE	R^2
1: $K_c = f(DVI)$	**0.16**	**0.14**	**0.95**	0.21	0.17	0.84
2: $K_c = f(IPVI)$	0.41	0.34	0.65	**0.19**	**0.16**	**0.93**
3: $K_c = f(MSAVI)$	**0.18**	**0.15**	**0.95**	0.20	0.18	0.86
4: $K_c = f(MSAVI_2)$	0.34	0.30	0.51	0.41	0.38	0.49
5: $K_c = f(PVI)$	**0.19**	**0.17**	**0.94**	0.19	0.17	0.89
6: $K_c = f(RVI)$	0.39	0.32	0.48	**0.17**	**0.12**	**0.89**
7: $K_c = f(SAVI)$	0.20	0.17	0.94	0.20	0.18	0.89
8: $K_c = f(WDVI)$	**0.15**	**0.12**	**0.94**	0.21	0.17	0.81
9: $K_c = f(NDVI)$	0.41	0.34	0.64	**0.19**	**0.16**	**0.93**

Validations of the results show relatively high correlation coefficients (R^2) between FAO K_c and calculated K_c of the models for different location as well as different time period. Also validation of the 10th model, $K_c = f(\text{NIR}, \text{R})$, shows relatively good agreement between estimated RS based K_c and recommended FAO K_c. Figures 3 and 4 illustrate these agreements for site 2 and for 2006-2007 growing season, respectively.

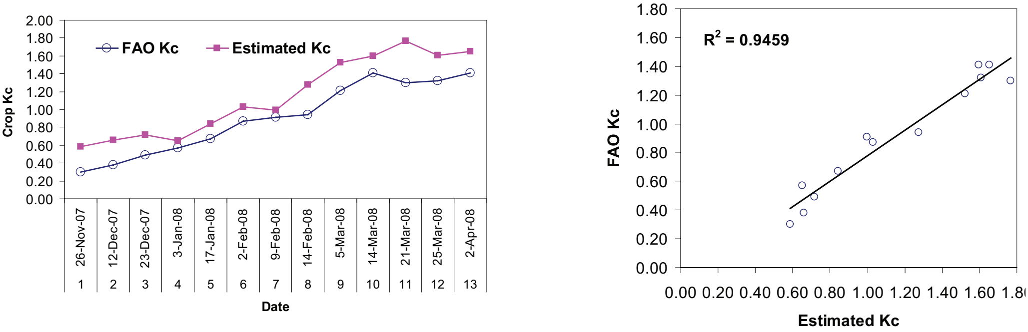

Fig. 3. Overall trend of estimated winter wheat crop coefficient (K_c = 16*NIR-21*R+0.5) and also its correlation with recommended FAO Kc in site 2 during 2007-2008 cropping season

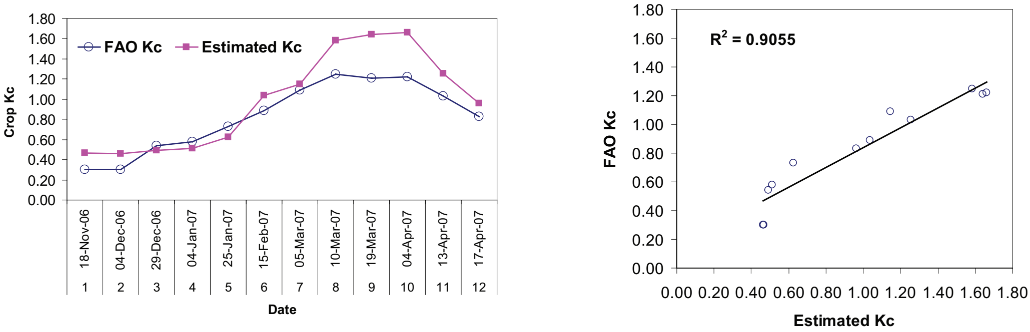

Fig. 4. Overall trend of estimated winter wheat crop coefficient (K_c = 16*NIR-21*R+0.5) and also its correlation with recommended FAO Kc during 2006-2007 cropping season

4. CONCLUSIONS AND RECOMMENDATIONS

This paper illustrates the potential of remotely sensed vegetation indices for estimation of winter wheat crop coefficient, suggested by FAO-56 paper. The main advantage of the proposed methodology is in the high spatio-temporal resolution and low cost of satellite imagery, which enables remotely sensed data to be used toward updating traditional crop coefficient curves and improving the management of water in semi-arid parts of the world. Updating the tabulated crop coefficients can be performed on a pixel by pixel basis, using the actual dates of agricultural practices obtained from space-borne imagery. In addition, within field variability caused by local stress factors can be depicted and accounted in the remote sensing approach.

The results showed that SAVI, MSAVI and PVI are the most preferred RS indicators for estimation of winter wheat crop coefficient. As Red and NIR portions of the spectrum are the key formative features of these indices, another simple equation was introduced for estimation of wheat K_c for the studied region. This equation also was successfully tested for a different location and a different cropping season, separately. However, generalization of the introduced equation is dependent on more evaluation and development for other agro-climatological conditions and also other remote sensing platforms (e.g. Landsat).

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