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REMOTE SENSING INDICES FOR CROP WATER MANAGEMENT

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ABSTRACT

Remote sensing has become a very powerful tool for crop condition assessment and management. The objective of this study was to understand the effectiveness of basal crop coefficient (Kcb) values estimated from remote sensing and their application in real time crop water requirement. During the crop growing season, the value of Kc for most agricultural crops increase from a minimum value at emergence in relation to change in canopy development, until a maximum Kc is reached at full canopy cover. The study was carried out for the Cotton crop in Sirsa district of Haryana. A spectral index such as SAVI (Soil Adjusted Vegetation Index) and Fractional Vegetation Cover (Fc) was used to estimate Kcb value. High spatial resolution Landsat TM 5 images were used to generate a spectral profile of NDVI, SAVI, and Fc for different crop cover. Using, available empirical models from literature, crop coefficient was derived from SAVI values. Reference Crop Evapotranspiration (ET0) was estimated using Blaney-Criddle Method, taking weather data from ICAR Research Station Observatory. The crop coefficients derived from Remote Sensing data were used along with ET0 values to estimate crop evapotranspiration (ETc). The result showed that the spatial distribution of seasonal ETc varied depending upon sowing date and other condition. The estimated crop evapotranspiration (ETc) pattern was compared with fractional vegetation cover. Spatial distribution map of cotton ETc, basal crop coefficient, and fractional vegetation cover showed areas of high and low water demand. This work can help in water management practices for better irrigation management.

KEYWORDS: Crop Evapotranspiration (ETc), SAVI, NDVI, Basal crop Coefficient, Fractional vegetation Cover and remote sensing.

INTRODUCTION

Cotton is an important fiber crop in the world [1].Being a warm climate crop, it is grown dry sub–tropical climates having adequate rainfall and ample sunshine during the growing period. Air temperature of 32^0 C to 35^0 C is considered optimum for normal growth of cotton plants with a minimum and maximum range 16^0 C to 38^0 C [2]. The major cotton producing countries are china, India, USA, Pakistan, Brazil and Uzbekistan which contribute approximately 80% of world's cotton production. The basic aim of efficient water requirement strategy is not only to irrigate crop to avoid any physiological stress but also to ensure against the application of excess water. Availability of soil water encourages crop growth leading to high water use while insufficient water content in soil leads to wilting or death of crop plants [3].Multispectral vegetation indices computed as differences, ratios or a linear combination of reflected light in visible and near infrared spectrum have been found to be closely related to several crop growth parameters [3-4]. The simple ratio and normalized difference vegetation index have used for estimating plant cover, green plant biomass and leaf area index. The potential application of remotely sensed vegetation indices as near real-time surrogates for crop coefficient estimate was proposed over two decades ago by [5], Who pointed out the similarity between the seasonal pattern of vegetation indices for wheat and that of wheat crop coefficient. Multispectral vegetation indices computed from crop canopy reflectance measurement were demonstrated to function effectively as near real time surrogates for corn [6-7] beans [8] and cotton [9]. Major benefits of vegetation indices based crop coefficient is the ability to account for variations in plant growth due to abnormal weather condition and improved irrigation scheduling due to better estimation of water use and more appropriate timing of irrigation. Normalized difference vegetation index and soil adjusted vegetation index are the two predominant vegetation indices for estimating crop coefficient. Crop coefficient can be estimated from spectral measurement because the basal crop coefficient (K_{cb}), the component of the crop coefficient that represent transpiration, and the vegetation indices are both sensitive to leaf area index (LAI) and ground cover fraction (F_c) [10]. Some authors have suggested that relationship between K_{cb} and Vegetation indices are linear [6, 11-12] but others have found a nonlinear relationship [13-14]. According to theoretical relations derived by [10], the linearity of this relationship depends on the crop architecture and definition of vegetation index applied.

[15] have used vegetation indices to derive K_{cb} value for wheat crops, and found that close agreement between simulated and measured crop evapotranspiration (ET_c), coefficient of determination and efficiency was larger than 0.85 and RMSE was around 0.40 mm per day. [6] (W. Bausch and C. Neale 1987) outlined the potential for developing crop coefficient from reflected canopy radiation by relating agronomic variable that effect evapotranspiration (ET) with spectral data obtained over plant canopy. They showed that the seasonal curve of the normalized vegetation index (NDVI) described by [16] for corn was similar to its K_{cb} curve calculated from [2].

ET is a combined term for evaporation; water lost from the soil surface, and transpiration, water is diffused into the atmosphere from a plant surface through stomata. Energy is needed for water to evaporate either from soil or plant surfaces. Evapotranspiration is expressed in units of water depth per unit time.

Transpiration is an important variable for efficient planning and management of irrigation water in arable crops.it represents a major part of the consumptive use of water supplied through irrigation and rainfall [17]. Crop water requirement varies widely during the growing season mainly due to changes in canopy characteristics and climatic conditions [18] . A fundamental requirement for accurate irrigation scheduling is the determination of actual crop evapotranspiration (ET_c) for each day during the growing period. A practical and extensive applied method for estimating ETc is crop coefficient (K_c) approach [18-19], in which an experimentally developed dimensionless crop coefficient (K_c) is multiplied to reference crop evapotranspiration (ET_0) to compute crop evapotranspiration (ET_c). Values of K_c determined for most agricultural crops will vary in relation to change in vegetative growth until the effective full cover is attained. After full canopy cover, the K_c will tend to decline, the extent of which is primarily dependent on the particular growth characteristics of the crop [20-21]. K_c can be estimated from spectral vegetation indices since both of them are related to leaf area index and fractional ground cover [2]. Crop coefficient (K_c) based estimation of ET_c is one of the most commonly used methods for irrigation water requirement at the field scale. Crop evapotranspiration (ET_c) can be calculated using the K_c value defined as the ratio of crop evapotranspiration to reference evapotranspiration (ET_0) defined by weather data [22], During the crop growing season, the value of K_c for most agricultural crops increase from a minimum value at emergence in relation to change in canopy development, until a maximum K_c is reached at full canopy cover. A crop coefficient curve is the seasonal distribution of K_c often expressed as a smooth continuous function or some other time-related index. Crop coefficient primarily depends on the dynamics of canopies, light absorption by a canopy, canopy roughness which affects turbulence, crop physiology, leaf age and surface wetness [23].As crop canopy develops, K_c value increases, until most of the evaporation come from transpiration and soil evaporation is a minor component. This occurs because the interception of radiant energy by foliage increases until the lightest is intercepted before it reaches the soil. The normalized difference vegetation index has been used extensively for vegetation monitoring, crop yield assessment and drought detection [21, 23-24]. Increase in crop coefficient caused by higher temperature results in a decrease in soil water and a decline of NDVI, while dense vegetation induces more evapotranspiration and lowers the land surface temperature [25] or the transpiring is cooler [14].There was a strong correlation between the NDVI estimated K_c and measured K_c with r^2 greater than 0.90 [32]

STUDY AREA

Sirsa district in Haryana state, India, lies between $29^0$14' and 30^0 North latitude and 74^0 29' and 75^0 18'East longitudes, forming the extreme west corner of Haryana shown in Fig.1. It is bounded by Punjab in the north, Ganga Nagar district of Rajasthan in the west and Hisar district in the east. It lies in the arid hot agro-ecological zone of India. In Kharif season, major crops in Sirsa are cotton and rice. Sirsa falls under the northern cotton belt. The time of cotton sowing is from May to June and the picking is done in the month of October-November.

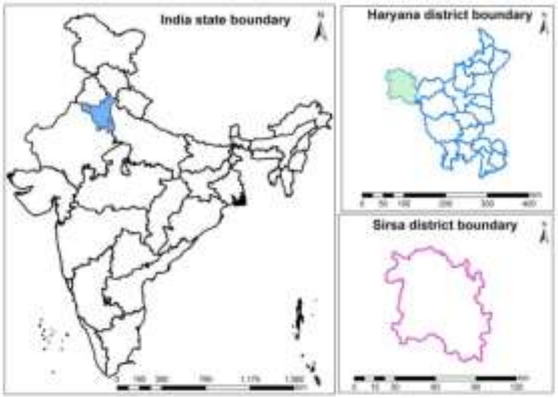

Figure 1: Map of study area

MATERIAL AND METHODS

3.1 Data Description

Daily meteorological data were collected from AWS station, Central Institute of Cotton Research, Sirsa from July to November 2009. The air temperature was used to compute Reference crop evapotranspiration (ET_o). In addition to meteorological data, high spatial resolution images acquired by Landsat were collected during the growing season of cotton. Total 8 images were used in the study. Preparation of remote sensing indices and description of the formula used for K_{cb} estimation, crop evapotranspiration were discussed in section 2.3.

3.2 Generation of remote sensing database

3.2.1. DN to radiance Conversion

$$L\lambda = \frac{(\mathrm{Lmax} - \mathrm{Lmin})}{(\mathrm{Qcalmax} - \mathrm{Qcalmin})} * (\mathrm{DN} - \mathrm{Qcalmin}) + \mathrm{Lmin} \quad \ldots (1)$$

$L\lambda$ = spectral radiance at sensor's aperture for each band ($Wm^{-2}Sr^{-1}\lambda^{-1}$)
Lmax = maximum spectral radiance for each band
Lmin = minimum spectral radiance for each band
Qcalmax = Maximum Digital number Value
Qcalmin = Minimum Digital number Value

3.2.2. Atmospheric correction for retrieving surface reflectance

The FLAASH (Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes) atmospheric correction module in ENVI 4.4 software was used to convert radiance images into reflectance values for each pixel.

3.2.3. Preparation of Remote sensing indices

Three Vegetation indices (VI) were considered in this study, the normalized Vegetation difference index, [26].Normalized Difference Vegetation index (NDVI) is a measure of the amount and vigor of the vegetation at the surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. NDVI is a good indicator of green biomass, leaf area index, and patterns of production.

$$\mathbf{NDVI} = \frac{(\mathbf{NIR} - \mathbf{RED})}{(\mathbf{NIR} + \mathbf{RED})} \quad \ldots\ldots\ldots \ (2)$$

Where NIR = reflectance in near infrared band
RED = reflectance in Red band
Soil Adjusted Vegetation index [27]

$$\mathbf{SAVI} = \frac{(\mathbf{NIR} - \mathbf{RED})}{(\mathbf{NIR} + \mathbf{RED} + \mathbf{L})} * (\mathbf{1} + \boldsymbol{L}) \quad \ldots\ldots \ (3)$$

Where NIR = reflectance in near infrared band
RED = reflectance in red band
L = soil normalization factor, generally considered to be 0.5

Fractional Vegetation Cover [28]

$$\mathbf{Fc = 1 - \frac{(SAVImax - SAVI)}{(SAVImax - SAVImin)}} \text{ ...... } \mathbf{(4)}$$

Where Fc = Fractional vegetation cover $SAVI_{max}$ =Maximum value of SAVI associated with dense vegetation
$SAVI_{min}$ =Minimum value of SAVI associated with bare soil
Formula used in this study for the estimation of basal crop coefficient K_{cb} is taken from [28]

$$\mathbf{Kcb = Kcb, max * \frac{(SAVI - SAVImin)}{(SAVImax - SAVImin)}} \text{ .... } \mathbf{(5)}$$

Where K_{cb} =Basal crop coefficient
K_{cb},Max=basal crop coefficient at effective full ground cover, 1.30 [29]
SAVImax=Maximum value of SAVI associated with dense vegetation
SAVImin=Minimum value of SAVI associated with bare soil.

3.2.4. Computation of reference crop evapotranspiration (ET_0)

The blaney-criddle method was used to compute reference evapotranspiration (ET_o), this method use only air temperature. Reference evapotranspiration ET_o (mm/day) can be calculated as

$$\mathbf{ET_o = p*(0.46\ Mean +8)} \text{ .... } \mathbf{(6)}$$

ET_0=Reference crop evapotranspiration (mm/day) as an average for a period of 1 month
Tmean=mean daily temperature (^{0}C)
P=mean daily percentage of annual daytime hours

3.2.5. Estimation of crop evapotranspiration

$$\mathbf{ET_c = K_{cb} * ET_o} \text{ .... } \mathbf{(7)}$$

Where
ET_c = crop evapotranspiration (mm/day)
K_{cb}-basal crop coefficient based on remote sensing
ET_o=Reference crop evapotranspiration

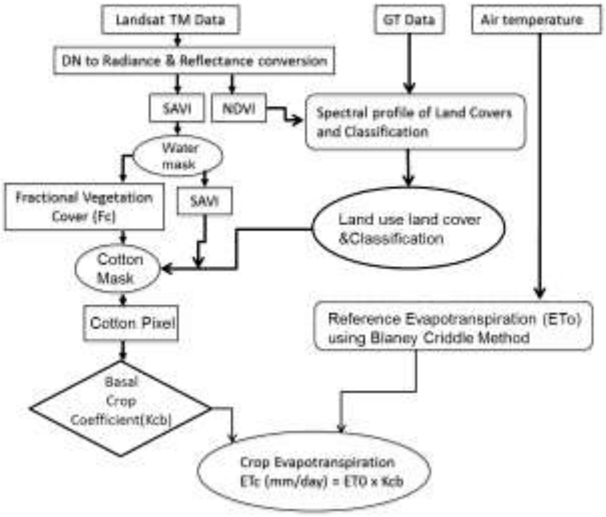

Figure 2: Flow chart of Methodology

RESULT AND DISCUSSION

3.1. Data Classification and Generation of Cotton crop mask

Remote sensing vegetation indices such as NDVI and SAVI were generated from reflectance data**.** With the help of ground truth data, data was classified and the different land cover was differentiated by seasonal variation of spectral profile. Major crops in the study area are cotton, rice and rice are mostly cultivated along the Ghghar River, because the soil along the river is red soil and suitable for rice cultivation.in the south of the river, the mostly land is affected by waterlogging due to which most of the area became salt affected and not suitable for agriculture. Cotton is well distributed in the study area. Satellite False color composite image and Land use and land cover map were shown in Fig.3a & 3b.furthermore, fractional vegetation cover, SAVI were masked for a cotton pixel with the help of classified cotton area. Basal crop coefficient (K_{cb}) were estimated using the fractional vegetation cover index only to relate it with cotton growth as fractional vegetation cover indicate crop growth. Cotton Masked fractional vegetation, SAVI, NDVI, K_{cb}, and ET_c were further classified into ten classes to separates the growth variation in different classes. Color symbology maintain same for all 10 classes of SAVI, NDVI, Fractional cover, ET_c and K_{cb} to relates each other. Each class can be correlated to corresponding Class in Graph and Image shows a spatial variation of crop water requirement.

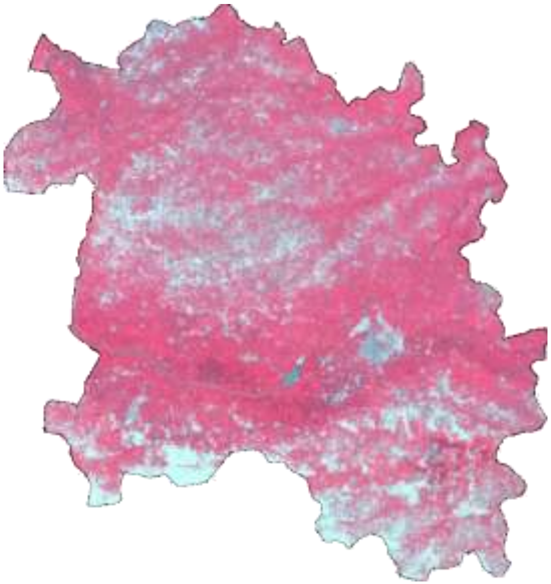

Figure 3a: False color composite image of Sirsa district, Haryana.

Figure 3b: Land use land cover map of Sirsa district, Haryana.

3.2 Seasonal variation of NDVI pattern of cotton Analysis of seasonal variation of NDVI throughout the season shows different sowing dates in the study area. Higher NDVI indicates a greater level of photosynthesis activity [30].Different NDVI profile of 10 classes of cotton shows different growth, which indicates different cotton sowing dates in the study area, from May 1st fortnight to June 1st fortnight.

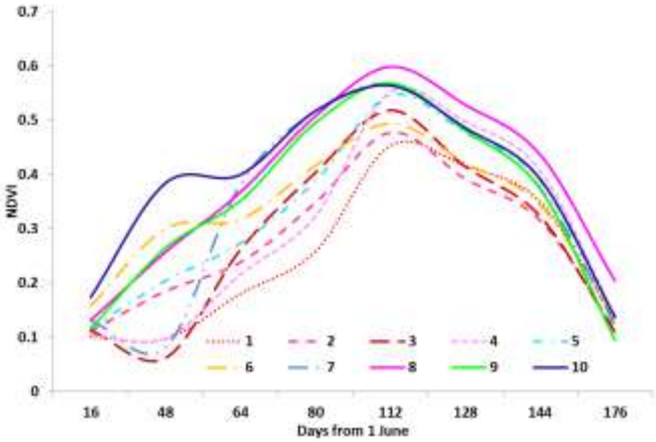

Figure 4: Seasonal variation of NDVI profile of cotton crop

But growth pattern was similar only the difference was vegetative growth. NDVI value also indicates Peak was occurred at 112 days from June 1st, mean at 21 September. Decline starts from 21 September and harvested in November. Average maximum and minimum NDVI was 0.59 and 0.45. The dip in NDVI value in classes mainly 3 and 7 at Day 48, it was because of scattered cloud over the study area on 19 July 2009 shown in Fig.4.Interclass variability is due to differences in agricultural practices such as sowing date, irrigation, and fertilization.

3.3 Evaluation of relationship between SAVI and Crop Coefficient

The reflectance-based crop coefficient developed by [11] was based on NDVI. But NDVI was found to be very sensitive to optical properties of soil background at incomplete vegetative cover condition [31]. The dip in SAVI and basal crop coefficient (K_{cb}) value in classes mainly 3 and 8 at Day 48 was because of scattered cloud over the study area on 19 July as shown in Fig.5a&5b.

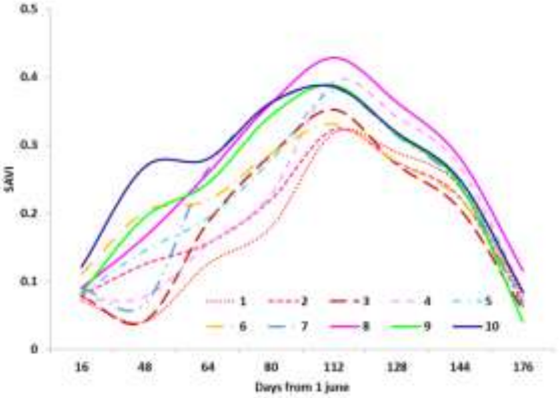

Figure 5a: Seasonal variation of SAVI

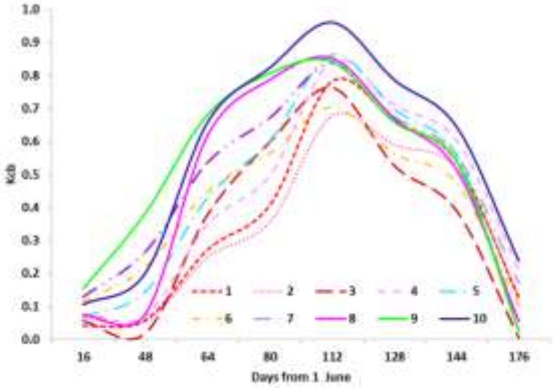

Figure 5b: Seasonal Variation of K_{cb}

We have used SAVI as vegetation index to estimate fractional vegetation cover, basal crop coefficient (K_{cb}) because SAVI was not affected by wet soil surface in the background while NDVI is sensitive to the dry and wet surface. NDVI is more susceptible to non-ideal sky condition than SAVI. Additional calibration of K_{cb} estimated from SAVI was not required for soil background conditions. SAVI is less sensitive to optical properties of soil background than NDVI [31]. Since the SAVI does not saturate at the effective cover (LAI=3), estimated K_{cb} from NDVI will be higher compared to SAVI. Average maximum and minimum K_{cb} value at peak was 0.96 and 0.68 while SAVI was 0.42 and 0.31. Crop coefficient and SAVI curve follow the pattern of the growth curve and decline from 21 September because senescence of the cotton starts after 21st September.

3.4 Evaluation of relationship between Crop water requirement and Crop fraction

Due to non-availability of reference data of crop water requirement, ET_C for validation, crop fraction was used for validation of the results. Spatial variation of ET_C follows the similar pattern of crop fraction as shown in Fig. 6a & 6b.The dip in Fractional vegetation cover in classes mainly 3 and 8 at Day 48 was because of scattered cloud while a dip in ETc classes 1& 2 was due to low vegetation cover. Dip in ETc class 8 was also due to the cloud only. Maximum and a minimum value of fraction cover at peak means at 21 September were 0.74 and 0.52 while ET_c was 5.76 & 3.98 mm/day as shown in Fig.6a&6b. Monthly and spatial variation of crop evapotranspiration ET_c are shown in Fig.7a & Fig.7b.

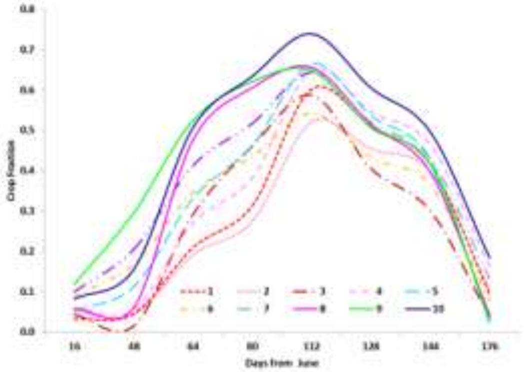

Figure 6a: Seasonal Variation of crop fraction(F_c)

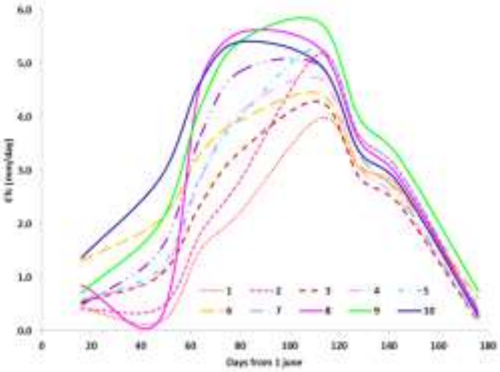

Figure 6b: Seasonal variation of ET_c

Table 1 shows the total water requirement for 10 classes of cotton in the study area, monthly water requirement was estimated and then seasonal crop water requirement was estimated by aggregation of monthly water requirement during June-November.

Table1: Monthly water requirement of ten classes of cotton in study area

Month/ Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
June	12.58	12.32	16.09	17.55	17.05	39.22	14.33	25.68	21.37	41.04
July	32.24	32.86	32.64	34.10	36.77	64.88	47.45	88.35	63.17	89.07
August	57.94	72.06	88.71	107.25	106.62	112.44	131.71	158.18	148.84	155.97
September	119.28	155.35	128.51	141.32	158.51	132.98	148.55	158.53	172.87	149.52
October	88.99	102.80	81.12	85.27	103.23	88.63	90.65	99.63	111.94	94.64
November	6.04	5.12	2.54	3.01	6.82	9.15	2.70	5.40	11.22	4.17
Total	**317.06**	**380.51**	**349.61**	**388.50**	**428.99**	**447.30**	**435.38**	**535.76**	**529.40**	**534.41**

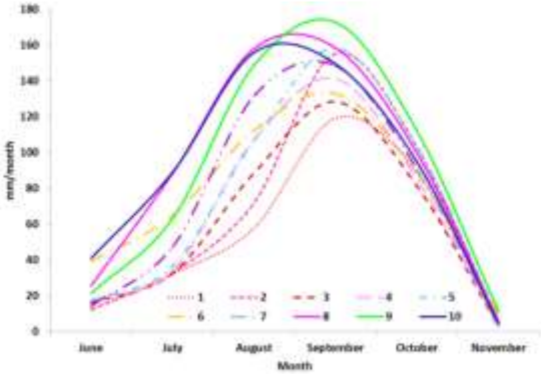

Figure 7a: Monthly variation of ET_c

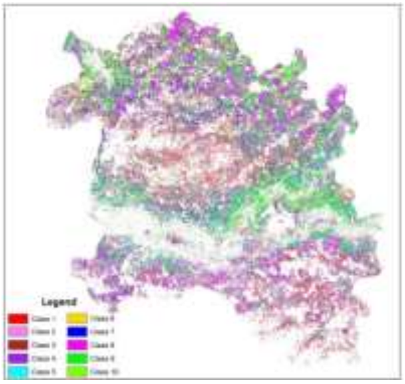

Figure 7b: Spatial Variation of ET_c

CONCLUSIONS

The remote sensing based K_{cb} estimation technique has the potential to provide the ability to detect and quantify the spatial differences in ETc information and crop growth stages. Another promising aspect of using remote sensing based K_{cb} is its ability to provide a direct approach for determining actual ET_c condition when crop growth and water use to deviate from optimum conditions. This technique could eliminate the additionally filed observations. Remote sensing based K_{cb} estimation follow the similar pattern of seasonal variation of crop fraction, SAVI, and NDVI.

Remote sensing based crop evapotranspiration, ET_c also helps to understand the spatial variation of crop water requirement and generated crop evapotranspiration, ET_c map can be used by farmers, irrigation management practices.

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