J. Agric. Res. Technol., 47 (3) : 381-388 (2022) https://doi.org/10.56228/JART.2022.47320

Estimation of Crop Coefficients Based on Normalize Difference Vegetation Index

Hamimu Idrisa[1], S. A. Kadam[2] and S. D. Gorantiwar[3]
Department of Agricultural Engineering,
Mahatma Phule Krishi Vidyapeeth, Rahuri - 413 722 (India)

Abstract

Crop coefficient is one of the most important parameters used for the estimation of crop evapotranspiration (ETc). Crop coefficient (Kc)-based estimation of crop evapotranspiration is most commonly used methods for irrigation water management. However, crop coefficient approach used for estimation ETc using the generalized crop coefficients mentioned in Irrigation and Drainage Paper No. 56 of the Food and Agricultural Organization of the United Nations can contribute to crop evapotranspiration estimates that are substantially different from actual crop evapotranspiration. The colinear relationship between the crop coefficient curve and a satellite-derived Normalized Difference Vegetation Index (NDVI) showed potential for modeling a crop coefficient as a function of the NDVI, which is also one among the methods used for estimation of ETc in irrigation water management. The present study was conducted with objectives to present the techniques and procedures to develop and estimates Kc based on vegetation index (NDVI) extracted from satellite data. The relationships between and NDVI and crop coefficients (Kc) of wheat and chickpea for corresponding months were developed. The regression models developed are: $(Kc)_{NDVI}$ = 6.3268*NDVI-1.4207 for wheat and $(Kc)_{NDVI}$ = 5.7866 * NDVI-1.6699 for chickpea. The models showed strong relationships with R^2= 0.86 and R^2=0.84 for wheat and chickpea, respectively. The model and techniques to develop and estimate crop coefficients can be used in other regions in the global, and hence estimate crop evapotranspiration. The crop coefficients (Kc) estimated based on NDVI are useful for irrigation scheduling, evaluating irrigation performance, irrigation water management, and estimation of water use efficiency.

Key words : NDVI, Crop coefficient, Sentinel, Remote sensing and GIS, Sina command area, India.

Crop coefficient is a ratio between the actual crop evapotranspiration (ETc) under the standard condition and the reference crop evapotranspiration (ETo). The Kc values integrate crop characteristics, which are, crop type, climate, and growing stages and integrated or averaged effects of evaporation from the soil surface (Allen *et al*. 1998). Crop coefficient (Kc) can be estimated by applying different methods, but mainly, conventional and remote sensing. The conventional method uses two approaches, the first is single Kc approach, this method integrates the relationship between ETc and ETo into a time-averaged Kc curve that does not separate evaporation and transpiration. The second, is the dual Kc approach, this approach separates Kc into the algebraic sum of a basal crop coefficient (Kcb) and a wet soil evaporation coefficient (Ke) and it account separately evaporation and transpiration (Allen *et al*, 1998). Basal crop coefficient (Kcb) is the ration between crop evapotranspiration (ETc) to the reference evapotranspiration (ETo) at a dry soil surface and with a little soil evaporation and at a potential rate of transpiration (Wright 1982; Allen *et al*., 1998, Allen; 2000; Singh and Irmak, 2015). The basal crop coefficient represents crop transpiration and their Kc values have to be adjusted for surface soil moisture condition. Between the two, a dual approach is preferred mostly for better estimation of Kc values, particularly for daily basis irrigation

1. Irrigation Engineer, Ministry of Water and Irrigation, Tanzania, 2. Associate Professor and 3. Head.

scheduling. It is very difficult to accurately estimate the crop coefficient by dual due to the dynamic of soil water content in space and time, which also be challenging tasks in the computation of crop evapotranspiration (ETc) especially in regional scale.

Single Kc approach has mainly used conventional methods by the researchers, but this method has some errors in estimating crop evapotranspiration ETc due to the empirical nature, especially when used with different climatic conditions away from where it or they were developed. For these reasons, Kc values have to be calibrated to overcome these errors.

Remote sensing is a powerful and effective technology that overcome all issues of conventional single crop coefficient method and the potential exists for estimating locally calibrated Kc curves. The Kc values derived from remotely sensed data provides information about the level of crop stand in the field (Bausch and Neale 1987; Singh and Irmak, 2015), crop development stage (Neale *et al*. 1989; Singh and Irmak, 2015), crop conditions (Bausch 1993; Singh and Irmak, 2015), water stress conditions (Bausch 1993; Singh and Irmak, 2015), and some of the management practices (Bausch and Neale 1987; Singh and Irmak, 2015).

Researchers have been using vegetation indices derived from multispectral remote sensed data or images to estimate crop coefficient (Kc) values at the field scale of corn (Bausch and Neale 1987; Bausch and Neale 1989; Bausch, 1995 and Singh and Irmak, 2015), wheat (Hunsaker *et al*. 2005 and Singh and Irmak, 2015), cotton (Hunsaker *et al*. 2003), and beans (Jayanthi *et al*. 2001 and Singh and Irmak, 2015). Singh and Irmak (2009) developed a regression model of type "Kcr = a NDVI + b" to establish the relationship between the NDVI and the ETo-based crop coefficients (Kc) for corn, soybeans, sorghum, and alfalfa. The results showed that, the coefficient of variation for NDVI and that of Kc of crops were lower during the midseason as compared to the early and late growing seasons. High values of coefficient of variation (CV) during early growing seasons can be attributed to differences in planting dates between the fields, whereas high CV during rate season can be attributed to differences in maturity dates of the crops, variety, and management practices. All crops showed a good relationship between Kc and NDVI except alfalfa. This approach is can be a useful tool for a large scale estimation of crop evapotran-spiration using the crop coefficient and reference evapotranspiration approach. Jorge *et al*. (2010) developed the linear relationship between NDVI and Kc considering maximum and minimum NDVI and corresponding maximum and minimum Kc values to determine the reflectance-based crop coefficients for corn. The relationship is Kcb-NDVI =1.37(NDVI)-0.017 with R^2=0.99. They converted this into grass-based Kcb using Kcb =1.36*(NDVI) - 0.031 relationship. The developed relationship facilitates computations of transpiration, considering only points over dry soil, but also without limiting transpiration. Water soil balance must be considered to get the important contribution of evaporation in crop coefficient from the soil to the crop coefficient during the days after irrigation or rainfall.

Kadam (2014a) developed linear, exponential, logarithmic, power, and second-order polynomial type of relationships between Kc, and NDVI by considering the growth and decline phases independently during the total crop growth period. The analysis showed that the best relationship of a second order polynomial with the maximum coefficient of determination (R^2) for sorghum being (KcL=0.354(NDVIspg)^2 + 0.504(NDVIspg) + 0.329, R^2= 0.974), chickpea being (KcL=1.147*(NDVIspg)^2 - 0.747*(NDVIspg) + 0.977, R^2 = 0.993) and wheat (KcL =

0.317*(NDVIspg)^2 + 0.562*(NDVIspg)+0.539, R2= 0.999). Pimpale *et al*. (2014a) estimated the spatial crop coefficient of chickpea using remote sensing and GIS. Using a standardized FAO56 Penman-Monteith approach for estimating ETc from reference evapotranspiration and tabulated generalized Kc. It was observed that, the pattern of vegetation index (VI) during the growing period is similar to the corresponding crop coefficient pattern. Also, a regression model was developed to establish the relationship between Normalized Difference Vegetation Index and the crop coefficients for chickpea crop, It was found that there exists a good linear relationship between Kc and NDVI (Kc_{PM} = 3.094 NDVI - 0.354) with the value of coefficient of determination (R^2) being 0.874 and a low root mean square difference. The results indicated that, the approach can be a very useful tool for estimation of spatial evapotranspiration of a large scale using the estimated crop coefficient. Kadam (2014 b) estimated Kcr, Kcrs, and Kca values for sorghum, chickpea, and wheat crops using "KcL-NDVIspg approach", "KcL-NDVIimg approach" and "Kc-analytical approach". The same 2 x 2 IRS LISS-III pixels selected for estimation of ETc were used to estimate Kc for these crops. The Kcr, Kcrs, and Kca values varied from 0.36 to 0.99, 0.35 to 0.96, and 0.76 to 1.0, respectively for sorghum. The Kcr, Kcrs, and Kca values varied from 0.17 to 1.20, 0.22 to 1.21, and 0.74 to 0.92, respectively for chickpea. The Kcr, Kcrs, and Kca values varied from 0.37 to 1.37, 0.29 to 1.38, and 0.33 to 1.01, respectively for wheat.

The main objective of the present study was to investigate the applicability of NDVI from Sentinel 2 satellite data to develop spatially representative of crop coefficients of wheat and chickpea grown in the Sina command area during *Rabi* season. Whereby the specific objectives were, to analyze the seasonal dynamics of crop coefficients (Kc) and the vegetation index (NDVI) and to develop a regression model to establish the relationship between the Kc values and vegetation index (NDVI) for wheat and chickpea crops.

Materials and Methods

Description of Study Area : The command area of the Sina Medium Irrigation Project is located between Ahmednagar and Beed districts, Maharashtra, India. The area lies between 74°57'0''E longitude and 18°49' 0''N latitude with 565m elevation. The study area is located in a scarcity area, having a mean daily maximum and minimum temperature of 39.4°C (May) to 12.6°C (December) respectively. The area has wind speed varying from 4.95 to 17.55 km h^{-1}, and is maximum during July month. The relative humidity (RH) varies from 20.5 to 81.5 percent and is maximum during August. The maximum, minimum, and average rainfall observed at Nimgaon Gangarda located within the command is 1258, 392, and 503mm, respectively. The study area has a total command area of 22468.35 ha. The soils in the command are classified as fine (clay, silt clay) and is distributed in about 42 percent area, moderately fine (clay loam) in 43 percent and medium (silt loam and loam) in 15 percent of the area. The command area comprises with gentle to moderate slope, very gentle to gently sloping pediment plains and inner terraces. The major crops grown in the Sina command area during *Rabi* season are wheat, chickpea, sorghum, onion, pigeon pea, sugarcane, cotton, and other mixed crops. The main source of water for irrigation is Sina Dam constructed in 1985 and it has a Gross capacity of 67.95 million cubic meters. The *Rabi* season in the study area starts from October and ending in April.

Data and resources used in this study

Remote sensing data : The Sentinel 2 satellite data were used as a primary input in this study. Sentinel 2 have a wide range of applications related to Earth's land and coastal water. This satellite mission provides information concerning agricultural and forestry activities helping in managing food security. Sentinel satellite images can be used to determine various plant indices including, leaf area chlorophyll and water content indexes. It is particularly very important for effective yield prediction and applications related to Earth's vegetation, as well as monitoring of the plant growth (Source: https://en.wikipedia.org/wiki/Sentinel-2). Spatial, spectral, and temporal resolution of satellite images are very important for the studies dealing with crop water requirements. Many studies on irrigation water management have indicated that Sentinel-2 has a high resolution which is applicable for hydrological purposes. These sensors are suitable for agricultural areas with medium to big fields due to their high spatial resolution. Sentinel-2 covering the part of the study area have been used in the present work. Sentinel 2 satellite has the following features; Multi-spectral data with 13 bands in the visible, near-infrared and short wave infrared part of the spectrum, systematic global coverage of land surfaces from 56°S to 84°N, coastal waters, and all of the Mediterranean Sea, revisiting every 5 days under the same viewing angles. At high latitudes, Sentinel swath overlap and some regions will be observed twice or more every 5 days, but with different viewing angles, has also spatial resolution of 10 m, 20 m and 60, 290 km field of view and is free and open data policy

Sentinel-2 satellite image has been downloaded from the United States Geological Survey website: https://earthexpolorer.usgs.gov acquired during the *Rabi* season of 2016-17. The details of the band characteristics and date of acquisition are presented in Table 1.

The acquisition of the satellite data considered crop data which includes crop phenology and canopy characteristics such as development stages and height (FAO – 56), crop area, and irrigation practices of the crops. Since the vegetation index (NDVI) of the crops increases from the initial to the mid-stage and decrease from mid to late final stage. The initial (stage1) of wheat takes 10-15 days, whereby development stage (stage 2) is 25 days, mid-season on stage (stage 3) is 50 days, late-season stage (stage 4) is 30 days, and the total height of wheat crop is 90-100 cm. For chickpea the initial stage (stage 1) have 10 days, whereby development stage (stage 2) takes 30 days, mid-season on stage (stage 3) takes 50 days and late-season stage (stage 4) takes 10 days, the total height of the crop ranges from 20-50 cm.

Ground truth data : The ground truth data collected using Hand GPS during *Rabi* season of 2016-17 were used in the identification of crops and aiding in the selection of training sets for image classification.

Software used : ArcGIS software v10.2 and Erdas Imagine v15 were used in this study, whereby ArcGIS 10.2 software was used to generate the GIS database and generation of the different thematic maps, and Erdas Imagine in this was used for generation of NDVI of Sina command area.

Methodology : The procedures and the techniques followed to develop thematic and derived maps, and hence estimation of crop coefficients of wheat and chickpea crops are explained here below;

Creation of False Composite Color (FCC) : Sentinel 2 satellite images were

Table 1. Acquisition dates of Sentinel-2 images used for the study covering crop growth stages

Date of pass	Crop growth stages
22/10/2016	Stage 1
21/11/2016	Stage 2
21/12/2016	Stage 3
20/01/2017	Stage 3
09/02/2017	Stage 4

processed in ArcMap v10.2 software to create False Composite Maps for *Rabi* seasons of 2016/17 by combining bands 2, 3, 4, and 8. The main objective of creating FCC is to increase spectral separation and enhances the interpretation and classification of features in the images. The FCC map created from an image acquired in 21st December 2016 were used to generate land use land cover map of the study area.

Image classification and selection of training sets : Image classification is the process of extracting information which categorized into classes from a multiband raster image. The resulting raster image is used to create raster maps. The idea of image classification is that different features on the surface of the earth have a different properties of spectral reflectance and emittance, in which their recognition is done through the classification processes. In other words, image classification process involves categorizing all pixels in an image or raw remotely sensed satellite data to obtain a given set of labels or land cover themes (Lillesand and Keifer, 1994; Mansor and Shafri, 2013).

In this study, supervised classification techniques were applied by selecting maximum likelihood. Whereby sample pixels in an image were selected as a representative of other pixels in ArcMap v10.2 software by taking training sets with the help of ground truth data taken by hand GPS in October 2016 and also with the help of NDVI map. The training set selections were taken according to major crop production in the study area during the *Rabi* season. Major crops like cotton, sorghum, sugarcane, chickpea, maize, onion, wheat, mixed crops, and other features such as water bodies, built-up land, fallow land, etc. in the study area were taken into considerations. Finally the crop types were identified under supervised classification and the cropping pattern map was successfully created. Later crop-wise distribution maps were created through reclassification of cropping pattern map and conversion of a raster image to a polygon. The areas under wheat and chickpea (polygons or distribution maps) were extracted to be used in creating crop-wise NDVI maps.

Estimation of NDVI from satellite data: NDVI stands for Normalized Difference Vegetation Index, which normally gives vegetative proportions in an area. NDVI is also a widely used graphical indicator of photosynthetically healthy green vegetation and used to estimate biophysical parameters of vegetation cover. Normalize Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared and red light. The NDVI ranges from -1 to +1, whereby negative value indicates the presence of water in the area and positive value close to +1 indicates the presence of dense green and healthy vegetation. And NDVI value close to zero, indicates an urbanized area, fallow, and or wasteland.

The False Composite Color (FCC) maps were processed in Erdas Imagine v15 software to extract vegetation information. Band 8 which is near-infrared and band 4 red light of sentinel 2 were used in the estimation of NDVI. The NDVI was calculated from the following formula;

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

where, NIR = near-infrared band 0.842 μm and R = red band 0.665μm

The distribution maps (polygons) of wheat and chickpea were then used to get crop-wise NDVI maps through masking. The crop-wise NDVI values for the entire growth of the wheat and chickpea crops were created.

Development of Kc and NDVI relationships: The crop coefficient equations for wheat and chickpea crops developed as per the growth stages recommended by FAO and Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, and which is denoted by Kct, were used to compute daily crop coefficients for wheat and chickpea. The calculated Kc values were used to develop the relationship with the crop-wise NDVI values of each crop. The empirical equations of wheat and chickpea are presented here below;

Wheat: $Kct=10.092(t/T)^5 - 20.039 (t/T)^4 + 12.871 (t/T)^3 - 7.0936 (t/T)^2 + 3.7412(t/T) + 0.5942$ 2)

Chickpea: $Kct=2.3266(t/T)^5 + 8.5503(t/T)^4 - 24.573 (t/T)^3 + 14.708 (t/T)^2 -1.8175(t/T) + 0.8965$ (3)

where; Kct = Crop Coefficient on t^{th} day, t = Day after sowing (DAS) and T = Total crop growth period (days)

The relationship between the estimated crop-wise NDVI and daily Kct values for wheat and chickpea crops was developed and the resulting equation is denoted as Kc_NDVI. The NDVI values used to develop a relationship with Kc can describe the canopy biophysical parameters. The linear, logarithmic, exponential, power, and second-order polynomial type of relationships were developed between Kc values estimated from equations 2 and 3 above and NDVI values estimated from satellite data. The relationships were developed by considering a single growth phase for crops during the growth period. The best relation was selected based on the maximum value of the coefficient of determination (R^2).

Results and Discussion

Estimation of crop-wise NDVI : The crop-wise NDVI values for wheat and chickpea crops derived from Sentinel-2 satellite data during the growth period are presented in Table 2, for the respective date of the satellite overpass.

The output from the ArcGIS software shows that, the NDVI values under wheat in October varied 0.24-0.76 with an average of 0.40, November ranged from 0.24-0.79 with an average of 0.41, in December the NDVI values ranged from 0.29-0.79 with the average of 0.41 and in January the NDVI values varied from 0.24-0.69 with the average of 0.32, similarly the NDVI values for chickpea in November ranged from 0.30-0.77 with the average of 0.46, December values ranged from 0.30-0.76 with the average of 0.56, January NDVI values ranged 0.29-0.70 with an average of 0.40 and February ranged 0.31-0.67 with the average of 0.32. The average values of NDVI were used in the development of a relationship with Kct.

The spatial distribution of NDVI values for the wheat and chickpea are shown in Fig. 1 and Fig. 2, respectively.

Development of Kc-NDVI relationships: The relationships between Kc and NDVI for different crops were developed using the values presented in Table 3. The analysis between Kc and NDVI was carried out over the entire growth period of the crops. The best fit linear relationships were developed for both wheat and chickpea. The Kc-NDVI model relationships developed are presented below;

For wheat: $Kc_{NDVI} = 6.3268*NDVI - 1.4207$ (4)

For chickpea: $Kc_{NDVI} = 5.7866*NDVI - 1.6699$ (5)

Table 2. NDVI values for wheat and chickpea crops during growth period - *Rabi* season 2016-17

Crop	DAS	NDVI
Wheat	39	0.40
	68	0.41
	98	0.41
	118	0.32
Chickpea	29	0.46
	59	0.56
	89	0.40
	109	0.32

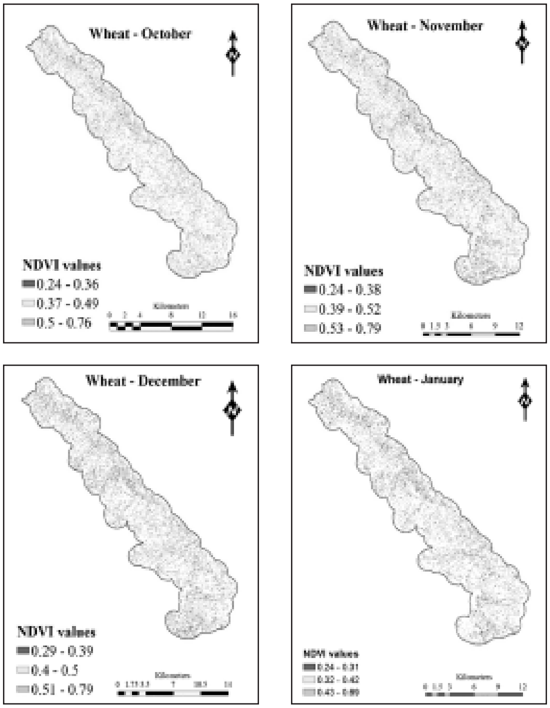

Fig. 1. Spatially distributed NDVI of wheat

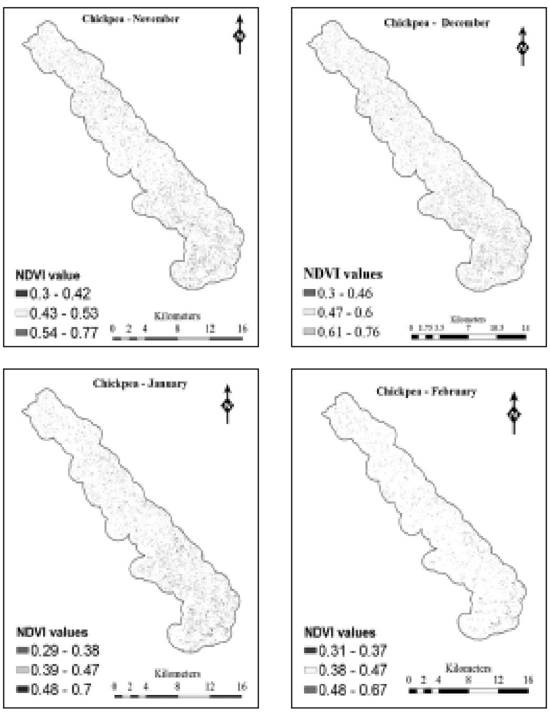

Fig. 2. Spatially distributed NDVI of chickpea

Table 3. NDVI, Kc_t values for wheat and chickpea crops

	NDVI	Kc_t
Wheat	0.40	0.84
	0.41	1.32
	0.41	1.29
	0.32	0.65
Chickpea	0.46	0.97
	0.50	1.20
	0.39	0.65
	0.32	0.15

There is a good relationship between Kct and NDVI as the coefficient of determination for wheat (R^2 = 0.7026) and that of chickpea (R^2 = 0.9832), meaning that the model developed can be used to determine the Kc values for wheat and chickpea, respectively. The models were used to estimate the spatially distributed Kc values for wheat and chickpea for the *Rabi* season of 2016-17.

After the development of Kc and NDVI relationships, crop coefficients Kc based on NDVI of different dates were generated using the Raster calculator available in ArcGIS software. The output from the software showed that, the estimated Kc values increased as the crops grow up and decrease as crop became matured and dried. The coefficient of determination between the spatially estimated Kc and that of the conventional method was 0.84 and 0.89 for wheat and chickpea crops, respectively, for the data obtained during *Rabi* season 2016-17.

Conclusion

The present study developed the linear regression models for wheat (Kc_{NDVI} = 6.3268*NDVI - 1.4207) and chickpea (Kc_{NDVI} = 5.7866*NDVI - 1.6699) to establish the general relationship between the vegetation index (NDVI) from Sentinel 2 satellite data and the crop coefficients (Kc). Also, NDVI is specific to crop at each pixel and Kc represents the actual crop growth conditions in the field. Sentinel 2 satellite images were used to estimate crop coefficients of wheat and chickpea, spatially and temporally during the *Rabi* season 2016-17. Coefficients of determination R^2 for all crops explains the strength of the model developed, in which all models developed were very strong.

NDVI is an indication for the presence of health and density vegetation cover and the plant vigor, and it also measures the surface reflectance and gives a quantitative estimation of vegetation growth and biomass (Wu, Li, Wang, and Yan, 2016), meaning that it captures most of the variation observed in crop coefficients, under no water stress condition. The coefficient of determination of the models developed are 0.70 and 0.98 for wheat and chickpea. Whereby when tested with the satellite images of *Rabi* season 2016-17, the coefficient of determination between values obtained through conventional equations and those of satellite were 0.84 and 0.89 for wheat and chickpea, respectively.

The techniques and procedures used to develop these models and quantifying crop coefficients from NDVI which are presented in this study can be useful in other regions in the global, for managing irrigation water. It is concluded that, the crop coefficients (Kc) estimated based on NDVI are useful for irrigation scheduling, evaluating irrigation performance, irrigation water management, and estimation of water use efficiency.

References

Bausch, W. C. and C. M. U. Neale. 1987. Crop coefficients derived from reflected canopy radiation: A concept. Transactions of ASAE. 30(3): 703-709.

Bausch, W. C. and Neale, C. M. U. 1989. Spectral inputs improve corn crop coefficients and irrigation scheduling. Transactions of ASAE. 32(6): 19011908.

Bausch, W. C. 1993. Soil background effects on reflectance-based crop coefficient for corn. Remote Sensing of Environment. 46 (2): 213-222.

Calera, A., Martinez, C. and Melia, J. 2001. A procedure for obtaining green plant cover: relation to NDVI in a case study for barley. International Journal of Remote Sensing. 22: 3357-3362.

FAO. 1992. Guidelines for predicting crop water requirements. Irrigation and Drainage paper 24, Food and Agricultural Organization of United Nations, Rome.

Farg, E., Arafat, S. M., Abd EL-Wahed, M. S., and EL-Gindy, A. M. 2012. Estimation of evapotranspiration (ETc) and crop coefficient (Kc) of wheat, in the South Nile Delta of Egypt, using integrated FAO-56 approach and remote sensing data. The Egyptian Journal of Remote Sensing and Space Sciences, 15: 83-89.

Pakhale, G., Gupta, P., Nale, J. 2010. Crop and Irrigation Water Requirement Estimation by Remote Sensing and GIS: A case study of Karnal district, Haryana, India. International Journal of Engineering and Technology 2(4): 207-211.

Pimpale, A. R., Rajankar, P. B., Wadatkar, S. B., Ramteke, I. K. 2014. Determination of spatial crop coefficient of chickpea using remote sensing and GIS. AIJRFANS, 14-349.

Gontia, N. K. and Tiwari, K. N. 2010. Estimation of Crop Coefficient and Evapotranspiration of Wheat (*Triticum aestivum*) in Irrigation Command Using Remote Sensing and GIS. Water Resour Manage 24(2010): 1399-1414.

Kadam, S. A. 2014. Spatial decision support system based on remote sensing approach for irrigation water management. Unpublished Ph.D. thesis submitted to Mahatma Phule Krishi Vidyapeeth, Rahuri. 2014.

Kadam, S. A, Gorantiwar, S. D., Das, S. N., and Joshi, A. K. 2015. Estimation of actual evapotranspiration by remote sensing. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Special Issue 4.

Kamble, B., Irmak. A., and Hubbard, K. 2013. Estimating Crop Coefficients Using Remote Sensing-Based Vegetation Index. Remote Sensing (ISSN. 2072-4292). (5):1588-1602.

Singh, R. K. and Ayse Irmak. 2009. Estimation of crop coefficients using satellite remote sensing. ASCE Journal of Irrigation and Drainage Engineering. 135:597.