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Developing Empirical Relations to Estimate Single Crop Co-Efficient of Banana Crop using Landsat-8 Satellite Images

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Abstract – **Traditional method such as lysimeter provides point values of crop co-efficient values for any crop. While it can vary in space. To account spatial variation satellite images can be used for determining Kc values. Thus, this study was carried out to demonstrate the usage of Landsat-8 satellite images for determining Kc values for banana crop for different growth stages. In this study, four empirical relations were developed using satellite-based indices for four growth stages. All developed relations showed strong association (R^2 = 0.84) between Kc values and satellite-based indices (NDVI and SAVI). The developed equations were also validated against field-based Kc values. The results showed the negligible error given by developed equation (BIAS = 0.424, RMSE = 0.00425). Thus, it is suggested that these equations can be employed to determine Kc values of banana for area having similar plant and climatic characteristics.**

Keywords – **Evapotranspiration, Banana Crop, landsat-8, Kc Values.**

I. Introduction

Several approaches exist to estimate crop water requirements which are based on water balance and energy balance, Water balance approaches require sophisticated setup or field experiments which limit the use of these methods up to evaluation and validation purposes, while energy balance-based methods use weather parameters to determine water demand of crops. These methods are widely used including Pakistan. Crop evapotranspirati--on (ETc) is calculated by the approach of the crop coefficient in the energy balance system, whereby the effect of the different weather conditions is incorporated into the reference evapotranspiration (ETo) and the characteristics of the crop into the crop coefficient (Kc). A single crop coefficient combines the influence of both crop transpiration and soil evaporation (Kc).

The crop coefficient (Kc) is simply the crop evapotranspiration ratio observed for the studied crop over that witnessed under the same conditions (Kc = ETc/ETo) for the well calibrated reference crop.

The values of Kc are unique to each crop and are typically obtained from data sets from Lysimeter. The value of Kc for most agricultural crops rises during the crop growing season from the minimal value at the time of development, in response to changes in the growth of the canopy, until the peak Kc is attained at about the full coverage of the canopy. A crop coefficient curve is Kc's periodic distribution, frequently interpreted in time or some other time-related index as a smooth continuous function. After a full cover is obtained in the crop season, the Kc begins to decline at a point. The level of decline mainly depends on the characteristics of crop growth and the control of irrigation during the late season. Crop coefficients rely primarily on canopy characteristics, light absorption by the canopy, unevenness of the canopy, which influences turbulence, crop physiology, leaf age, and moistness of the soil. The ratio of transpiration to evapotranspiration increases as a crop canopy grows, after most of the evapotranspiration comes by transpiration, and a minor portion is soil evaporation. This happens because, until most light is intercepted before it enters the surface, the interception of radiant energy by the foliage increases. Furthermore, for the single crop coefficient, the relationships between spectral indices and crop coefficients are generally observed. The Normalized Difference Vegetation Index (NDVI) was used widely for crop yield assessment and drought detection in vegetation monitoring. A higher degree of photosynthetic activity is suggested by greater NDVI. Increased crop coefficient due to higher temperature results in a decrease in soil water and a decrease in NDVI, whereas dense vegetation causes further evapotranspiration and decreases the temperature of the ground surface, or cooler is the transpiring canopy. Limitations have been used on a regional scale in the existing protocol for estimating Kc and the resulting consumptive water. Due to inherent variability in the date of emergence, land use pattern, previous precipitation, emissivity, vegetation quantity, and atmospheric boundary conditions, such as air temperature, wind speed, and vapour pressure deficit, the Kc varies in space and time.

Traditionally Kc values are determined through sophisticated experimental setup, such as lysimeter. This method is considered as the most accurate method of measuring Kc values. However, this method is quite expensive, laborious, provide point values and unable to provide spatial variations. These days use of remote sensing in agriculture sector as mentioned above became popular due to its capability to provide both spatial and temporal information.

Thus, this study was embarked upon to demonstrate the use of satellite images-based indices in determining Kc values of banana crop.

II. Materials and Methods

Study Area:

This study was conducted at village Ghulam Muhammad Nizamani Tando Muhammad Khan, located at Latitude = 25.1959” and Longitude = 68.6429” with banana crop. The area of interest was cultivated with Banana crop admeasuring 72 acres. In the figure 1, the L1, L2 and so on, shows the number of plants.

Fig. 1. Location of study area.

GPS Survey:

The 280 co-ordinates were systematic randomly distributed recorded to cover crop overall investigated area.

Computation of Field Data Based Kc Values:

The ground truth Kc values for different growth stages of banana crop were computed using following equation:

$$Kc\ stage(n) = Kc\ stage\ (n)(tab) + [0.04(u_2\text{-}2)\text{-}0.004\ (RH_{min}\text{-}45)](\frac{h}{3})^{0.3} \qquad (1)$$

Where,

$K_{c\ Stage(n)\ (Tab)}$ = Is the standard values according to FAO approach.

u_2 = Is the average wind speed [m/s].

RH_{min} = Is the average minimum relative humidity [%].

h = Is the Plant height for each growth stage [m].

The relative humidity and wind speed data used in Kc determination were obtained from DRC for last ten years. The average values were used in computation.

The data with regard to heights of the banana crop for five months from January to December 2018 were measured at the interval of 25 days.

In the table 2.1 column 2 Kc values for different stages values were adopted from FAO water requirement manual.

Table 2.1. The meteorological and field data for the growth period.

Month	**Kc Stage (n) Table**	**Wind Velocity**	**Relative Humidity (RHm)**	**Plant Height**
	FAO	(m/s)	%	(m)
January	1.2	0.34	50.199	0.305
February	1.2	0.32	39.465	0.610
March	1.2	0.53	38.653	0.762
April	1.2	1.06	35.049	1.067
May	1.09	2.26	41.594	1.951
June	1	3.25	51.602	2.287
July	1	2.59	56.684	2.348
August	1	1.83	60.639	2.439
September	1.02	1.25	54.896	2.439
October	1.11	0.34	44.7	2.591
November	1.19	0.20	39.346	2.591
December	1.2	0.52	43.826	2.591

Development of Satellite Image Based Kc Empirical Relations

Table 2.2. Details of landsat-8 images downloaded from "usgs" website for all months of 2018.

Satellite Data		
S. No	**Satellite Information**	**Specification**
1	Satellite Name	Landsat 8 ETM+ Images
2	Resolution of Image	30mx30m
3	Temporal Resolution	15 day
4	Coordinate System	Universal Transverse Meretor (UTM)
5	North UTM Zone 42	Path 151, Row 43
S. No	**Months**	**Date of Satellite Pass**
1	January	6/1/2018
2	February	7/2/2018
3	March	11/3/2018
4	April	12/4/2018
5	May	14/5/2018
6	June	15/6/2018
7	July	1/7/2018
8	August	18/08/2018
9	September	19/08/2018
10	October	5/10/2018
11	November	6/11/2018
12	December	8/12/2018

Acquisition of Landsat-8 Images:

Required 12 images were downloaded from USGS website of different 12 months of 2018.

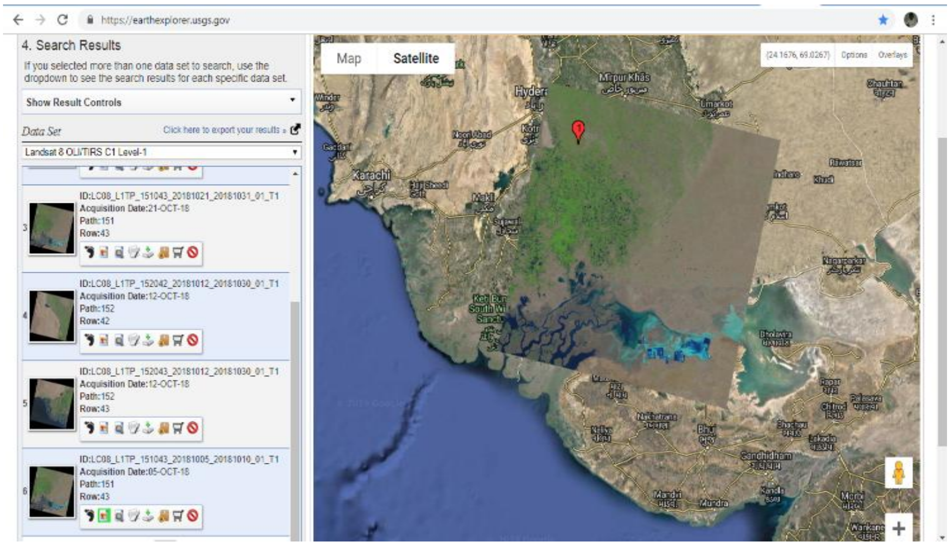

Fig. 2. Acquisition of landsat-8 images.

Development of Multiple Linear Regression Equation

Step Wise Multiple Linear Regression Technique:

To statistically analyses the results, the stepwise linear regression model was used to drive the linear equation for Kc prediction from NDVI and SAVI. In addition, to validate the model, cross-validation was applied by using equivalent sample numbers for different positions within the same region.

$Y = a + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots..\varepsilon$ (General Formula) (i)

$Kc = a + \beta_1 NDVI + \beta_2 SAVI$ (Equation to be developed) (ii)

Normalized Difference Vegetation Index (NDVI) expressed as equation (2) was calculated from Landsat-8 for four different crop stages following Eq. (3). The theory behind NDVI would be that the red band in which chlorophyll is active induces substantial sunlight absorption, while the near infrared (NIR) band in which the spongy-mesophyll leaf structure of a plant is present produces significant reflectance (Tucker et al., 1991). Therefore, according to the growth point, NDVI values differ. The SAVI (eq-3) was also used in conjunction with NDVI.

$$NDVI = \frac{(\rho NIR - \rho red)}{(\rho NIR + \rho red)} \quad (2)$$

Where,

$\boldsymbol{\rho}_{NIR}$ = Reflectance in the near infrared band (Band 5).

$\boldsymbol{\rho}_{red}$ = i Reflectance in the red band (band 4).

From Landsat, the Soil-Adjusted Vegetation Index (SAVI) was determined for the four separate crop stages after Eq. Oh. (4). SAVI seems to be the best index used to classify arid zone vegetation, according to (Huete, 1988), understanding the sparse distribution of vegetation between bared soil patches.

$$AVI = (1 + L) * \frac{(\rho NIR - \rho red)}{(\rho NIR + \rho red + L)} \quad (3)$$

Where,

$\boldsymbol{\rho}_{NIR}$ = Reflectance in the near infrared band (Band5).

$\boldsymbol{\rho}_{red}$ = Reflectance in the red band (Band4).

L = parameter to minimize the soil influence (0.5). Its value, as deter-mined for arid zones by Huete (1988), is 0.5.

Validation of Developed Equations

Following criteria were used to validate newly developed equation. When values of these two criteria are minimum it means tested models are good.

Root Mean Square Error

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (Oi - E_i)^2} \quad (4)$$

Where,

$\sum$ = Summation.

n = Total numbers (Observations).

Oi = Field based observed Kc value.

Ei = Estimated Kc value.

BIAS

$$\text{BIAS} = \frac{\sum_{i=1}^{n}(E_i - Oi)}{\sum_{i=1}^{n} Oi} \tag{5}$$

Where,

$\sum$ = Summation.

n = Total numbers (Observations).

Oi = Field base observed Kc value.

Ei = Estimated Kc value.

III. Results and Discussions

Normalized Difference Vegetation Index (NDVI) for Growth Stages

These are the NDVI maps for month February, May, August and December are shown in fig 3. In these maps blue color shows the vegetation and white color show the buildings dense lines show the bare soil. And in these maps small value shows the low vegetation and larger value show the high vegetation. In these maps value increase it means plants are well waters (plants healthier).

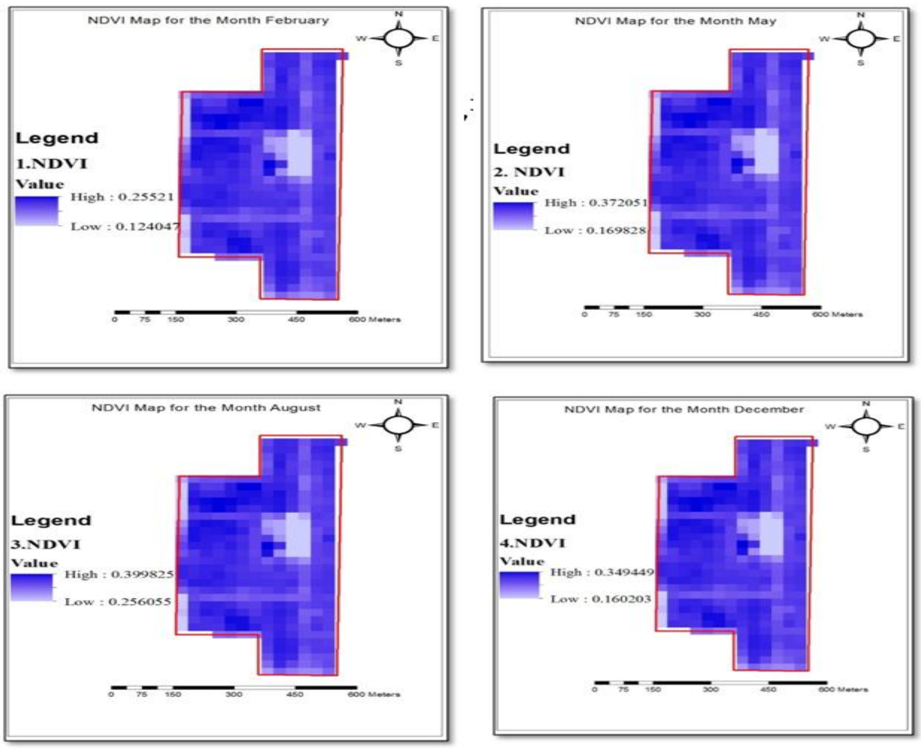

Fig. 3. Normalized Difference Vegetation Index (NDVI) for growth stages.

Soil-Adjusted Vegetation Index (SAVI) for Growth Stages

The SAVI maps for month February, May, August and December are shown in fig 4. In these maps red color shows the vegetation and white color show the buildings and dense lines show the bare soil. And in these maps small value shows the low vegetation and larger value show the high vegetation. In these maps value increase as compare to the NDVI maps due to one adjusted factor/parameter "L" to minimize the soil influence.

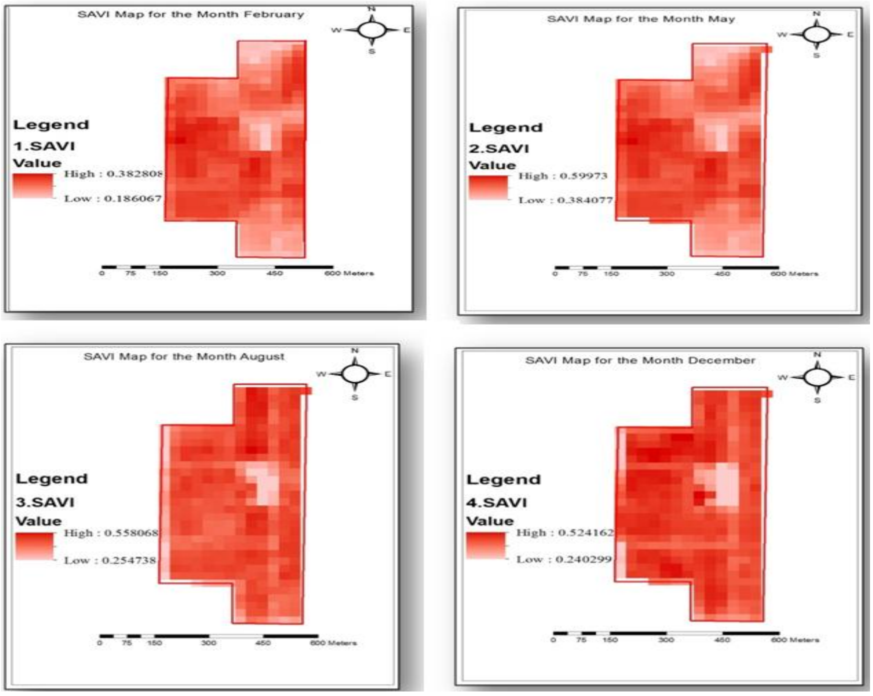

Fig. 4. Soil Adjusted Vegetation Index (SAVI) for growth stages.

Developed Equations for the Initial Growth Stage

Developed equation and regression statistics for the initial, development, middle and late growth stages are tabulated in table 3.1, 3.2, 3.3, and 3.4. The regression statistic coefficient of determination and adjust coefficient of determination were almost similar to each other. From p value significance level of 0.05, it shows that NDVI and SAVI are good contributor or significant contribute in determining Kc values at initial, development, middle and late growth stages.

The summary of developed equation is presented in table 4.5. This table shows the initial, development, middle and late growth stages equations and corresponding months for which these equations are applicable.

Table 3.1. Developed equation and regression statistics for the initial growth stage.

Equation	**Kc = 1.14 + (-1974.12*NDVI) + (1316.10*SAVI)**
Regression Statistics	
R Square (coefficient of determination)	0.84
Adjusted R Square	0.83
Standard Error	0.001
Observations	15

Coefficients		P-value
Intercept	1.143172806	0.00
NDVI	-1974.12934	0.02
SAVI	1316.102814	0.03

Table 3.2. Developed equation and regression statistics for the development growth stage.

Equation	**Kc = 1.11 + (261.097*NDVI) +(-174.069*SAVI)**	
Regression Statistics		
R Square (coefficient of determination)		0.83
Adjusted R Square		0.83
Standard Error		0.00019
Observations		15
Coefficients		P-value
Intercept	1.111381793	0.00
NDVI	261.0979357	0.03
SAVI	-174.0692378	0.03

Table 3.3. Developed equation and regression statistics for the middle growth stage.

Equation	**Kc = 0.93 + (-456.498*NDVI) + (304.335*SAVI)**	
Regression Statistics		
R Square (coefficient of determination)		0.84
Adjusted R Square		0.83
Standard Error		0.0001
Observations		15
Coefficients		P-value
Intercept	0.936110399	0.00
NDVI	-456.4982785	0.02
SAVI	304.3356863	0.03

Table 3.4. Developed equation and regression statistics for the late growth stage.

Equation	**Kc = 1.1456 + (-17.584*NDVI) + (11.723*SAVI)**
Regression Statistics	
R Square (coefficient of determination)	0.84
Adjusted R Square	0.84
Standard Error	0.00
Observations	15

Coefficients		P-value
Intercept	1.145256092	0.00
NDVI	-17.5841733	0.03
SAVI	11.72300793	0.03

Table 3.5. Prediction equations for different growth stages.

Crop	Growth Stages	Months	Days	Region	Equations
Banana	Initial	January	120	Tando Muhammad Khan (Sindh)	Kc = 1.14 - (1974.13*NDVI) + (1316.1*SAVI)
		February			
		March			
		April			
	Development	May	61		Kc = 1.11 + (261.097*NDVI)- (174.069*SAVI)
		June			
	Mid	July	123		Kc = 0.93 - (456.498*NDVI) + (304.335*SAVI)
		August			
		September			
		October			
	Late	November	61		Kc = 1.14 - (17.584*NDVI) + (11.723*SAVI)
		December			

Validation of Different Growth Stages

These tables (tables 3.5, 3.6, 3.7 and 3.8) showing validation results of initial, development, middle and late growth stages equations in terms of BIAS and RMSE. From the results of BIAS and RMSE it can be seen model or equation performed well. As BIAS and RMSE values are minimum. The BIAS values are less than 1%. The error is very minimum.

Table 3.6. Validation of initial growth stages.

Field based Kc value	(Kc) Equation	(Differences)	(Differences)^2	RMSE	BIAS (%)
1.143	1.138	0.005	0.00002	0.005	0.426
1.143	1.138	0.0051	0.00002		
1.142	1.138	0.0044	0.00019		
1.141	1.138	0.0027	0.000007		
1.143	1.138	0.0047	0.00002		
1.142	1.138	0.0045	0.00002		

Field based Kc value	(Kc) Equation	(Differences)	(Differences)^2	RMSE	BIAS (%)
1.141	1.137	0.0037	0.00001		
1.143	1.135	0.0073	0.00005		
1.143	1.136	0.0068	0.00004		
1.142	1.136	0.0062	0.00003		
1.143	1.138	0.0045	0.00002		
1.142	1.138	0.0042	0.00001		
1.143	1.138	0.0046	0.00002		
1.140	1.137	0.0027	0.000007		
1.143	1.137	0.0060	0.00003		

Table 3.7. Validation of development growth stages.

Field Based Kc Value	(Kc) Equation	(Differences)	(Differences)^2	RMSE	BIAS (%)
1.111	1.109	0.0017	0.000003		
1.110	1.109	0.0014	0.000002		
1.111	1.109	0.0018	0.000003		
1.111	1.109	0.0016	0.000002		
1.111	1.109	0.0016	0.000002		
1.110	1.109	0.0016	0.000002		
1.111	1.109	0.0017	0.000003		
1.110	1.109	0.0013	0.000001	0.001	0.148
1.110	1.109	0.0015	0.000002		
1.110	1.109	0.0017	0.000003		
1.111	1.109	0.0020	0.000004		
1.110	1.109	0.0017	0.000003		
1.110	1.109	0.0014	0.000002		
1.110	1.109	0.0014	0.000002		
1.110	1.109	0.0014	0.000002		

Table 3.8. Validation of middle growth stages.

Field based Kc value	(Kc) Equation	(Differences)	(Differences)^2	RMSE	BIAS (%)
0.935	0.929	0.006	0.00003		
0.936	0.929	0.006	0.00004	0.006	0.671
0.934	0.929	0.005	0.00002		

Field based Kc value	(Kc) Equation	(Differences)	$(Differences)^2$	RMSE	BIAS (%)
0.935	0.929	0.005	0.00003		
0.935	0.929	0.005	0.00003		
0.936	0.929	0.006	0.00004		
0.936	0.929	0.006	0.00004		
0.935	0.929	0.005	0.00003		
0.935	0.929	0.006	0.00003		
0.936	0.929	0.006	0.00004		
0.935	0.929	0.005	0.00003		
0.936	0.929	0.006	0.00004		
0.935	0.929	0.006	0.00004		
0.936	0.929	0.006	0.00004		
0.936	0.929	0.006	0.00004		

Table 3.9. Validation of late growth stages.

Field based Kc value	(Kc) Equation	(Differences)	$(Differences)^2$	RMSE	BIAS (%)
1.145	1.140	0.005	0.00002	0.005	0.454
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		
1.145	1.140	0.005	0.00002		

Maps of Crop Coefficient (Kc) Prepared by Developed Equation

These maps showing Kc values of initial, development, middle and late growth stages.

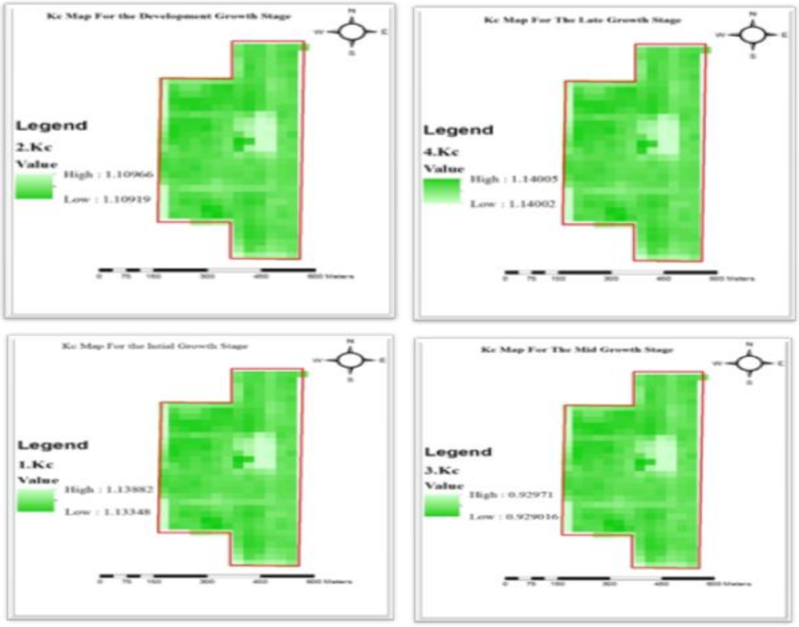

Fig. 5. The predicted crop co-efficient (Kc) for growth stages.

The vegetation indices estimated from Landsat-8 satellite photos indicated that the middle season growth phase NDVI and SAVI values were higher than both the production phase and the late season developmental stage. The layouts are shown in Figs for the vegetation indices. From 3 and 4.

The findings of the data analysis using the sequential multiple linear regression for the Kc prediction equation of the different growth stages from NDVI and SAVI for each growth stage are shown.

For each growth stage, the result prediction equations were used for predicting and mapping the banana crop Kc. The analysis also shows that through the different growth stages, NDVI, SAVI, Kc, and predicted Kc had the same trend. By multiplying the picture of the crop coefficient by the amount of evapotranspiration, the banana crop was determined. The layouts of the criteria for mapped wheat water and the crop coefficient for various stages of growth are shown in Fig. 5. Cross validation has been applied, and the result shows that for the three separate growth phases, the correlation between the measured (Kc) and expected (Kc) has been shown.

The results showed a high R2 and modified R2 for the projected crop coefficient values for the 0.403, 0.086, 0.451 and 0.304, -0.065, 0.359 and -0.115 stages of production, mid-season and late-season growth, accordingly, suggesting that the measurement of crop coefficients and water demand using remote sensing data is essentially important. In addition, the study showed that estimating the crop coefficients as well as the requirements for crop water using Landsat data is necessary if soil evaporation is insignificant and plants were not under stress. In addition, Landsat satellite images were powered by vegetation indices, and both crop parameters were determined, and projected values followed the same pattern through the various stages of growth.

IV. Discussion

In order to estimate the banana crop coefficient using vegetation indices derived from remote sensing data, the study showed high R2 and modified R2 values, which used integrated metrological data to estimate, but needed accurate climate data measured in the field, which is unfortunately difficult and costly for some developing countries. In certain parts of the globe, the tabulated FAO-5crop coefficient value does not seem to apply.

V. Conclusion

The developed empirical relations predicted well the value of single crop coefficients. Thus, it is concluded that satellite image-based indices (NDVI, SAVI) are the significant contributors in determining Kc value. It is inferred on the basis of validation results that use of satellite imagery for the estimation of Kc values is significantly effective and reliable method.

Satellite imagery-based studies for estimating Kc values should be carried out for different crops. In future studies, Reference Evapotranspiration (ETo) should be estimated using satellite data to compute water requirement. Fine resolution satellite data like SPOT 6/7 should be used for determining crop coefficient (Kc) values and results should be compared with Landsat-8 data.

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