

RESEARCH ARTICLE

Application of reflectance based vegetation index to derive dual crop co-efficient for summer sesame

■ A. P. Lakkad^{1*}, S. G. Patel², Vibhuti A. Patel³ and M. G. Varma⁴

SUMMARY

Dual crop co-efficient approach was applied to estimate seasonal water requirement for summer sesame using reflectance based vegetation indices. Field experiment was conducted to collect the required various crop physiologic parameters and NDVI data for the study crop during 2018 and 2019. Basal crop co-efficients and soil evaporation co-efficients collected from FAO-56 for initial mid and end stages of summer sesame were adjusted for study area using local weather parameters. Spectrum® Field Scout CM 1000 NDVI Meter were used to collect the NDVI data at various stages of study crop. The NDVI was measured from crop canopy and soil surface at 7 days intervals between 12.00 to 13.00 clocks. NDVI Based Basal Crop Co-efficient and Soil evaporation co-efficient were derived using standard methods. FAO estimated crop co-efficients were compared with NDVI based crop co-efficients. The co-efficient of determination of the fitted regression equation was found to be 0.836 and 0.765 for drip irrigation and 0.783 and 0.867 for surface control irrigation system for summer sesame during 2018 and 2019, respectively. Crop growing stage wise water requirement per unit area was estimated for both treatments. Results indicates that among these two methods, NDVI method estimate lowest water requirement in both cases *i.e.* total water requirement and during all the crop growth stages for both irrigation systems while daily crop water requirement was lower for all growth stages in drip system as compare with control system.

Key Words : Basal crop co-efficient, Dual crop co-efficient, Soil evaporation co-efficient; NDVI

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It is imperative to develop water saving technologies for judicious utilization of available water in agriculture to ensure future food security of the country. A better understanding of the water balance is essential for exploring water-saving techniques. One of the most important concepts regarding water balance is crop evapotranspiration (ET_c) which is a key factor for determining proper irrigation scheduling and for improving

water use efficiency in irrigated agriculture. Most of the irrigation scheduling models uses the single K_c approach to compute ET_c . However for high frequency irrigation using micro irrigation systems for crops that only cover part of the soil, and when the soil is often wetted by rain or irrigation, the dual crop co-efficient approach can lead to more accurate estimates of crop evapotranspiration ET_c . Dual crop co-efficient (K_c) approach permits estimation of the transpiration and evaporation components of evapotranspiration more accurately and capturing impacts of irrigation frequency and total water use during the crop growing season. NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum and is adopted to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not. Healthy vegetation will have higher value of the NDVI. But from the bare soil, same levels of red and near-infrared light will be reflected and hence they will show the value of NDVI as zero. The study was undertaken to analyse the application of reflectance based vegetation index to derive dual crop co-efficients for summer sesame.

MATERIAL AND METHODS

Study location:

A field experiment was conducted during the summer season of 2018 and 2019 at the departmental farm of College of Agricultural Engineering and Technology, Navsari Agricultural University, Dediapada (Gujarat). Research site is situated at 21°37'39"N latitude, 73°34'57"E longitude and at an altitude of 169 m above the mean sea level. The study area is located in the Dediapada region of Narmada district in the South Gujarat Agro-climatic Zone of Gujarat state. The average annual rainfall of the tract was about 1,139 mm, average maximum and minimum temperature were 34.4 °C and 22.0 °C, while the average maximum and minimum relative humidity were 73.1% and 41.5%, respectively. The average annual wind speed was 5.4 km.h⁻¹, and average annual bright sunshine hour was 7.2 h.

Dual crop co-efficient approach:

The FAO-56 recommended use of dual crop co-efficient approach as a more precise method for determining daily water consumption by plants (Allen *et al.*, 1998). This method uses two types of co-efficients, *viz.*, basal crop co-efficient (K_{cb}), and the soil evaporation

co-efficient (K_e), for estimation of crop co-efficient for a particular crop growth stage. The actual evapotranspiration (ET_a) was calculated from crop co-efficient K_c using Eq. 1.

$$ET_a = K_c \times ET_0 \quad \dots(1)$$

where,

ET_0 = Reference crop evapotranspiration as estimated using PM method, and

K_c = Crop co-efficient.

The factor K_c represents an integrated effect of crop transpiration and soil evaporation in the dual crop co-efficient approach and can be expressed by the Eq. 2 (Allen *et al.*, 1998).

$$K_c = K_{cb} + K_e \quad \dots(2)$$

where,

K_{cb} = Basal crop co-efficient, represents the transpiration component of the ET_0 , and

K_e = Soil water evaporation co-efficient, describes the evaporation component of ET_0 .

FAO adjusted basal crop co-efficient:

Basal crop co-efficients for initial, mid and end stages of summer sesame were collected from Table A of FAO Irrigation and Drainage Paper No-56 (Allen *et al.*, 1998). The adjusted basal crop co-efficients ($K_{cb(adj)}$) were derived using Eq. 3 based on local weather parameter of study area.

$$K_{cb(adj)} = K_{cb(Tab)} + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)] \frac{h^{0.3}}{3} \quad \dots(3)$$

where,

$K_{cb(Tab)} = K_{cb\ mid}$ or $K_{cb\ bend}$ (if ≥ 0.45),

$K_{cb\ mid}$ = Crop co-efficient K_c during mid-season stage,

$K_{cb\ bend}$ = Crop co-efficient K_c at the end of late season stage,

u_2 = Mean value for daily wind speed at 2 m height over grass during the mid or late season growth stage for $1\ m.s^{-1} \leq u_2 \leq 6\ m.s^{-1}$, $m.s^{-1}$,

RH_{min} = Mean value for daily minimum relative humidity during the mid or late season growth stage, %, and

h = Mean plant height during the crop growing period 2018 and 2019 (Table A), m.

FAO soil evaporation co-efficient:

Soil evaporation co-efficients were estimated using eq. 4.

Table A : Average plant height and root length during different crop growth stages

Sr. No.	Crop development stage	2018				2019			
		Plant height, mm		Root length, mm		Plant height, mm		Root length, mm	
		Border	Drip	Border	Drip	Border	Drip	Border	Drip
1.	Initial stage	44.9	46.3	60.5	57.9	46.9	45	61.1	66.1
2.	Development stage	222.9	263.6	95.3	92	163.9	171.8	98.8	99
3.	Mid stage	487.6	516.7	123.7	118.1	556.6	674.7	140	123.1
4.	End stage	590.3	598	188.6	213.9	819.2	820.2	183.9	173.9

$$K_c = K_r (K_{cmax} - K_{cb}) \leq f_{ew} K_{cmax} \quad \dots(4)$$

where,

K_c = Soil evaporation co-efficient,

K_{cb} = Basal crop co-efficient,

K_{cmax} = Maximum value of K_c following rain or irrigation,

K_r = Dimensionless evaporation reduction co-efficient dependent on the cumulative depth of water depleted (evaporated) from the topsoil,

f_{ew} = Fraction of the soil that is both exposed and wetted (fraction of soil surface from which most evaporation occurs), and

K_{cmax} = Upper limit of evaporation and transpiration from any cropped surface.

The values of K_{cmax} and evaporation reduction co-efficient (K_r) were computed respectively using Eq. 5 and Eq. 6.

$$K_{cmax} = \max \left\{ \left\{ 1.2 + [0.04(u_2 - 2) - 0.004(RH_{min} - 45)] \frac{h^{0.3}}{3} \right\} \{K_{cb} + 0.05\} \right\} \quad \dots(5)$$

$$K_r = \frac{TAW - De_{i-1}}{TEW - REW} \quad \text{for } De_{i-1} > REW \quad \dots(6)$$

where,

K_r = Dimensionless evaporation reduction co-efficient dependent on the soil water depletion (cumulative depth of evaporation) from the top soil layer ($K_r = 1$ when $De_{i-1} \leq REW$),

De_{i-1} = Cumulative depth of evaporation (depletion) from the soil surface layer at the end of day $i-1$ (the previous day), taken from SIMDualKc model, mm,

TEW (Total Evaporable Water) = Maximum cumulative depth of evaporation (depletion) from the soil surface layer when $K_r = 0$, mm, and

REW (Readily Evaporable Water) = Cumulative depth of evaporation, mm.

Reflectance based vegetation index:

A vegetation index is a quantitative measure used to measure the biomass or vegetative vigour usually from

combination of several spectral bands (range of wavelength), whose values are added, divided, multiplied in order to yield a single value that indicates the amount or vigour of vegetation. The state of the land vegetative condition can be explained with the help of vegetative parameters such as Normalized Difference Vegetative Index (NDVI). NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation or not. Healthy vegetation will have higher value of the NDVI. But from the bare soil or rocks same levels of red and near-infrared light will be reflected and hence they will show the value of NDVI as zero. The NDVI values ranges from -1 to +1 (pixel values 0 – 255). As NDVI values are comparatively convenient to measure either with the help of satellite data or an instrument called NDVI meter.

Plant reflectance: NDVI measurement :

Normalized difference vegetation index (NDVI) measurements were taken using the Spectrum® FieldScout® CM 1000 NDVI Meter (Spectrum Technologies Inc.). This hand held device can measure areas from 4 cm to 12 cm diameter. This is the same methodology that is incorporated in aerial or satellite imagery. The Spectrum CM 1000 NDVI meter displays the NDVI calculation (-1.0 to 1.0). The FieldScout CM 1000 NDVI Meter uses “point-and-shoot” technology to instantly measure reflected light in the red (660 nm) and near infrared (840 nm) spectral bands (Hughes *et al.*, 2014). This chlorophyll meter uses red and near infrared reflectance to calculate normalized difference vegetative index (NDVI). Laser guides outline the edges of the measured sample area. An ambient light sensor automatically corrects measurements for varying light conditions. The hand-held meter calculates and displays a running average for multiple readings.

NDVI measurements were made with the instrument about 30 to 45 cm above and at 90 degree

angle to the canopy. The NDVI was measured from crop canopy and soil surface at 7 days intervals between 12.00 to 13.00 clocks.

NDVI based basal crop co-efficient:

NDVI based basal crop co-efficient was derived using equation 7 (Daughtry *et al.*, 1983; Hatfield *et al.*, 1984; Wiegand and Richardson, 1984; Gallo *et al.*, 1985; Gonzalez-Dugo *et al.*, 2008).

$$K_{cb} = K_{cb \max} \times \left[1 - \left(\frac{NDVI_{\max} - NDVI_{\text{avg}}}{NDVI_{\max} - NDVI_{\min}} \right)^n \right] \dots(7)$$

where, $K_{cb \max}$ = Maximum value of basal crop co-efficient.

NDVI = Stage-wise average normalized difference vegetation index.

$NDVI_{\min}$ = Stage-wise maximum value of NDVI.

$NDVI_{\max}$ = Stage-wise minimum value of NDVI.

n = Damping co-efficient.

Maximum basal crop co-efficient (K_{cb}) value of 1.05 for sesame crop was taken from Table 17 of FAO 56 paper (Allen *et al.*, 1998). The stage-wise values of $NDVI_{\min}$, $NDVI_{\max}$ and NDVI were calculated using measured NDVI values. Damping co-efficient (n) was estimated using equation 8. (Bausch and Neale, 1990; D’Urso and Calera, 2006).

$$n = \frac{K}{K'} \dots(8)$$

The value of K ranges from 0.50 to 0.70 (Er- Raki *et al.*, 2007). The value of K was taken as 0.59 for this study using Fig. No. 9 (Hunsakar *et al.*, 2005) for sesame whiles the value of K’ was calculated using equation 9 (Ashrar *et al.*, 1984).

$$K' = \frac{0.5}{\cos\theta} \dots(9)$$

where, θ is a solar zenith angle.

The *solar zenith angle* is the *angle* between the *zenith* and the centre of the *Sun*’s disc. The solar zenith angles were calculated using online NOAA ESRL Solar Position Calculator at 12.30 pm for the day of measurement of crop NDVI (<https://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html>).

NDVI Based Soil evaporation co-efficient:

Soil evaporation co-efficient was estimated by using equation 10 (Er- Raki *et al.*, 2007).

$$K_c = 0.18 \times (1-f) \dots(10)$$

where, K_c = Soil evaporation co-efficient

f_c = Fraction of ground cover

The value of 0.18 is taken from Fig. 29 of FAO 56 Paper (Allen *et al.*, 1998)

Fraction of ground cover:

Fraction of ground cover can be calculated using equation 11 (Er- Raki *et al.*, 2007)

$$f_c = \frac{(NDVI_{\text{avg}} - NDVI_{\min})}{NDVI_{\max} - NDVI_{\min}} \dots(11)$$

where, $NDVI_{\text{avg}}$ = Stage-wise average normalized difference vegetation index.

$NDVI_{\min}$ = Stage-wise minimum value of NDVI.

Estimation of crop water requirement:

In this study, crop water requirement of summer sesame crop has been estimated. Crop water requirement is the amount of water needed to meet the water loss through evapotranspiration of the field. Estimation of the crop water requirement is derived from crop evapotranspiration (crop water use) which is the product of the references evapotranspiration (ET_0) and the crop co-efficient (K_c). The reference evapotranspiration (ET_0) was estimated based on FAO Penman-Monteith method (ET_0 calculator), using climate data (Allen *et al.*, 1998).

$$ET_c = ET_0 \times K_c \dots(12)$$

where, ET_c = Actual evapotranspiration (mm/day)

ET_0 = Reference evapotranspiration (mm/day)

K_c = Crop co-efficient

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

FAO dual crop co-efficient:

FAO basal crop co-efficient:

Basal crop co-efficient values for the three stages of initial, mid and end stage for *summer sesame* are 0.15, 1.05 and 0.20 respectively in FAO-56 paper (Allen *et al.*, 1998). These basal crop co-efficient values for *summer sesame* was adjusted for the study area from local data of daily wind speed, RH_{\min} and crop height using Eq. 3 for both the years and presented in Table 1.

FAO soil evaporation co-efficient:

Crop growth stage wise soil evaporation co-efficient for *summer sesame* was estimated for the study

area using K_{cmax} (maximum value of K_c following rain or irrigation), Reduction co-efficient (K_r) and fraction of soil surface from which most evaporation occurs (f_{cw}) by using Eq. 6 for both the years while K_{cmax} were derived from Eq. 5. Readily Evaporable Water (REW) and Total Evaporable Water (TEW) are required to estimate reduction co-efficient (K_r). REW and TEW were adopted as 9 and 20 respectively for clay loam soil as given in FAO paper 56 (Allen *et al.*, 1998). Crop growing stage wise K_r and K_{cmax} values are presented in Table 2.

Soil evaporation co-efficient was estimated on daily

basis using Eq. 4 and presented in Table 3. These values were used to derive daily dual crop co-efficient.

As per Table 3, values of soil evaporation co-efficient K_c are highest during initial stage because of more than 90 % area of cropped field were not covered by crop canopy and exposed to atmosphere. While from development to end stage, the values of soil evaporation co-efficient K_c decrease sequentially because of continuously increase of crop canopy cover of cropped field during this period. During end stage, these values were slightly decrease because of irrigation of the field

Table 1: FAO adjusted basal crop co-efficient (K_{cb}) for summer sesame

Sr. No.	Year	Crop development stage	Drip irrigation system	Surface control irrigation system
			K_{cbadj}	K_{cbadj}
1.	2018	Initial stage	0.13	0.13
		Development stage	0.48	0.48
		Mid stage	0.81	0.80
		End stage	0.24	0.24
2.	2019	Initial stage	0.12	0.12
		Development stage	0.47	0.48
		Mid stage	0.80	0.80
		End stage	0.26	0.26

Table 2: Stage wise reduction co-efficient (K_r) and maximum crop co-efficient (K_{cmax})

Sr. No.	Year	Crop development stages	Drip irrigation system		Surface control irrigation system	
			K_r	K_{cmax}	K_r	K_{cmax}
1.	2018	Initial stage	0.51	1.18	0.57	1.18
		Development stage	0.51	1.20	0.65	1.20
		Mid stage	0.52	1.24	0.56	1.24
		End stage	0.41	1.24	0.48	1.24
2.	2019	Initial stage	0.57	1.17	0.57	1.17
		Development stage	0.58	1.19	0.66	1.20
		Mid stage	0.38	1.23	0.56	1.23
		End stage	0.38	1.26	0.49	1.26

Table 3 : FAO soil evaporation co-efficient (K_c)

Sr. No.	Year	Crop development stage	Drip irrigation system	Surface control irrigation system
			K_c	K_c
1.	2018	Initial stage	0.53	0.59
		Development stage	0.36	0.51
		Mid stage	0.21	0.25
		End stage	0.41	0.48
2.	2019	Initial stage	0.60	0.60
		Development stage	0.48	0.49
		Mid stage	0.16	0.25
		End stage	0.38	0.49

was terminated during maturity period of crop.

FAO crop co-efficient:

Crop co-efficient (K_c) for each growth stages of summer sesame crop was derived by summation of basal crop co-efficient (Table 1) and soil evaporation co-efficient (Table 3) for each stages and presented in Table 4. Table 4 Depicts that crop co-efficient values are increase from initial to mid stage of crop period while during end stage they decrease for both the treatment during both years.

NDVI based basal crop co-efficient (K_{cb}):

Crop growth stage wise basal crop co-efficient for

summer sesame was estimated for the study area using Eq. 7 and presented in Table 5.

NDVI based soil evaporation co-efficient:

Crop growth stage wise soil evaporation co-efficient values for *summer sesame* was estimated for the study area using Eq. 10 and f_c (fraction of ground cover) was estimated using Eq. 11 for both the years and presented in Table 6.

NDVI based crop co-efficient (K_c):

Crop co-efficient (K_c) for each growth stages of *summer sesame* crop was derived by summation of basal crop co-efficient (K_{cb}) and soil evaporation co-efficient

Table 4: FAO crop co-efficient (K_c) for summer sesame

Sr. No	Year	Crop development stage	Drip irrigation system	Surface control irrigation system
1.	2018	Initial stage	0.66	0.72
		Development stage	0.84	0.99
		Mid stage	1.02	1.05
		End stage	0.65	0.72
2.	2019	Initial stage	0.72	0.73
		Development stage	0.95	0.97
		Mid stage	1.06	1.05
		End stage	0.64	0.74

Table 5 : NDVI based basal crop co-efficient (K_{cb})

Sr. No.	Year	Crop development stage	Drip irrigation system	Control irrigation system
1.	2018	Initial stage	0.38	0.37
		Development stage	0.57	0.45
		Mid stage	0.63	0.63
		End stage	0.39	0.39
2.	2019	Initial stage	0.43	0.35
		Development stage	0.53	0.45
		Mid stage	0.59	0.62
		End stage	0.50	0.32

Table 6: NDVI based soil evaporation co-efficient (K_e)

Sr. No.	Year	Crop development stage	Drip irrigation system	Control irrigation system
1.	2018	Initial stage	0.17	0.16
		Development stage	0.16	0.15
		Mid stage	0.14	0.14
		End stage	0.15	0.12
2.	2019	Initial stage	0.16	0.16
		Development stage	0.16	0.15
		Mid stage	0.15	0.14
		End stage	0.16	0.16

(K_c) for each stages and presented in Table 7. Table 7 Depicts that crop co-efficient values are increase from initial to mid stage of crop period while during end stage they decrease for both the treatment during both years.

Comparison of FAO adjusted K_c and NDVI based K_c for drip irrigation system:

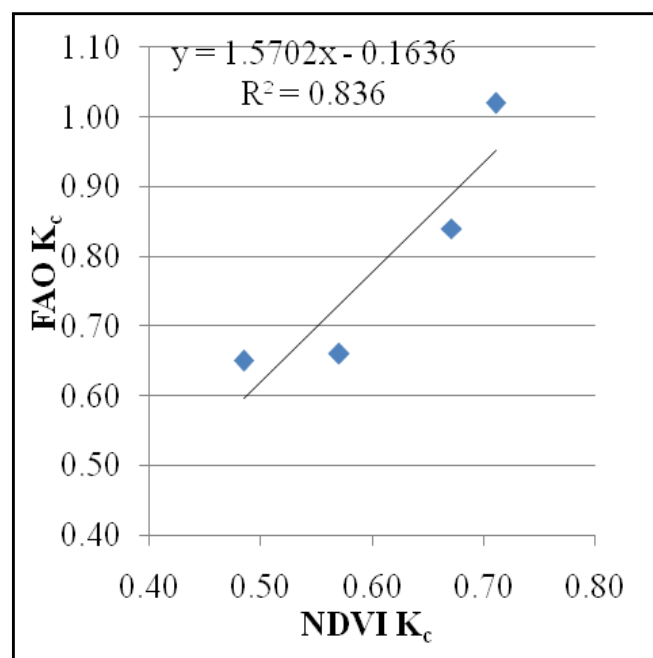
FAO estimated crop co-efficient (K_c) values using FAO 56 method (Allen *et al.*, 1998) were compared with NDVI based crop co-efficient (K_c). Results showed that there exists a linear relation between the FAO estimated K_c and NDVI K_c . The co-efficient of determination of the fitted regression equation was found to be 0.836 and 0.765 during summer sesame during 2018 and 2019,

respectively for drip irrigation system as shown in Fig. 1.

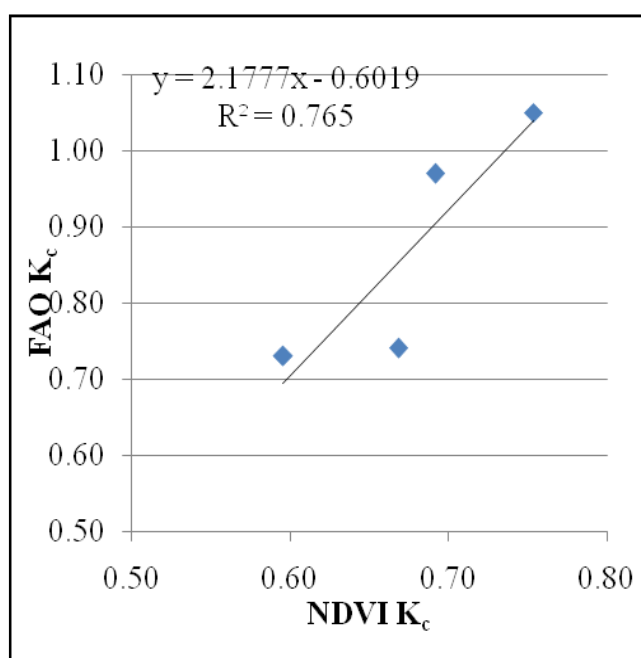
Comparison of FAO adjusted K_c and NDVI K_c for control irrigation system:

FAO estimated crop co-efficient (K_c) values using FAO 56 method (Allen *et al.*, 1998) were compared with NDVI based crop co-efficient (K_c). Results showed that there existed a linear relation between the FAO estimated K_c and NDVI K_c . The co-efficient of determination of the fitted regression equation was found to be 0.783 and 0.867 during summer sesame during 2018 and 2019, respectively for surface control irrigation system as shown in Fig. 2.

Sr. No.	Year	Crop development stage	Drip irrigation system	Control irrigation system
1.	2018	Initial stage	0.57	0.53
		Development stage	0.67	0.60
		Mid stage	0.71	0.78
		End stage	0.48	0.51
2.	2019	Initial stage	0.59	0.51
		Development stage	0.69	0.60
		Mid stage	0.75	0.77
		End stage	0.66	0.48



2018



2019

Fig. 1: Comparison between the NDVI K_c and FAO K_c for drip irrigation system

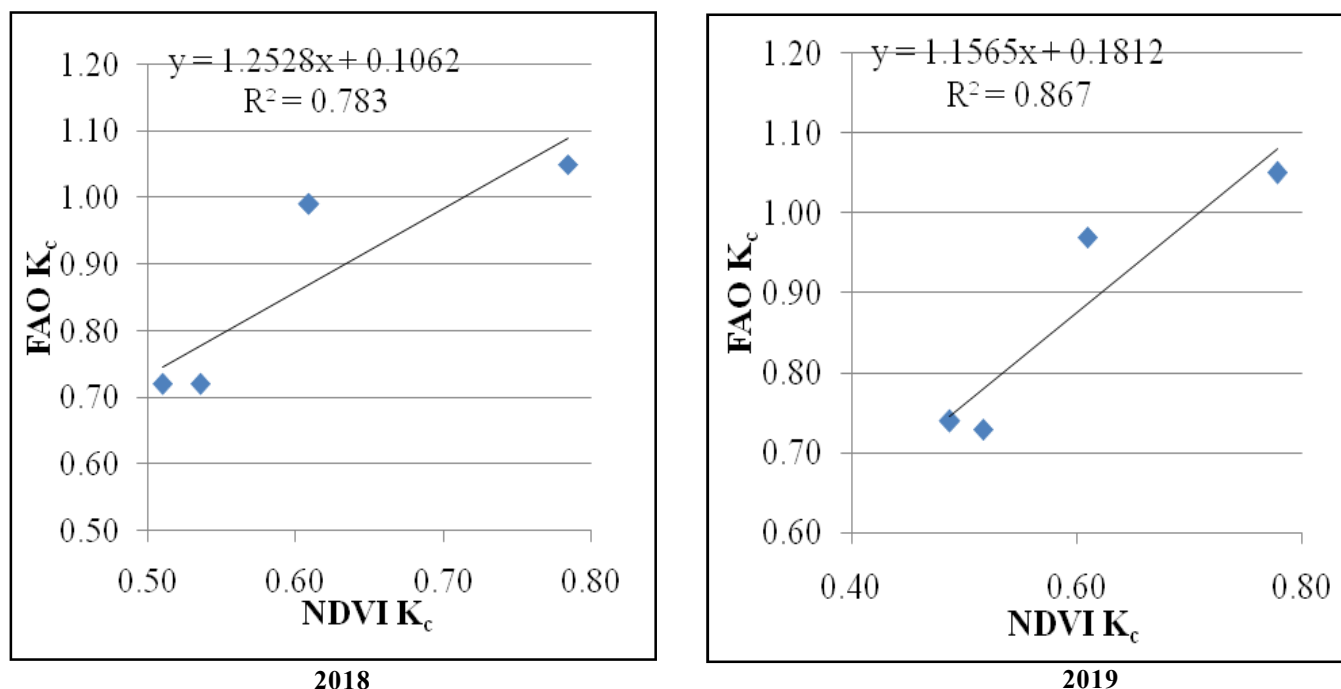


Fig 2 : Comparison between the NDVI K_c and FAO K_c for control irrigation system

Crop water requirement:

Crop water requirement using FAO adjusted K_c :

The stage wise water requirements of summer sesame were estimated using estimated FAO adjusted crop co-efficient (K_c) and reference evapotranspiration (ET_0) for both years 2018 and 2019 and presented in Table 8. It shows that daily crop water requirement was lower for all growth stages in drip system as compare with control system.

Crop water requirement using NDVI K_c :

The stage wise daily water requirements of summer sesame estimated using NDVI based K_c and reference evapotranspiration (ET_0) are presented in Table 10 for

both year of 2018 and 2019. The table shows that daily crop water requirement was lower during initial and development stages in drip system as compared with control system while daily crop water requirement was higher during mid stage in control system as compare with drip system.

Crop growing stage wise water requirement for summer sesame:

Crop growing stage wise crop water requirement of summer sesame estimated through dual crop co-efficient approach using FAO 56 method and NDVI method are presented in Table 10 and Table 11. The table shows that irrigation by surface control irrigation

Sr. No.	Year	Crop development stages	Average crop water requirement (mm/day)	
			Drip irrigation system	Surface control irrigation system
1.	2018	Initial stage	2.81	3.13
		Development stage	4.40	5.21
		Mid stage	5.82	6.00
		End stage	4.88	5.41
		Initial stage	3.22	3.23
2.	2019	Development stage	5.45	5.54
		Mid stage	6.15	6.74
		End stage	5.27	6.26
		Initial stage	3.22	3.23

Table 9 : Crop water requirement using NDVI based K_c method

Sr. No.	Year	Crop development stages	Average crop water requirement (mm/day)	
			Drip irrigation system	Control irrigation system
1.	2018	Initial stage	2.58	2.42
		Development stage	3.59	3.26
		Mid stage	4.29	4.73
		End stage	3.67	3.86
2.	2019	Initial stage	2.74	2.38
		Development stage	4.15	3.66
		Mid stage	4.97	5.14
		End stage	5.61	4.09

Table 10 : Total water requirement (mm) for drip irrigation system

Sr. No.	Year	Crop development stages	FAO method	NDVI method
1.	2018	Initial stage	56.25	51.64
		Development stage	132.00	107.86
		Mid stage	174.60	128.75
		End stage	48.87	36.71
		Total	411.72	324.96
2.	2019	Initial stage	64.46	54.90
		Development stage	163.57	124.66
		Mid stage	184.55	149.36
		End stage	52.78	56.18
		Total	465.36	385.11

Table 11 : Total water requirement (mm) for control irrigation system

Sr. No.	Year	Crop development stages	FAO method	NDVI method
1.	2018	Initial stage	62.65	48.51
		Development stage	156.30	97.97
		Mid stage	180.00	142.06
		End stage	54.14	38.65
		Total	453.09	327.20
2.	2019	Initial stage	64.63	47.65
		Development stage	166.22	109.85
		Mid stage	202.28	154.19
		End stage	62.65	40.99
		Total	495.78	352.70

system requires more water as compare to drip irrigation system while total crop water requirement is lowest in case of NDVI method among these two methods.

Crop growing stage wise water requirement per unit area was estimated for both treatments. Table 9 and 10 indicates that among these two methods, NDVI method estimate lowest water requirement in both cases

i.e. total water requirement and during all the crop development stages for both irrigation systems. The study indicates that NDVI K_c model can estimate actual crop co-efficient and accurate daily water requirement in case of drip irrigation system. Total water requirement was highest in case of FAO method while it was lower in case of NDVI method for both irrigation systems.

Conclusion:

Based on the results obtained at various stages of methodology, following conclusions could be drawn:

– The co-efficient of determination (R^2) for NDVI based K_c compared with FAO adjusted K_c were 0.836 & 0.765 for drip system and 0.783 & 0.867 for control system for 2018 and 2019, respectively.

– In case of FAO 56 method, total water requirement of summer sesame was estimated at 411.6 and 465.1 mm per unit area in drip system and 453 and 495.6 mm per unit area in control system for both year 2018 and 2019, respectively. In FAO 56 method water saving in drip system as compare to control system is 9.14 and 6.05 % for both year 2018 and 2019, respectively.

– In case of Normalized Difference Vegetation Index (NDVI) method, total water requirement of summer sesame was estimated at 324.96 and 385.11 mm/unit area in drip system and 327.20 and 352.70 mm/unit area in control system for both year 2018 and 2019. In NDVI method, the water saving in drip system as compare to control system is 0.69 and -9.18 % for both year 2018 and 2019, respectively.

– Dual crop co-efficient values estimated in the study region was varying from the FAO-56 reported values at different growth stages for sesame. Therefore, it can be concluded that the regional crop co-efficient (K_c) values need to be estimated and used for more accurate irrigation scheduling at regional scales.

– Among these two methods used in this study, NDVI method is more appropriate because it can provide more reliable and actual crop co-efficient and crop water requirement for the study region for *summer sesame* crop.

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