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Water use efficiency and crop coefficients of dry season oilseed crops

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ABSTRACT

Eastern India receives higher average annual rainfall (1000–2000 mm) but 80% of it occurs within the June–September (rainy season), whereas the winter season (November–March) is dry. Due to a shortage of soil moisture, most rainfed areas of the region remain fallow during the winter season and cultivation (mainly rice) is confined to the rainy season only (June–September). To explore the possibility of double cropping in the rainfed rice areas, three oilseed crops, viz., linseed (*Linum usitatissimum* L.), safflower (*Carthamous tinctorious* L.), mustard (*Brassica juncea* L.), were grown in a representative rainfed area of eastern India, i.e. Dhenkanal, Orissa, during the dry/winter season by applying irrigation water at phonological stages. Study revealed that with three supplemental irrigations, the highest WUE was achieved by safflower followed by linseed with the mean values being 3.04 and 2.59 kg ha^{-1} mm^{-1}, respectively. Whereas, with one irrigation, the highest water use efficiency (WUE) was achieved for safflower (1.23 kg ha^{-1} mm^{-1}) followed by linseed (0.93 kg ha^{-1} mm^{-1}). Of the three crops studied, safflower withdrew maximum water followed by mustard and crops were shown to use 90–105 mm more water than linseed. With three irrigations, average maximum rooting depths were 1.66, 1.17 and 0.67 m for safflower, mustard and linseed, respectively, which were 13.5, 10.6 and 11.4% higher than for single irrigated crops because of more wet sub soils and decrease of soil strength. The crop growth parameters like leaf area, dry biomass were also recorded with different levels of irrigation. The research work amply revealed the potential of growing these low water requiring oilseed crops in rice fallow during dry/winter season utilizing limited irrigation from harvested rainwater of rainy season. Crop coefficients (K_c) of three winter season oilseed crops were derived using field water balance approach. Study showed that LAI was significantly correlated with K_c values with the R^2 values of 0.91, 0.89 and 0.94 in linseed, safflower and mustard, respectively. When LAI exceeded 3.0, the K_c value was 1 in safflower and mustard whereas in linseed corresponding LAI was 2.5. Study revealed that the K_c values for the development and mid season stage were slightly higher to that obtained by the procedure proposed by FAO, which might be due to local advection.

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1. Introduction

Determination of crop coefficient under local climatic condition is the base to improve planning and efficient irrigation management in many field crops. Increased water use efficiency of field crops was possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration and providing irrigation at critical growth stages (Eck, 1984; Wang, 1987; Turner, 1987; Wang et al., 2001; Hunsaker et al., 1996; Kipkorir et al., 2002; Norwood and Dumler, 2002; Kar et al., 2005). For most agricultural crops a relation can be established between evapotranspiration and climate by the introduction of the crop coefficient (K_c), which is the ratio of crop evapotranspiration (ETc) to reference evapotranspiration (ETo) (Doorenbos and Kassam, 1979). Reference crop evapotranspiration (ETo) can be estimated by many methods. The Penman–Monteith equation with its new definition of ETo is recommended by FAO experts as the standard method of crop water requirement calculation (Allen et al., 1998). Field water balance is commonly used to measure actual water use or crop evapotranspiration (ETc) when lysimeter facilities are not available (Prihar and Sandhu, 1987). Since localized K_c values are not always available in many parts of India and due to lack of locally determined crop water use data, the values of K_c as suggested by FAO (Allen et al., 1998) are being widely used to estimate crop water requirements. In all cases, no or very little attempt was made to experimentally verify the estimates locally. Much is known about the crop water requirements of important cereals like wheat, rice, etc. using field water balance and/or lysimeter study in field experimental plots at various agro-ecological conditions of India (Prihar et al., 1976; Singh and Sinha, 1987; Singh, 1989; Tyagi et al., 2000) but crop water requirements of some pulses and oilseed are to be known for fitting these crops in the rice fallow of eastern India (Assam, West Bengal, Jharkhand, Orissa, Chhatisgarh and Eastern Uttar Pradesh). The region receives plenty of rainfall (1000–2000 mm) during rainy season (June–September) but the winter season is dry and shortage of soil moisture restricts the good crop production in that season. Efficient capture and retention of precipitation during rainy season and its recycling to second crops during winter season as per the water requirements may be one of the best options to increase the cropping intensity and productivity in the region. Quantifying the rooting depth is necessary for knowledge about water and nutrient extraction patterns of different crops at different depths (Merril, 1992; Merril et al., 2002). Some earlier workers (Zaman et al., 2000; Das, 2001; Prasad et al., 2000; Singh et al., 2000; Kar et al., 2005) attempted to increase productivity and cropping intensity of the rainfed rice areas of eastern India with supplemental irrigation to second crops, like wheat, barley, rajmash, sunflower, maize in rice fallow. In the present paper, the crop coefficients of three dry season oilseed crops were determined for computing crop water requirements locally. The crop growth parameters, (leaf area, biomass, root depth), productivity and water use efficiency of those crops with different levels of supplemental irrigation were also studied to explore the possibilities of growing these crops in rice fallow. The relationship between K_c values and leaf area index of these crops was also established for three dry season oilseed crops.

Table 1 – Normal as well as actual weather data during crop growth period

Parameters	Month				
	November	December	January	February	March
Total rainfall (mm)					
2001–2002	20.1	10.0	22.1	1.1	0.0
2002–2003	13.8	22.8	11.7	0.0	0.0
Normal	25.2	4.5	15.5	17.2	25.4
Mean maximum air temperature (°C)					
2001–2002	32.9	30.1	30.2	32.2	35.9
2002–2003	32.4	30.2	30.9	36.5	38.7
Normal	32.2	29.4	30.9	36.1	38.1
Mean minimum air temperature (°C)					
2001–2002	11.9	9.9	10.1	10.4	12.9
2002–2003	13.1	10.4	9.7	10.0	12.7
Normal	11.5	9.0	9.3	10.3	12.5
Mean relative humidity (%)					
2001–2002	68	53	57	56	61
2002–2003	52	57	57	61	60
Normal	63.5	60.5	61	54	49.5
Mean open pan evaporation (mm day^{-1})					
2001–2002	4.5	4.1	3.2	4.1	4.7
2002–2003	4.3	4.5	2.8	3.7	4.1
Normal	3.9	4.0	3.1	4.2	5.8

2. Material and methods

2.1. Normal weather during crop growth period

The normal as well as prevailing weather conditions during two crop growth seasons (2001–2002 and 2002–2003) are given in Table 1. The spatial location of the experimental site is given in Fig. 1. The study revealed that the mean monthly maximum temperature during crop growth period ranged from 38.7 °C in March (2002–2003) to 30.1 °C in December (2001–2002). On the other hand, mean minimum temperature varied between 24.6 °C in July and 9.0 °C in December. The pan evaporation varied from 2.8 mm in January (2002–2003) to 4.7 mm in March (2001–2002). As per the expected trend, the actual rainfall was meager during crop growth period (dry/winter season). In the first crop year (2001–2002) only 20.2, 10.0, and 22.1 mm rainfall

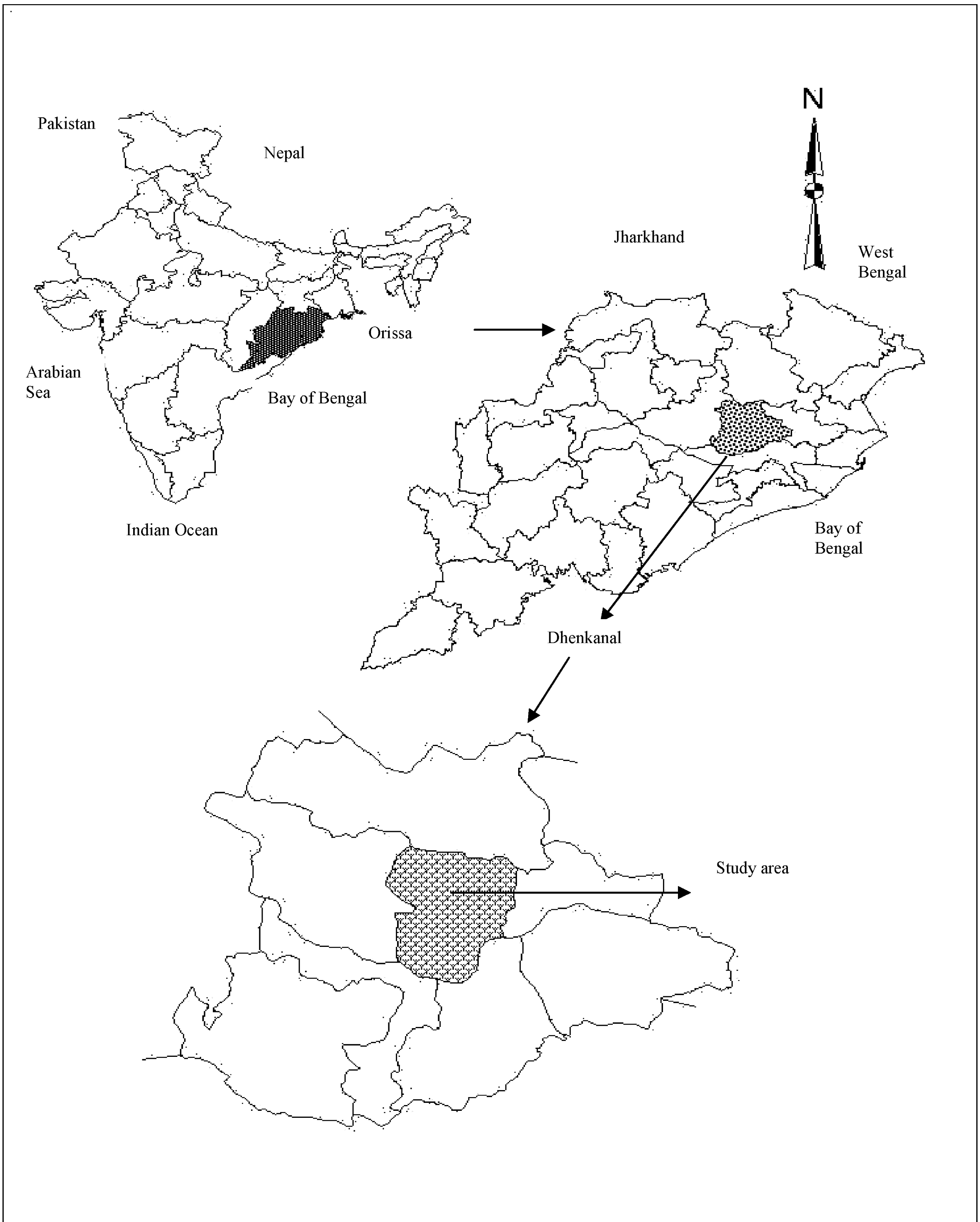

Fig. 1 – Location of the study area.

	I_1	I_2	I_3
R_1	LN	MU	SF
	SF	LN	LN
	MU	SF	MU
R_2	SF	LN	SF
	MU	SF	MU
	LN	MU	LN
R_3	SF	LN	SF
	LN	SF	MU
	MU	MU	SF

Fig. 2 – Layout of the experimental field.LN, Linseed; SF, Safflower; MU, Mustard. *I*1, One irrigation; *I*2 two irrigation; *I*3 three irrigation (from recycling of harvested rain water); R1, R2 and R3 are three replications.

occurred in November, December and January, respectively, and in another study year (2002–2003), the rainfall was 13.8, 22.8, and 11.7 mm in November, December and January, respectively. Study revealed that weather during crop growth periods was almost comparable with that of the normal.

2.2. *Characterization of soil properties*

The physical and physicochemical properties of soils were determined using standard procedures. The particle size analysis was carried out by International Pipette method and organic carbon by Walkey and Black method. Soil water retention characteristics ($\Psi - \theta$) were determined by using pressure plate apparatus as per the procedure described by Richards (1949). Saturated hydraulic conductivity was determined by constant head method (Klute, 1965). Available water in the soil was computed by subtracting the amount of water held at 1.5 MPa (permanent wilting point) from that at 0.033 MPa (field capacity).

2.3. *Crop management and measurement of crop growth parameters*

Three dry season oilseed crops, viz., linseed (*Linum usitatissimum* L.), safflower (*Carthamous tinctorious* L.) and mustard (*Brassica juncea* L.) were sown on 17 November, 2001 and 13 November, 2002, in rice fallow after the harvest of rainy season rice (cv. Lalat) (layout is given in Fig. 2). Irrigation treatments were one, two, or three irrigations and in each irrigation 60 mm of water was applied through gated pipe from harvested rainwater of rainy season. Plots were bordered to prevent runoff. The crops were irrigated on different dates based on critical phenological stages of the crop (Table 2). The summary of practices for growing these crops is given in Table 3. In regard to fertilizer management of these crops, half of the nitrogen and full dose of phosphorus and potash were applied as basal dose at the time of sowing by placement method. The remaining half of the nitrogen was applied at the time of first irrigation. The experiments were conducted in split plot design where the main plot was used for irrigation treatments and crops were sown in the subplots (Fig. 2). The number of replications was three with the individual subplot size being 6 m $\times$ 4 m. The maximum root length of different crops was observed by digging trench profiles at the stage of physiological maturity. Biometric observations, viz., leaf area index (LAI) and above ground dry biomass of different crops with varying irrigation levels were recorded at 10-day interval using the method of Kar et al. (2005). Grain yields of different crops were harvested by hand harvesting from two rows of the center of each plot. The net return was computed in Indian Rupees (One Indian Rupees US$ 0.0229) by subtracting fixed cost (interest on land) and operational expenses of cultivation (seeds, irrigation, fertilizers, ploughing and cost of other agro inputs) from gross income of the produce.

Table 2 – Irrigation scheduling at different growth stages of winter crops

Irrigation treatments	Crops		
	Linseed	Safflower	Mustard
One	50% flowering	50% flowering	50% flowering
Two	50% flowering + grain filling	Secondary branching + seed formation	50% flowering + siliqua development
Three	Secondary branching + 50% flowering + grain filling	Secondary branching + 50% flowering + seed formation	Secondary branching + 50% flowering + siliqua development

Table 3 – Package of practices for growing different crops

Crop	Variety	Spacing (cm × cm)	Fertilizer dose, N:P:K	Date of sowing		Date of harvesting	
				2001–2002	2002–2003	2001–2002	2002–2003
Linseed	Sekhar	30 × 10	40:20:20	17.11.2001	13.11.2002	25.02.2002	24.02.2003
Safflower	Bhima	30 × 10	40:40:20	17.11.2001	13.11.2002	25.02.2002	24.02.2003
Mustard	Pusa Bold	30 × 15	40:30:20	17.11.2001	13.11.2002	25.02.2002	24.02.2003

2.4. Computation of crop coefficients (K_c)

$$K_c = \frac{ETc}{ETo} \quad (1)$$

where ETc is actual evapotranspiration or actual water use and ETo is reference evapotranspiration; ETo is estimated using the Penman–Monteith method.

The actual water use (AWU) was estimated as per the equation,

$$AWU = ER + I + \Delta S + \int_{t_2}^{t_1} F_x \, dt \quad (2)$$

where ER, effective rainfall (mm), calculated using USDA soil conservation services methods, I, irrigation (mm), ΔS, change in soil moisture storage.

To compute the actual water use the soil water content was measured gravimetrically once a week from 0 to 0.15 m, 0.15 to 0.30 m, 0.30 to 0.45 m 0.45 to 0.60 m, 0.60 to 0.90 m and 0.90 to 1.20 m soil layers.

F_x, vertical flux (mm day^{-1}) up to the depth of 1.20 m, computed following Darcy's law

$$F_x = -K\frac{\delta H}{\delta Z} \quad (3)$$

where K is the hydraulic conductivity (mm day^{-1}), and $\delta H/\delta Z$ is hydraulic gradient.

For estimating K_c, growth stages of crop were divided into four stages: initial, crop development, mid season, and late season stage (Doorenbos and Pruitt, 1977). Generally, the K_c curve reflects an initial stage with low values and then arising limb during increased phase and a peak where the crops attains maximum cover and growth followed by a decreasing limb when leaves start shedding at the end of the growth cycle. The change in the slope of the curve reflects a change in the stage. For this study, the initial, development, mid season and late seasons of crop were identified based on phenological observations.

Water use efficiency (WUE) was determined by dividing the grain yield by the actual water used (sum of soil water at planting – soil water at harvest + irrigation water + effective rainfall) and expressed as kg ha^{-1} mm^{-1} (Kar et al., 2005).

3. Results and discussion

3.1. Soils of experimental site

Taxonomically the soils of the experimental area belongs to category of Fine, Loamy, Mixed Hyperthermic Typic Haplaustalf. The upper layer (0–0.15 m) of the soil profile was sandy loam in texture whereas next two layers (0.15–0.30 and 0.30–0.45 m) were sandy clay loam in nature (Table 4). The bulk density was 1.55 Mg m^{-3} at 0–0.15 m soil depth and it increased with depth, for the 0.9–1.2 m layer it was 1.62 Mg m^{-3}. The pH was slightly to

Table 4 – Important soil properties of the experimental site

Soil depth (m)	Particle size distribution (%)			Textural class	Bulk density (Mg m^{-3})
	Sand	Silt	Class		
(a) Particle size analysis					
0.00–0.15	53.0	30.0	17.0	sl	1.55
0.15–0.30	52.2	25.8	22.1	scl	1.55
0.30–0.45	46.0	25.0	29.2	scl	1.58
0.45–0.60	45.6	27.4	29.0	scl	1.60
0.60–0.90	43.6	22.4	33.9	cl	1.60
0.90–1.20	42.6	23.6	33.8	cl	1.62

Soil depth (m)	θ_s (m^3 m^{-3}) at 0.01 MPa	θ (m^3 m^{-3}) at 0.33 MPa	θ (m^3 m^{-3}) at 1.5 MPa	Available water content (m^3 m^{-3})
(b)Water retention properties				
0.00–0.15	0.283	0.220	0.092	0.128
0.15–0.30	0.203	0.227	0.103	0.124
0.30–0.45	0.334	0.269	0.113	0.154
0.45–0.60	0.341	0.276	0.118	0.158
0.60–0.90	0.321	0.261	0.111	0.150
0.90–1.20	0.309	0.279	0.178	0.162

Fig. 3 – Maximum above ground biomass of different crops as influenced by irrigation levels (pooled data of 2001–2002 and 2002–2003).

Fig. 4 – Maximum leaf area index of different crops as influenced by irrigation levels (pooled data of 2001–2002 and 2002–2003).

moderately acidic and no salt problem (low EC) was detected in the soil profile. The fertility status of the soil was very low. The organic carbon content was the highest (0.60%) at the upper layer (0–0.15 m) while at the deeper layer (0.9–1.2 m) it was only 0.07%. The Olsen P and available K (NH4OAc-K) were 2.9 mg P kg^{-1} and 75 mg K kg^{-1} of soils, respectively, at upper soil layer (0–0.15 m). The available water at field capacity was 0.220 $m^3\,m^{-3}$ at 0–0.15 m depth and the highest water content of 0.276 $m^3\,m^{-3}$ was determined at 0.45–0.60 m soil depth. The available water ranged between 0.128 and 0.162 $m^3\,m^{-3}$ at different soil depths.

3.2. *Crop growth, productivity and water use efficiency*

3.2.1. *Crop growth parameters with different levels of irrigation*

Two main crop growth parameters, viz., maximum above ground biomass and leaf area index were measured with different levels of irrigation and are presented in Figs. 3 and 4, respectively (pooled data of 2001–2002 and 2002–2003). Study revealed that in linseed with one irrigation, mean above ground biomass of 355 g m^{-2} was achieved (Fig. 3). Maximum above ground biomass of 497 g m^{-2} was observed when two irrigations were applied to this crop, which was 26% higher than that of single irrigated crop. With three irrigations above ground biomass of 509 g m^{-2} was obtained in linseed.

In safflower with one irrigation, this crop acquired maximum above ground biomass of 575 g m^{-2} and 16% above ground biomass was enhanced when two irrigations were applied. Whereas, with three irrigations above ground biomass of 872 gm^{-2} were obtained, 34.1% higher than that of single irrigation.

With one irrigation, mean above ground biomass of 395 g m^{-2} was achieved by mustard crop and 33.7% above ground biomass was enhanced when two irrigations were applied to this crop. With three irrigations above ground biomass of 812 g m^{-2} was obtained for this crop, which was 51.3% higher than that of single irrigation.

The highest leaf area index was also observed with three supplemental irrigations for all the crops. In linseed with three

Table 5 – Yield and water use efficiency (pooled data of 2 years) of different crops with limited irrigation (pooled data of 2001–2002 and 2002–2003)

	Treatments	Linseed	Safflower	Mustard
Crop yield (kg ha^{-1})	I_1	212^c	392^c	246^c
	I_2	701^b	762^b	547^b
	I_3	845^a	1258^a	938^a
	L.S.D. ($P < 0.05$)	49.33	91.95	22.30
Water use (mm)	I_1	227^c	319^c	279^c
	I_2	279^b	363^b	321^b
	I_3	325^a	413^a	381^a
	L.S.D. ($P < 0.05$)	19.39	22.27	20.84
Water use efficiency (kg ha^{-1} mm^{-1})	I_1	0.93^b	1.23^c	0.88^c
	I_2	2.51^a	2.11^b	1.71^b
	I_3	2.59^a	3.04^a	2.45^a
	L.S.D. ($P < 0.05$)	0.74	0.25	0.59
Profitability (Rs. ha^{-1})	I_1	0^c	2488^c	190^c
	I_2	3510^b	7088^b	4205^b
	I_3	4450^a	16840^a	9570^a
	L.S.D. ($P < 0.05$)	84.82	368.71	39.81

I_1, One irrigation, I_2, two irrigation, I_3, three irrigation. Values within a column followed by the same superscripts 'a–c' are not significantly different at 5% level of significance using DMR Test.

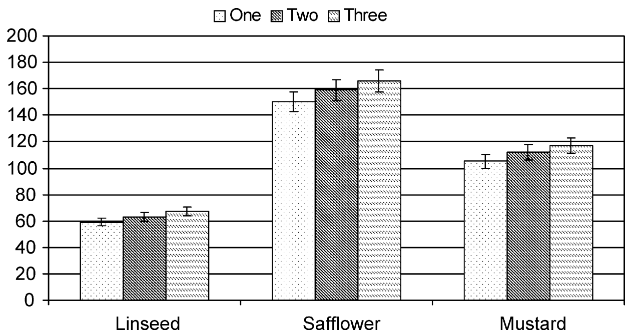

Fig. 5 – Maximum rooting depth of different crops as influenced by irrigation levels (pooled data of 2001–2002 and 2002–2003).

irrigations mean peak LAI of 3.7 was obtained, whereas with one irrigation peak LAI was only 2.2. With two irrigations 36.2% higher LAI (3.5) was obtained than that of the single irrigated crop (Fig. 4). On the other hand, in safflower, the highest leaf area index was observed with three irrigations with the mean value being 5.7, which was 21.3 and 28.9% higher than that of with one and two irrigations, respectively. With one and two irrigations this crop achieved LAI of 5.15 and 5.7, respectively. The highest leaf area index (3.35) of mustard crop also was observed with three irrigations with the mean value being 5.35, which was 84% higher than the single irrigated plots. This crop acquired peak LAI of 2.9 and 3.5 with one and two irrigations, respectively (Fig. 4).

3.2.2. *Grain yield and profitability with supplemental irrigation*

The study revealed that supplemental irrigation had a significant effect ($P < 0.05$) on grain yield of all the three oilseed crops (Table 5). In linseed with one supplemental irrigation, 212 kg ha^{-1} grain yield was obtained. With two supplemental irrigations, grain yield was enhanced by 69% (701 kg ha^{-1}) and with three irrigations 845 kg ha^{-1} grain yield was obtained, which was 298% higher than that of single irrigation. In regard to profitability, no net economic return was obtained from the crop with one irrigation, whereas, Rs. 3510 ha^{-1} and Rs. 4450 ha^{-1} net return were obtained with two and three supplemental irrigations, respectively.

The study revealed that in safflower with one irrigation only 392 kg ha^{-1} grain yield was obtained and yield was enhanced by 48% when two irrigations were applied over one irrigation. Whereas with three irrigations 1258 kg ha^{-1} grain yield was obtained, 220% higher than for a single irrigation. The yield difference among different levels of irrigation was found statistically significant (at 5% level of significance) in this crop. In regard to profitability, Rs. 2488 ha^{-1}, Rs. 7088 ha^{-1} and Rs. 16840 ha^{-1} per hectare net profits were obtained with one, two and three irrigations, respectively (Table 5).

The study revealed that supplemental irrigation had a significant effect ($P < 0.05$) on grain yield of mustard also (Table 5) and with one supplemental irrigation, mean yield of 246 kg ha^{-1} was obtained in this crop. With two supplemental irrigations, grain yield was enhanced by 55% for this crop over one irrigation. The crop achieved 938 kg ha^{-1} grain yield with three irrigation, which was 281% higher than for a single irrigation. In regard to profitability, Rs. 190 ha^{-1}, Rs. 4205 ha^{-1} and Rs. 9570 ha^{-1} net return were obtained from this crop with one, two and three irrigations, respectively.

3.2.3. *Field water use and water use efficiency*

The WUE of 0.93 and 2.51 kg ha^{-1} mm^{-1} was obtained with one and two irrigations, respectively. The WUE increased significantly by 169% when two irrigations were applied over one irrigation in linseed. With three supplemental irrigations, the highest WUE was achieved with the mean value being 2.59 kg ha^{-1} mm^{-1} (Table 5). The study also revealed that enhancement of WUE from two to three irrigations was not significant, (at 5% level of significance) in linseed, which might

Table 7 – Derived crop coefficients of different winter crops (based on field water balance approach)

Stage	ETo (mm)	AWU (mm)	K_c
Crop: Linseed			
Initial	82.4 ± 1.23	29.4 ± 1.11	0.35
Development	122.4 ± 3.56	112.5 ± 3.66	0.91
Mid season	136.2 ± 4.52	160.6 ± 4.56	1.17
Late season	81.6 ± 1.27	23.6 ± 0.99	0.28
Crop: Safflower			
Initial	103 ± 2.21	38 ± 0.69	0.37
Development	142 ± 3.65	134 ± 2.21	0.94
Mid season	160 ± 2.64	206 ± 3.21	1.29
Late season	84 ± 1.12	29.3 ± 0.14	0.35
Crop: Mustard			
Initial	100 ± 2.56	39 ± 0.35	0.39
Development	138 ± 3.21	128 ± 2.29	0.92
Mid season	148 ± 2.26	194 ± 3.25	1.31
Late season	102.7 ± 3.25	43 ± 0.68	0.42

Table 6 – Percentage of total extracted water at different soil depths (pooled data of 2001–2002 and 2002–2003)

Soil depth (m)	Linseed			Safflower			Mustard		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
0.00–0.30	45.1^b	45.4^b	48.5^a	29.4^a	29.1^a	29.3^a	35.2^a	36.4^a	35.6^a
0.30–0.60	46.6^a	48.3^a	46.9^b	24.6^b	25.3^b	25.5^b	32.1^b	32.6^b	32.8^b
0.60–0.90	5.01^c	3.98^c	3.42^c	22.4^c	22.8^c	20.0^c	17.9^c	18.9^c	18.6^c
0.90–1.20	3.29^d	2.32^d	2.06^d	18.4^d	17.5^d	17.0^d	14.7^d	11.9^d	13.0^d
LSD ($P < 0.05$)	1.49	1.51	1.17	0.99	1.1	1.46	1.22	1.22	1.45

I_1, One irrigation, I_2, two irrigation, I_3, three irrigation. Values within a column followed by the same superscripts 'a–d' are not significantly different at 5% level of significance using DMR Test.

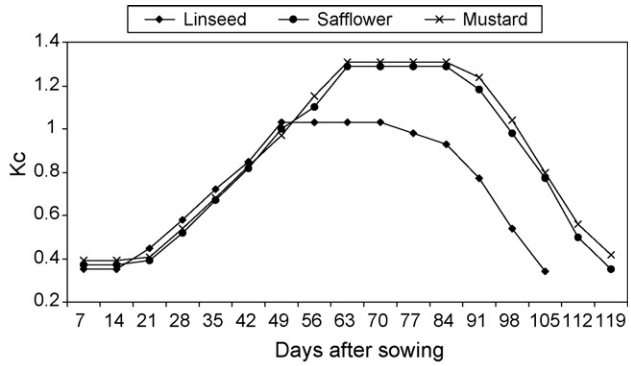

Fig. 6 – Variation of crop coefficients with days after sowing.

be due to increased water application resulting in increased crop water use without a corresponding increase in yield for linseed.

The study revealed that in safflower with one irrigation, the water use efficiency (pooled data of 2 years) of 1.23 kg ha^{-1} mm^{-1} was achieved. The WUE increased significantly by 71% (2.11 kg ha^{-1} mm^{-1}) when two irrigations were applied over one irrigation. With three supplemental irrigations, the highest WUE was achieved with the mean value being 2.96 kg ha^{-1} mm^{-1}.

Supplementary irrigation had significant effect ($P < 0.05$) on water use efficiency of mustard (Table 5). The mustard crop achieved WUE of 0.88 kg ha^{-1} mm^{-1} with one irrigation and the WUE increased significantly by 94% (1.71 kg ha^{-1} mm^{-1}) when two irrigations were applied over one irrigation. With

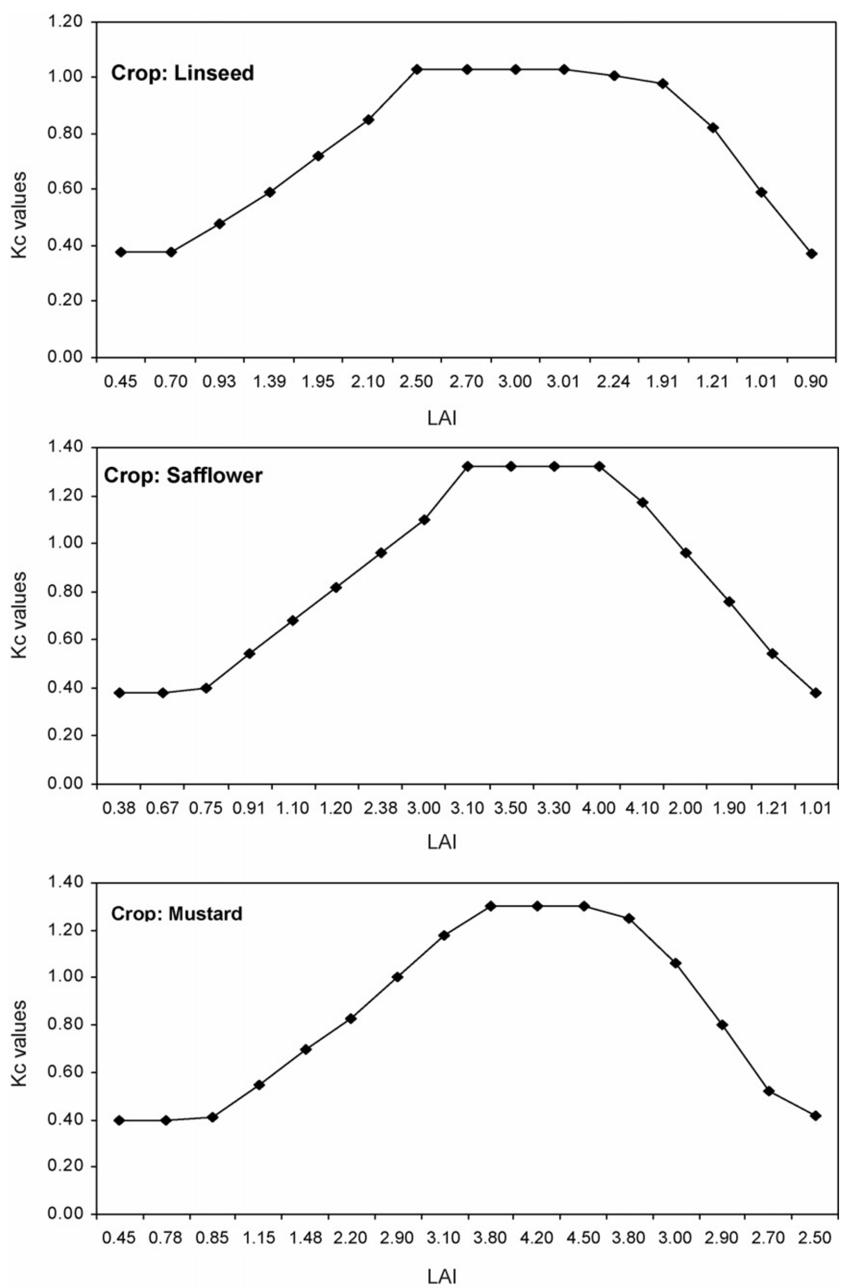

Fig. 7 – Variation of leaf area index with days after sowing.

three irrigations 2.45 kg ha^{-1} mm^{-1} water use efficiency was achieved by this crop (Table 5).

3.2.4. Maximum rooting depth studies and water extraction pattern

The maximum rooting depth of different crops in rainfed rice fallow was measured and average results of 2 years are presented in Fig. 5. The water uptake of different crops from different depths was also studied and the percentage of total water use extracted at different depth has been given in Table 6. Among three oilseed crops studied, linseed was shallow rooted (maximum depth 0.67 m) that extracted about 90% soil moisture from the 0 to 0.60 m soil layer. The shallow rooting behaviour of the linseed crop will be advantageous for adapting to improved moisture conditions of the surface soil. With three irrigations, average maximum rooting depth was 0.67 m in linseed, 11.4% higher than for single irrigated crop, which might be due to wetter sub soils and decrease of soil strength.

Of the three crops studied, safflower had the greatest water use (Table 6) followed by mustard and both the crops were shown to withdraw from 90 to 105 mm more water than linseed. Safflower with its tap root and organized root growth system was found to be the most deeply rooted of the crops grown in rainfed rice fallow of the region and has the capability of extracting subsoil water at greater depths than other oilseed crops. Safflower extracted 20–22.8 and 17–18.4% of total water use at 0.60–0.90 and 0.90–1.20 m depths, respectively. Safflower produced 392 and 762 kg ha^{-1} grain yield with one and two irrigations, respectively, when the crop fulfilled 68.6 and 78.4% of its crop water requirements. With three irrigations, safflower achieved average maximum rooting depth of 1.66 m, 13.5% higher than for single irrigated crops.

In linseed, average maximum rooting depth was 1.17 m when three irrigations were applied for mustard, which was 10.6% higher than for single irrigated crops. The variation of rooting depth in different crops was positively correlated with soil water extraction for mustard also. With one and two irrigations, this crop achieved maximum rooting depth of 1.05 and 1.12 m, respectively. The study revealed that the maximum rooting was increased with more number of supplemental irrigation for all the three crops, which might be due to wetter subsoils and decrease of soil strength (Fig. 5).

3.3. Determination of crop coefficients

The actual evapotranspiration (AET) at four different growth stages was measured using the methodologies mentioned in Section 2 (Table 7). The crop coefficients derived at four growth stages were extrapolated using a best-fit polynomial equation and are presented in Fig. 6. Study revealed that in linseed crop coefficient values were 0.35, 0.83, 1.03 and 0.28 at initial, development, mid and late season, respectively. During the first stage of crop growth, which covered the period from sowing through 3 weeks after sowing (WAS), highest K_c value was 0.35 and it could be due to low LAI (<1) at this stage. During the crop development stage (4–7 WAS), K_c values further increased from 0.35 to 0.83. During the mid season of crop growth starting from 8 to 12 WAS, the maximum value of K_c was 1.03 during 13 WAS when leaf area index was >2.5, close to the grain filling stage. On the other hand, in safflower K_c values of 0.37, 0.94, 1.29 and 0.35 were achieved at initial, development, mid season and late season, respectively. The highest K_c was observed when LAI exceeded 3, coincided with seed filling stage (Table 7). In mustard K_c values of 0.39, 0.92, 1.31 and 0.42 were achieved at initial, development, mid season and late season, respectively. The highest K_c was observed when LAI exceeded 4 in mustard, coincided with seed filling stage like safflower (Table 7). A relationship was drawn (Fig. 7) between K_c and LAI for three oilseed crops and it was found that leaf area index was significantly correlated with K_c values with the R^2 of 0.91, 0.89 and 0.94, respectively. The variation of K_c with days after sowing (DAS) is given in Fig. 6. Study revealed that the crop coefficients declined rapidly during the last crop growth stage covering the maturity period. Study also revealed that during the crop development and maturity stages, the estimated K_c values were 11–23% higher in different crops than the values reported by FAO, although the values of initial and mid season were identical. The higher values could be mainly due to local advection and experiments were performed in small plots.

4. Conclusion

The study amply revealed the possibility of growing low water requiring oilseeds profitably in rainfed rice fallow with supplemental irrigation at critical growth stages. Enhancement of WUE from two to three irrigation was not significant in the case of linseed, which might be due to increased water application resulting in increased crop water use without a corresponding increase in the yield of linseed. On the other hand, WUE was increased significantly from 2 to 3 irrigations in safflower and mustard. Therefore, to achieve higher WUE and profitability from these crops, at least three supplemental irrigations were required to grow these in rainfed rice fallow of eastern India. Safflower with its tap root and organized root growth system was found the most deeply rooted and had the capability of extracting soil moisture at greater depths. Among the crops, with three irrigations, more net economic return was obtained from safflower. Study showed that LAI is significantly correlated with K_c values, when LAI exceeded 3.0, the K_c value was 1 in safflower and mustard. During the crop development and maturity stages, the estimated K_c values were 11–23% higher in different crops than the values reported by FAO, although the values of initial and mid season were identical. The higher values could be mainly due to local advection and experiments were performed in small plots.

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