Vol. 43, No. 1, pp 63-71, 2015

Indian Journal of Soil Conservation

Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Influence of sowing seasons and irrigation levels on surface energy balance, radiation utilization and water use efficiency of sunflower in an eastern Indian watershed

Gouranga Kar[1] and Ashwani Kumar

ICAR-Directorate of Water Management, Chandrasekharpur, P.O. Rail Vihar, Bhubaneswar-751023, Odisha.
[1]E-mail:kar_wtcer@yahoo.com

ARTICLE INFO

Article history :
Received : October, 2013
Revised : July, 2014
Accepted : September, 2014

Key words :
Crop water use,
Energy balance,
Phenology,
Radiation use efficiency,
Sunflower

ABSTRACT

Surface energy balance, water use efficiency and radiation utilization efficiency of sunflower were studied under different sowing dates and irrigation regimes in Bahasuni watershed, Dhenkanal, Odisha. The latent heat flux of the crop varied with the photo-thermal environments and values ranged between 8.64 to 18.77 MJ m^{-2} day^{-1} under different treatments. It was revealed that during mid-growth stage when canopy was fully developed and water did not limit transpiration (wet soil), latent heat flux consumed most of the energy from net radiation. As the soil dried towards maturity, water became less available for evapotranspiration and the energy was used mostly for heating the soil (soil heat flux) or heating the air (sensible heat flux). Supplemental irrigations had significant effects on crop growth and radiation utilization efficiency (RUE) of the crop in dry season. Mean values of RUE were 1.44, 1.63 and 1.73 g MJ^{-1} with three, four and five irrigations, respectively. The water use efficiency (WUE) of the crop also varied with sowing dates and irrigations. Averaged over years and irrigations, winter season crops registered high WUE with the values being 3.16 and 3.28 kg $ha^{-1}mm^{-1}$ for second (October-February) and third sown (June-November) crops, respectively.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the major edible vegetable oils consumed in India and is also used in the preparation of vanaspati and manufacture of soaps and cosmetics. Due to rich source (64%) of linoleic acid which is good for heart patients, the popularity of sunflower cultivation in India is increasing. Presently, the productivity of sunflower in India (6.08 q ha^{-1}) is far below compared to the productivity of other major producers of the crop like Russia, Ukraine, Argentina and China (average world's productivity is 1271 kg ha^{-1}) (Anonymous, 2008). Since sunflower is a day neutral crop and has got wide adaptability to different soils, seasons and agro-climatic conditions, it is grown in different seasons like in rainy, winter and summer. But probable reasons for low productivity of this crop in eastern India is unavailability of adequate irrigation during winter and summer and plenty of rainfall with low solar radiation during rainy season. Depending upon the harvesting period of previous rice crop, farmers sow winter sunflower from October to January. But with delayed sowing higher temperatures reduce the vegetative and reproductive phases of the crop; as a result, crop growth parameters and productivity also decrease (Goyne *et al.,* 1990; Flagelia *et al.,* 2002; Aiken, 2005; Font *et al.,* 2008; Craufurd and Wheeler, 2009). Similar observations were also found by other researchers on maize and *Brassica* (Jat *et al.,* 2012; Adak *et al.,* 2012; Adak *et al.,* 2013). With reference to response of day length on duration of the crop, contrasting information is available. Some studies indicated that short days accelerate sunflower development (Dyer *et al.,* 1959; Doyle, 1975), others reported that sunflower development was photo-period neutral (Robinson *et al.* 1967; Goyne *et al.,*1989). Energy balance, latent heat flux and water use efficiency under different photo-thermal environments provide information on crop water requirement and will be helpful for irrigation scheduling of the crop during winter/dry season (Kar *et al.,* 2004; Shen *et al.,* 2004; Figuerola and Berliner, 2006). Further radiation interception, the efficiency of conversion of intercepted radiation to dry matter and partitioning of dry matter to grain varies in different seasons with different photo-thermal environments, as a result productivity of the crop differed (Gallaghar and Biscoe, 1978; Kar *et al.,* 2005; Figuerola and Berliner, 2006; Kar *et al.,* 2013).

Keeping the importance of above points in view, a field experiment was conducted in Bahasuni watershed of Dhenkanal, Odisha with the objective to investigate the energy balance, radiation utilization and water use efficiency of the crop under different photo-thermal environments during four seasons in order to suggest a suitable sowing period for obtaining higher crop productivity. The rate of phenological development with maximum temperature, minimum temperature and day length was also correlated. The watershed is mainly dominated by rainfed rice but based on agro-climate and soil analysis, sunflower has been considered as a promising option for diversifying cropping system on upland during rainy season and on medium and lowlands in rice fallow of winter season.

2. MATERIALS AND METHODS

Site Description

The on-farm experiment was carried out during 2007-08 and 2008-09 at Bahasuni watershed of Dhenkanal district, Odisha, India (Latitude $28^0 60'$ N and Longitude of $85^0 57'$ E). As per the Indian Meteorological Department, the study area has 4 climatic seasons *viz.,* rainy or southwest monsoon (June to September), retreating monsoon (October to November), winter (December to February) and pre-monsoon or summer (March to May) seasons. About 72% of total annual rainfall (1440 mm) occurs during southwest monsoon period. In post monsoon or other seasons, rainfall is meager and erratic; cropping is not possible without providing supplemental irrigations in those seasons. The soil texture of the study area varied from sandy loam to sandy clay loam.

Crop Management

Sunflower cv. 'KBSH-1' was grown four times in a year during different climatic seasons following standard package of practices. Treatments comprised of combinations of four sowing dates (S_1 = 23rd June, 2007, S_2 = 18th October, 2007, S_3 = 23rd November, 2007, S_4 = 3rd January, 2008 and S_1 = 25th June, 2008, S_2 = 17th October, 2008, S_3 = 26th November, 2008, S_4 = 3rd January, 2009) in main plots and three irrigation regimes (I_1 = Three irrigations, I_2 = Four irrigations, I_3 = Five irrigations) in sub-plots with split-plot statistical design.

Since in winter/dry season, the rainfall was meager and erratic, the crop was irrigated based on critical phenological stages. In each irrigation, 70 mm water was applied from harvested rainwater of the pond through gated pipe. I_1 = Three irrigations (four leaved stage + beginning of flowering stage + seed filling stage); I_2 =Four irrigations (four leaved stage + flower bud stage + beginning of flowering stage + seed filling stage); I_3 = Five irrigations (four leaved stage + flower bud stage + beginning of flowering stage + seed formation stage + seed filling stage). Due to continuous rain during growth period of June sown crop (S_1) in both the years, no irrigation was needed to apply in this treatment and the crop grew as a rainfed crop. Phenological developmental rate from emergence to flowering, flowering to seed filling, seed filling to maturity were correlated with prevailing maximum temperature, minimum temperature and day length as per the procedure proposed by Hammer *et al.* (1982) and Rezadoust *et al.* (2010).

$$1/D = f(t) \times f(p) \qquad \ldots\ldots (1)$$

Where, f (t) and f (p) are functions of day length and temperature, respectively and D is the number of days between two particular phenological stages.

Plant samples were collected from five plants at different important phenological stages like secondary branching, flower bud initiation, flowering, seed formation, seed filling and maturity stages of the crop for leaf area index (LAI) and dry biomass analysis. The threshed seeds were hand cleaned, dried and weighed for grain yield and oil content analysis. The LAI and dry biomass were determined using the procedure of Kar and Verma (2005).

$$\text{Leaf area index (LAI)} = \frac{\text{Sum of the leaf area of all leaves}}{\text{Ground area of field from where the leaves are measured}} \qquad \ldots\ldots(2)$$

Surface Energy Balance

Bowen ratio (β) energy balance method was used to compute latent heat flux which is a micro-meteorological method to quantify latent heat flux (Shen *et al.,* 2004; Kar and Kumar, 2007; Kar and Kumar, 2013).

The energy balance equation is

$$R_n = LE + H + G \qquad \ldots(3)$$

$$\Rightarrow R_n - G = LE\,(1 + H/LE) = LE\,(1 + \beta) \qquad \ldots(4)$$

$$LE = \frac{(R_n - G)}{(1 + \beta)} \qquad \ldots\ldots(5)$$

On the other hand, Bowen ratio (β) =

$$\frac{\text{Sensible heat loss (H)}}{\text{Evaporative heat loss } (\lambda E)} \qquad \ldots\ldots.(6)$$

$$= \frac{C_p P_a (T_2 - T_1)}{L\varepsilon\,(e_2 - e_1)} \qquad \ldots.\ (7)$$

Where, C_p = Specific heat capacity of air (1 J g^{-1} °C^{-1}); P_a = Atmospheric pressure (101.3 kPa); L = Latent heat of vaporization (2449 J g^{-1}); ε = Ratio of the molecular weight of water to that of air (0.622).

$$\text{So, } \beta = \frac{(1 \times 101.3)\ (T_2 - T_1)/\ Z_2 - Z_1}{2449 \times 0.622\ (e_2 - e_1)\ /\ Z_2 - Z_1} = 0.067\ \frac{(\delta T\ /\ \delta Z)}{(\delta e\ /\ \delta Z)} \quad \ldots\ldots (8)$$

Where, R_n-G = available energy, T_1 is the temperature at height, z_1, T_2 is the temperature at height, z_2, e_1 is the vapour pressure at height, z_1, e_2 is the vapour pressure at height, z_2.

R_n was measured using BABUC M net radiometer. The soil heat flux 'G' was computed with the equation, Gs = 0.4*Rn (Exp(-K*LAI)), where 'K' is the extinction coefficient, and LAI = Leaf area index (Kar and Kumar, 2009).

The sensors to measure temperature, humidity and wind velocity were installed inside the cropped field on a tower at a distance of 0.5 m which measures theses parameters at 1-hour interval at 3 different heights. The output of all meteorological sensors were recorded with a datalogger and retrieved afterwards.

Radiation Utilization Efficiency (RUE) and Intercepted Photosynthetically Active Radiation (IPAR)

The rate of increase of biomass density, B (g m^{-2}), is proportional to the absorbed photo-synthetically active radiation, APAR (MJ m^{-2} d^{-1}) (Monteith, 1972).

$$\frac{dB}{dT} = \varepsilon APAR \quad \ldots\ldots(9)$$

Where, ε is the radiation use efficiency (RUE) (g MJ^{-1}). Hence, the cumulative biomass can be obtained by integrating equation (9):

$$B = B_0 + \varepsilon\ APAR \quad \ldots\ldots (10)$$

Where, APAR is the cumulative absorbed PAR flux density and B_o is the biomass density at time zero. Regression of B vs. APAR should be a linear regression line of slope and intercept zero, if no biomass is present prior to the start of photosynthesis (Pitman, 2000). In this study, the dry biomass at different stages was measured and corresponding accumulated photosynthetically active radiation (APAR) was computed to estimate radiation utilization efficiency (RUE) using the following relationship:

$$\varepsilon\ (g\ MJ^{-1}) = \frac{B\ (g\ m^{-2})}{APAR(MJ\ m^{-2})} \quad \ldots\ldots (11)$$

The mean daily values of solar radiation received above the crop canopy during different weeks of the crop growth were estimated using Penman (1948) formula and the photosynthetically active radiation was calculated by multiplying it with 0.48 following Monteih (1972) and Kar *et al.* (2013).

The intercepted PAR (IPAR) was measured using light transmission meter (EMS-7) as per the following relationship:

IPAR = Incident radiation on the canopy - reflected radiation by the canopy - transmitted radiation through the canopy + reflected from the ground.

IPAR (%) at any canopy height =

$$\frac{\text{PAR received any height of the canopy}}{\text{PAR incident above the crop canopy}} \times 100 \quad \ldots\ldots (12)$$

Crop Water Use and Water Use Efficiency

Soil samples from the net plot area were taken during sowing and at periodic intervals from 00.15, 0.150.30, 0.300.45, 0.450.60 and 0.600.75 m soil depths with the help of screw auger. Based on the soil moisture percentage, crop water use (CWU) and the WUE of the crop were calculated.

Crop water use (mm) = Profile soil moisture depletion (mm) + Effective rainfall (mm) + Groundwater contribution (mm). Since the groundwater table depth was above 2 m, groundwater contribution (mm) was considered as nil.

Water use efficiency (kg ha^{-1} mm^{-1}) =

$$\frac{\text{Grain yield (kg ha}^{-1})}{\text{Crop water use (mm)}} \quad \ldots\ldots.(13)$$

Statistical Analysis

Data were analyzed statistically for analysis of variance (ANOVA) following the method described by Gomez and Gomaz (1984) using SAS 9.2 package. The significance of difference among means was compared by using Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

Phenological Development Rate and its Relationship with Photo-thermal Environment

The photo-thermal environments of two crop seasons (2007-08 and 2008-09) at different phenological stages of the crop for four sowing seasons are presented in Table 1. The first sown (S_1) crop experienced higher temperature, continuous rain with more cloudy and humid weather whereas second (S_2) and third sown (S_3) crops experienced cooler temperature and clear sky during the growth period. Average maximum and minimum temperatures were 2-4°C higher in first sown crop, compared to the growth period of second and third sown crops. The last and fourth sown (S_4) crops again experienced higher temperature and more dryness. In regard to duration of phenological stages, the second (S_2) and third (S_3) sown crops took more days to achieve all growth stages than that of first (S_1) and fourth (S_4) sown crops which might be attributed to existence of cooler temperature during growth period of second and third sown crops. As a result, the phenological development

Table: 1
Photo-thermal environments during crop growth period as influenced by different sowing dates

Sowing dates	Maximum temperature (^{O}C)			Minimum temperature (^{O}C)			Day length (hrs) Phenological stages			Solar radiation (MJ m^{-2})			Rainfall (mm)		
	V_F	F_SF	SF_M	V_F	F_SF	SF_M	V_F	F_SF	SF_M	V_F	F_SF	SF_M	V_F	F_SF	SF_M
S_1:															
2007-08	32.2	32.8	31.7	24.7	24.8	24.1	13.8	13.3	12.7	16.7	15.3	17.3	328	255	345
2008-09	31.8	31.6	31.1	25.1	25.2	24.5	13.7	13.4	13.6	15.7	14.8	17.1	399	302	198
S_2:															
2007-08	28.1	27.3	27.8	16.4	15.5	16.3	11.3	10.3	11.2	20.8	21.8	21.9	10.1	2.5	3.9
2008-09	27.5	25.9	28.6	15.1	15.2	16.4	11.5	10.4	11.3	19.4	21.2	21.5	5.5	0.0	0.0
S_3:															
2007-08	27.9	29.1	29.8	16.1	16.1	17.1	11.6	11.5	11.4	20.2	20.3	22.5	12.2	5.0	4.8
2008-09	27.7	29.4	29.3	16.4	17.4	18.0	11.9	11.2	11.5	20.4	21.5	22.0	5.4	0.0	0.0
S_4:															
2007-08	29.5	34.4	35.8	18.5	18.5	22.3	12.8	12.3	12.5	22.2	23.3	27.8	5.0	3.8	4.5
2008-09	30.9	34.6	36.3	18.1	18.6	22.1	12.6	12.9	12.6	23.1	22.8	26.9	0.0	0.0	7.1

V_F: Vegetative to flowering, F_SF: Flowering to seed filling, SF_M: Seed filling to maturity

rate was slow in these sowings. First (June sown) and fourth (January sown) crops took less days for flowering, seed filling and maturity because of prevalence of higher temperature during growth period of these sowings. On the other hand, the different irrigation regimes had no significant effects on flowering and seed filling stages. Sowing dates and irrigations interaction had no significant ($p \leq 0.05$) effect on duration of phenological stages (Table 2).

Relationship was established between phenological development rate (PDR) of important growth stages (emergence to 50% flowering, 50% flowering to 50% seed filling, 50% seed filling to maturity) of the crop and existing photo-thermal environments (maximum temperature, minimum temperature, day length) (Table 3). Data showed

Table: 2
Duration of important phenological stages as influenced by sowing dates and irrigation regimes

Factors	50% Flowering	50% Seed Filling	Maturity
I. Sowing dates			
S_1	^{D}52.1	^{D}66.9	^{C}96.5
S_2	^{B}61.4	^{A}79.1	^{A}111.6
S_3	^{A}63.8	^{A}80.5	^{A}111.2
S_4	^{C}56.2	^{C}71.6	^{D}98.6
CD (5%)	2.2	3.4	1.9
II. Irrigation levels			
I_1	^{A}58.8	^{A}73.6	^{B}101.2
I_2	^{A}58.3	^{A}73.1	^{A}104.0
I_3	^{A}59.7	^{A}74.3	^{A}105.7
CD (5%)	NS	NS	2.9

S=Significant at 5% probability level, NS = Non significant at 5% probability level

Table: 3
Regression models for predicting developmental rate at different stages

Independent variables considered	Regression models	R^2
Stage-I : Emergence to flowering		
Maximum temperature (TMAX_f)	DR_{e_f}= 0.00274 +0.0048 TMAX_f	0.63
Minimum temperature (TMIN_f)	DR_{e_f}=0.0124 + 0.000241 TMIN_f	0.65
Day length (DL_f)	DR_{e_f}= -0.00166 +0.0015 DL_f	0.79
Multiple regression of all above variables	DR_{e_f}= 0.00636 – 0.000088 TMAX_f + 0.00045 TMIN_f +0.00109 DL_f	0.97
Stage-II : Flowering to seed filling		
Maximum temperature (TMAX_sf)	DR_{f_sf}= 0.043 +0.00045 TMAX_sf	0.21
Minimum temperature (TMIN_sf)	DR_{f_sf}= 0.049 + 0.00042 TMIN_sf	0.31
Day length (TMAX_sf)	DR_{f_sf}= 0.0269 +0.0023 DL_sf	0.28
Multiple regression of all above variables	DR_{f_sf}= 0.01346 – 0.00029 TMAX_sf + 0.00035 TMIN_sf +0.00310 DL_sf	0.47
Stage-III : Seed filling to maturity		
Maximum temperature (TMAX_m)	DR_{s_m}= -0.023 +0.0018 TMAX_m	0.67
Minimum temperature (TMIN_m)	DR_{s_m}= 0.124 + 0.000241 TMIN_m	0.65
Day length (DL_m)	DR_{s_m} = 0.0253 +0.000017 GDD_m	0.18
Multiple regression of all above variables	DR_{s_m}= -0.456 – 0.00061TMAX_m + 0.01035 TMIN_m +0.038 DL_m	0.76

DR_{e_f}= Developmental rate from emergence to flowering, DR_{f_sf}=Developmental rate from flowering to seed filling, DR_{s_m}=Developmental rate from seed filling to maturity that the development rate was significantly correlated with maximum and minimum temperatures during emergence to flowering and seed filling to maturity stages. On the other hand, day length was significantly correlated with vegetative phase of the crop but its effect on the PDR in reproductive stage was not found significant. Crop duration was found to be reduced when it was sown during summer and rainy seasons which might be attributed to existence of higher average temperature in these season than that of winter.

Crop Growth and Productivity under Different Photo-thermal Environments

The growth parameters like LAI and biomass were measured at different phenological stages (Fig. 1). Averaged over years and irrigations, peak LAI reached to a value of 5.88 at 65 DAS in the second (S_2) followed by third (S_3) sown crop (5.65) (Table 4). The first sown (rainy season) crop recorded statistically less LAI (4.90) than that of other sown crop which might be attributed to overcast weather and existence of higher temperature during growth period of the crop. The irrigation had direct impact on LAI, statistically minimum peak LAI (4.73) was recorded in I_1 (three irrigations), while the highest LAI of 6.22 was achieved when 5 irrigations (I_3) were applied.

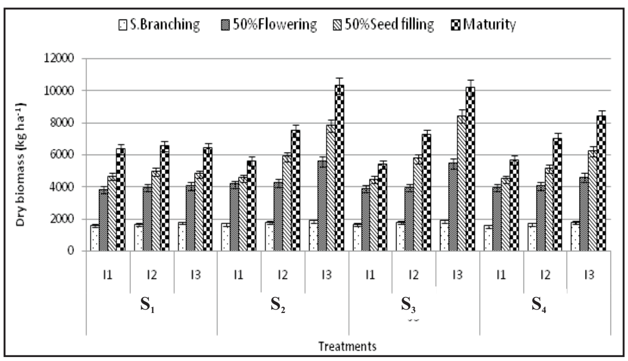

Fig. 1. Above ground dry biomass of sunflower at important phenological stages as influenced by photo-thermal environments (sowing dates and irrigations)

Similar trend was observed in case of total above ground dry matter (TAGDM) production. Maximum TAGDM of 7808 kg ha^{-1} was accumulated by second sown (S_2) crop followed by third (7793 kg ha^{-1}) and fourth sown crop (7015 kg ha^{-1}). However, the difference of biomass production between second (S_2) and third (S_3) sown crop was statistically non-significant throughout the season, while first sown (S_1) crop accumulated statistically lesser biomass as compared to other sowings. In regard to effects of irrigations on biomass production, I_5 (five irrigations) recorded the highest TAGDM (9613 kg ha^{-1}) which was statistically different from other irrigation treatments. The increase in TAGDM with higher level of irrigations was due to better crop growth, which gave maximum plant height, LAI, IPAR and RUE ultimately produced more biological yield. Different irrigation levels markedly increased grain yield of winter/dry season crop. Average over sowing dates and years, the seed yield of 749, 1243 and 1538 kg ha^{-1}was obtained with three, four and five irrigations, respectively. The first sown crop experienced higher temperature, continuous rain with more cloudy and humid weather whereas second and third sown crops experienced cooler temperature and favourable radiation regime during the growth period. The fourth sown (S_4) crop experienced again higher temperature and more dryness. As a result, productivity was less in first (989 kg ha^{-1}) and last sown crop (1038 kg ha^{-1}) whereas the productivity of second and third sown crops was 1261 and 1230 kg ha^{-1}, respectively.

Sowing dates and irrigation regimes separately had also significant ($p \leq 0.05$) influence on capitulum diameter and field capitulum index (FCI). However, oil content was significantly affected by irrigation levels of dry/winter season crop. But sowing seasons and irrigation interaction had no significant ($p \leq 0.05$) effect on growth and yield parameters (Table 4).

Intercepted Photosynthetically Active Radiation (IPAR) and Radiation Utilization Efficiency (RUE)

The IPAR at different phenological stages as influenced by sowing dates and irrigations were computed. The peak

Table: 4
Crop growth and productivity as influenced by sowing dates and irrigation regimes

	Plant height (cm)	Factors	Dry biomass (kg ha^{-1})	Head Diameter (cm)	Seed yield (kg ha^{-1})	Filled Capitulum Index	Oil (%)
I. Sowing dates							
S_1	^{C}186	^{D}4.82	^{D}6450	^{C}11.67	^{D}989	^{C}0.483	^{B}36.70
S_2	^{A}201	^{A}5.88	^{A}7808	^{A}16.79	^{A}1261	^{A}0.526	^{A}38.50
S_3	^{A}200	^{A}5.65	^{A}7793	^{A}16.27	^{B}1230	^{A}0.513	^{A}37.95
S_4	^{B}191	^{C}4.90	^{C}7015	^{B}14.02	^{C}1038	^{B}0.490	^{B}36.80
CD (5%)	4.1	0.72	475.6	1.8	24.5	0.14	1.23
II. Irrigation levels							
I_1	^{C}187	^{C}4.73	^{C}5560	^{C}12.95	^{C}749	^{C}0.466	^{C}36.86
I_2	^{B}195	^{B}5.48	^{B}7243	^{B}14.76	^{B}1243	^{B}0.507	^{B}37.51
I_3	^{A}199	^{A}6.22	^{A}9613	^{A}16.35	^{A}1538	^{A}0.536	^{A}38.09
CD (5%)	3.4	0.98	678.7	1.67	44.5	0.11	1.12

S=Significant at 5% probability level, NS = Non significant at 5% probability level values of IPAR have also presented in Table 5. Averaged across the years and irrigations, lowest peak intercepted PAR was 85% for the first (S_1) sown crop which was statistically significant from IPAR of second (90.1%), third (91.1%) and fourth sown crop (88.8%). The second (S_2) and third (S_3) sown crop recorded IPAR statistically at par.

Averaged over sowing dates and years, irrigation levels significantly affected the amount of radiation intercepted in winter/dry season crop (S_2, S_3 and S_4). The minimum peak intercepted PAR (83.3%) was achieved with three irrigations (I_1). The crop with 5 irrigations recorded peak IPAR of 92.8% (Table 5). The increase in IPAR with higher level of irrigations was due to better crop growth, which gave maximum plant height, LAI and total dry matter. The IPAR was also correlated with leaf area index and total dry biomass of the crop and are presented in Fig. 2(a) and Fig. 2(b), respectively. Study revealed that IPAR was more closely related with the leaf area index with the R^2 value of 0.94 than that of above ground biomass ($R^2 = 0.51$).

Maximum RUE (in terms of total biomass) under different sowing dates and irrigation regimes were derived. RUE was the highest (1.74 g MJ^{-1}) in case of second sown crop (S_2) which was significantly different from crop of other sowings (Table 5). Lowest RUE of 1.45 g MJ^{-1} was achieved in June sown crop (S_1). Significant differences were also found in RUE among irrigation treatments. Mean RUE of 1.44 g MJ^{-1} was observed in case of I_1 and the maximum value of mean RUE (1.75 g MJ^{-1}) was recorded from plots irrigated with five irrigations (I_3). Interaction between sowing dates and irrigation regimes was found to be non-significant on IPAR and RUE. The relationship between total biomass production and radiation utilization efficiency was also established and showed the linear relationship between them (Fig. 3) with the R^2 value of 0.75. RUE of different stages were also studied and are presented in Fig. 4. The RUE was found to be higher at 50% seed filling stage and our study also revealed that RUE did not increase after seed filling but the generality of this phenomenon remains to be tested.

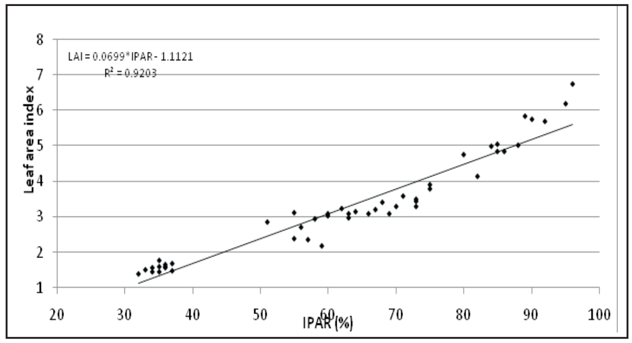

Fig. 2(a). Relationship between IPAR and LAI

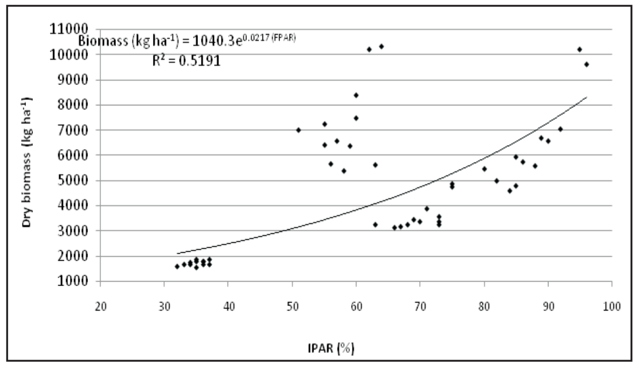

Fig. 2(b). Relationship between IPAR and dry biomass

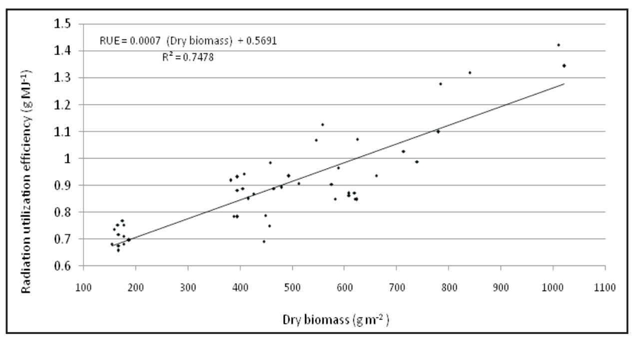

Fig. 3. Relationship between radiation utilization efficiency and dry biomass production

Table: 5
IPAR, radiation utilization efficiency and water use efficiency as influenced by sowing dates and irrigation regimes

Factors	IPAR (%)	RUE (g MJ^{1})	CWU (mm)	WUE (kg ha^{-1} mm^{-1})
I. Sowing dates				
S_1	^{C}85.0	^{D}1.45	-	^{*D}1.45
S_2	^{A}90.2	^{A}1.74	^{A}392	^{B}3.16
S_3	^{A}91.2	^{A}1.71	^{B}368	^{A}3.28
S_4	^{B}88.83	^{C}1.53	^{B}372	^{C}2.74
CD (5%)	1.76	0.07	11.2	0.11
II. Irrigation levels				
I_1	^{C}83.3	^{C}1.44	^{C}330	^{C}2.27
I_2	^{B}87.8	^{B}1.63	^{B}379	^{B}3.28
I_3	^{A}92.8	^{A}1.75	^{A}424	^{A}3.63
CD (5%)	3.2	0.55	13.2	0.18

*Rainwater use efficiency; S=Significant at 5% probability level, NS = Non significant at 5% probability level; IPAR = Intercepted Photosynthetically Active Radiation; RUE = Radiation Utilization Efficiency; CWU = Crop Water Use;WUE = Water Use Efficiency

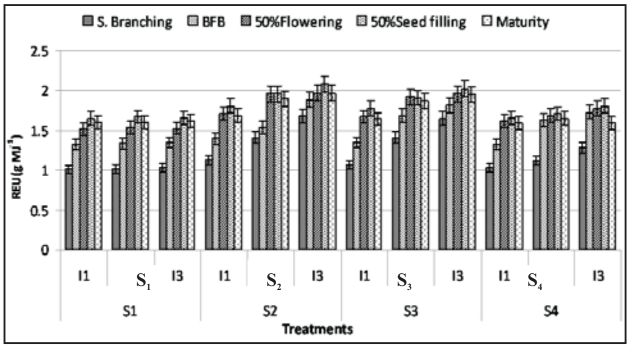

Fig. 4. Radiation utilization efficiency of sunflower at important phenological stages as influenced by photo-thermal environments (sowing dates and irrigations)

I_1 Three irrigations, I_2 = Four irrigations, I_3 = Five irrigations, S_1 = First sowing, S_2 = Second sowing, S_3 = Third sowing, S_4 = Fourth sowing,

Surface Energy Balance

The seasonal variation of surface energy fluxes over sunflower crop stand during two crop growth seasons (2007-08 and 2008-09) were measured at 7-10 days interval and mid-day average value of 10.00-15.00 hour are depicted in Fig. 5(a) and Fig. 5(b), respectively. Due to instrumentation limitation, measurements were restricted to I_3 plots (five irrigations). Study revealed that net radiation (R_n), amount of energy available for physical or biological processes over the crop varied from 14.8 to 25.7 MJ $m^{-2}day^{-1}$ in different sowing dates during two crop seasons. Due to existence of overcast weather the net radiation was less in rainy season which ranged between 14.1 to 21.2 MJ $m^{-2}day^{-1}$ during crop growth period of two crop seasons. On the other hand, net radiation was higher in case of post-winter/dry season crop summer season crop which varied between 17.8 to 25.7 MJ $m^{-2}day^{-1}$.

The latent heat flux (LE) which is the most important component of energy balance for irrigation management was largely dependent on leaf area index (LAI) and soil moisture content and showed peak when LAI was maximum. The mid-day average latent heat flux (on clear days) varied from 9.7 to 14.72 MJ $m^{-2}day^{-1}$ at different growth stages during June sown (S_1) crop. Whereas, in winter sown crop (S_2 and S_3), LE ranged between 8.55 MJ m^{-2} day^{-1} (6 DAS) to 18.7 MJ $m^{-2}day^{-1}$ (61 DAS) in different growth stages and years. In S_4 treatment LE varied from 8.64 to 16.77 MJ $m^{-2}day^{-1}$. The LE variation over the crop stand during different growing periods mainly occurred due to variation of solar radiation, temperature, vapour pressure deficit and soil moisture during the crop seasons. The LE by the crop of winter/dry season crop increased immediately after application of irrigation water because of availability of soil moisture to evapotranspire.

The seasonal course of soil heat flux (G) revealed that its variation during growth seasons clearly reflected the change of crop growth. The 'G' showed peak value during early vegetative and maturity periods when crop coverage was minimum and soil was dry. Afterwards, the course of 'G' was affected by development of crop canopy or leaf area index. Mid day averaged 'G' value of crop stand ranged from 0.754 to 8.1 MJ m^{-2} day^{-1} at different growth stages and seasons and 'G' reduced drastically with the application of irrigation water. The ratio of G/R_n from maximum LAI to senescence stage was found to be 6.8-14.8% over the crop. Soil heat flux showed declining trend during peak growth stage which coincided with maximum leaf area index (LAI) or maximum intercepted photosynthetically active

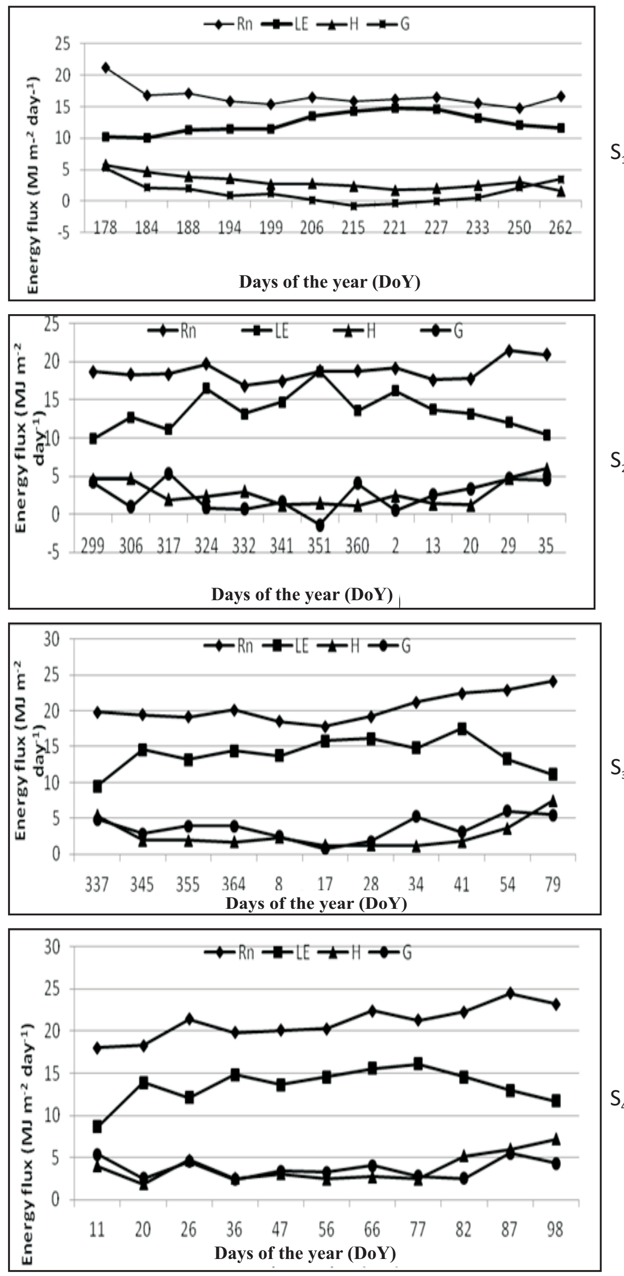

Fig. 5(a). Energy balance of sunflower under five irrigations as influenced by photo-thermal environments (sowing dates) during 2007-08

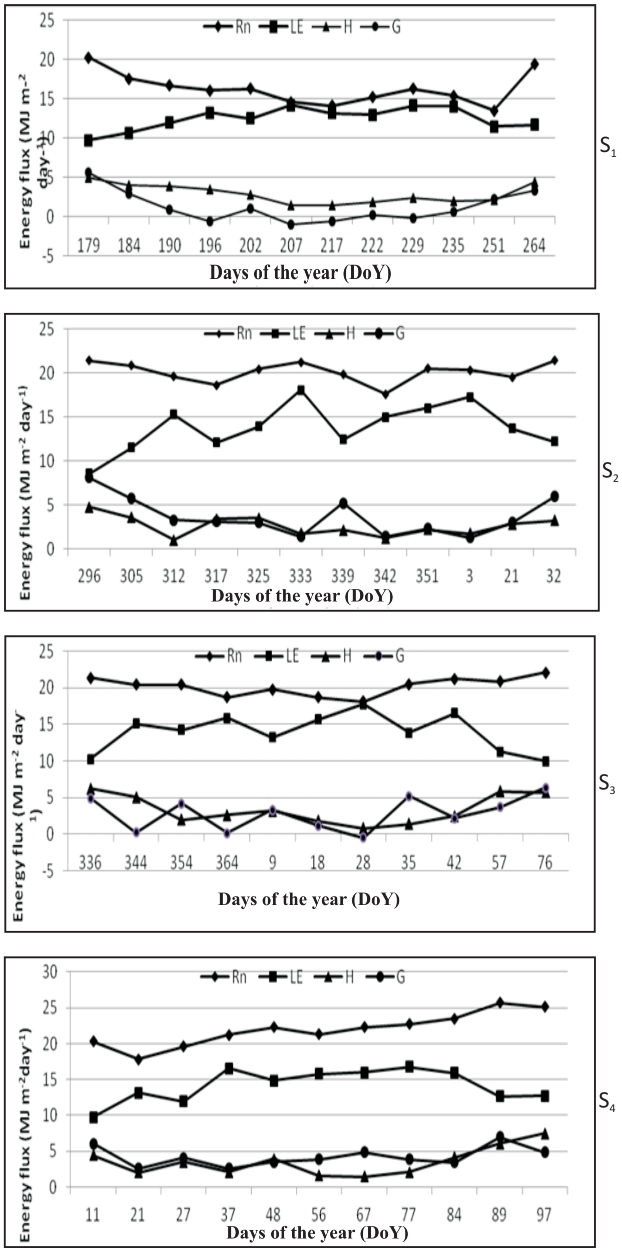

Fig. 5(b). Energy balance of sunflower under five irrigations as influenced by photo-thermal environments (sowing dates) during 2008-09

radiation (IPAR). In general, where water did not limit the transpiration and when soil was wet, latent heat flux consumed most of the energy from net radiation. As the soil dried, water became less available for evapotranspiration and the energy was utilized for heating the soil (soil heat flux) or heating the air (sensible heat flux).

Water-Use Efficiency

Water-use efficiency (WUE) is a common expression of plant productivity. It may represent the ratio of total above-ground dry biomass or dry seed weight to the seasonal evapotranspiration (ET). With this approach, different cultural practices can be assessed to determine optimum use of limited irrigation water. As per the methodology, CWU was measured at periodic interval and its variation with sowing dates and irrigations are presented in Table 5. Since due to excess rainfall, the CWU measurement was not possible for rainy season crop (S_1), these data were restricted to rest of the 3 sowing seasons. Averaged over sowing dates and irrigations, the CWU of 392, 368 and 372 mm occurred for S_2, S_3, S_4 treatments, respectively. Irrigation levels influenced the CWU significantly. Highest CWU of 424 mm was recorded when the crop was grown with 5 irrigations. While the CWU of 330 and 379 mm was recorded with three and four irrigations, respectively. The water use efficiency (WUE) of the crop also varied with sowing dates and irrigations. Averaged over years and irrigations, winter season crops registered high WUE with the values being 3.16 and 3.28 kg $ha^{-1}mm^{-1}$ for S_2 and S_3, respectively (Table 5). In regard to effect of irrigation, the WUE of 2.27, 3.28 and 3.63 kg ha^{-1} mm^{-1} was recorded with three, four and five irrigations, respectively.

4. CONCLUSIONS

Crop duration and productivity were reduced when temperature was increased during summer and rainy seasons. High temperatures speed up the phenological development of the crop and therefore, shortened growth duration for yield formation. Plant biomass, leaf area index, grain yield, intercepted photosynthetically active radiation, radiation utilization efficiency (RUE) were also found to be low when crop growth duration was reduced. Mean values of RUE (1.45, 1.74, 1.71 and 1.53 g MJ^{-1}) were computed with June (rainy), October (winter), November (Winter) and January (later winter and early summer) crop, respectively. The day length was found to be influential at vegetative stage but no role was found in reproductive phase of the crop. Supplemental irrigations had significant effects on plant biomass, leaf area index, grain yield, intercepted photosynthetically active radiation, radiation utilization efficiency (RUE) and water use efficiency of winter/dry season crop. Latent heat flux was largely dependent of leaf area index (LAI) and soil moisture content which showed peak when LAI was maximum. To obtain optimum growth and productivity, the crop should be sown during October-November when plant biomass, leaf area index, grain yield, intercepted photosynthetically active radiation and radiation utilization efficiency were maximum.

REFERENCES

Aiken, R.M. 2005. Applying thermal time scales to sunflower development. *Agron. J.,* 97(3):6-54.

Anonymous, 2008. Agricultural statistics at a glance. 2008. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, GoI, New Delhi.

Craufurd, P.Q. and Wheeler, T.R. 2009. Climate change and the flowering time of annual crops. *J. Exp. Bot.,* 60(9): 2529-2539.

Doyle, A.D. 1975. Influence of temperature and day length on phenology of sunflower in the field. *Aust. J. Exp. Agri. and Animal Hus.,*15(72): 88-92.

Dyer, H.J., Skok, J. and Scully, N.J. 1959. Photo periodic behavior of sunflower. *Bot. Gazette,* 121(1): 50-55.

Figuerola, P.I. and Berliner, P.R. 2006. Characterization of the surface layer above a row crop in the presence of local advection. *Atmosfera,* 19(2): 75-108.

Flagelia, Z., Rutunno, T., Tarantino, E., Dicatrina, R. and Decaro, A. 2002. Changes in seed yield and oil fatty acid composition of high oleic sunflower hybrids in relation to the sowing date and the water regime. *Europ. J. Agron.,* 17(3): 221-230.

Font, C., Andrade, F.H., Grondona, M., Hall, A. and Leon, A.J. 2008. Phenological characterization of near-isogenic sunflower families bearing two QTLs for photoperiodic response. *Crop Sci.*, 48(4): 1579-1585.

Gallaghar, J.N. and Biscoe, P.V. 1978. Radiation absorption, growth and yield of cereals. *J. Agric. Sci. Camb.,* 91(1): 47-60.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research with Special emphasis on Rice. International Rice Research Institute, Philippines.

Goyne, P.J., Schneiter A.A. and Cleary, K.C. 1990. Prediction of two time anthesis of a selection of sunflower genotypes. *Agron. J.,* 82(3): 501-505.

Goyne, P.J., Schneiter, A.A. and Cleary, K.C., Creelsman, R., Sarymeier, W. and Wooding, F. 1989. Sunflower genotypes response to photoperiod and temperature in field environments. *Agron. J*., 81(5): 826-831.

Hammer, G.L., Goyne, P.J. and Wooduff, D.R. 1982. Phenology of sunflower cultivars III. Models for prediction in field environments. *Aust. J. Agric. Res.,* 33(2):263-274.

Kar, G., Singh, R. and Verma, H.N. 2004.Spatial variability studies of soil hydro-physical properties using GIS for sustainable crop planning of a watershed of eastern India and its testing in a rainfed rice area. *Aus. J. Soil. Res*., 42(4): 369-379.

Kar, G. 2005. Radiation interception, rainwater and radiation utilization efficiency study of legume based intercropping in rainfed upland rice area of eastern India. *J. Agrometeorol.,* 7(1): 84-89.

Kar, G. and Verma, H.N. 2005. Phenology based irrigation scheduling and determination of crop coefficient of winter maize in rice fallow of eastern India. *Agric. Water Manage.,* 75(3): 169-183.

Kar, G. and Kumar, A. 2007. Surface energy fluxes and crop water stress index in groundnut under irrigated ecosystem. *Agric. Forest Meteorol.*, 146(1-2): 94-106.

Kar, G. and Kumar, Ashwani. 2009. Energy balance and crop water stress in winter maize under phenology-based irrigation scheduling. *Irr. Sci.* (Springer), 28(3): 211-220.

Kar, G., Kumar, Ashwani, Sahoo, N. and Mohapatra, S. 2013. Radiation utilization efficiency, latent heat flux, and crop growth simulation in irrigated rice during post-flood period in east coast of India. *Paddy Water Env.,*12(2): 285-297.

Monteith, J.L. 1972. Solar radiation and productivity in tropical ecosystems. *J. Appl. Ecol*., 9(3): 747-766.

Penman, H.I. 1948. Natural evaporation from open water bare soil and grass. *Proc. Roy. Soc. Lond. Ser. A.,* 193(1032): 120-146.

Pitman, J.I. 2000. Absorption of photo-synthetically active radiation, radiation use efficiency and spectral reflectance of bracken [*Pteridiumaquilinum* (L.) Kuhn] canopies. *Ann. Bot.,* 85 (Supplement B):101-111

Rezadoust, S., Karimi, M.M., Vazan, S.S., Ardakani, M.R., Kashani, A.M. and Gholinezhad, E. 2010. The modeling of development stages of sunflower on the basis of temperature and photoperiod. *Not. Bot. Hort. Agrobot. Cluj.,* 38(1): 66-70.

Robinson, R.A., Bernat, L.A., Geise, H.A., Jhonson, F.K., Kinman, M.L., Mader, E.L., Oswald, P.M., Putt, E.D., Swellers, C.M. and Williams, J.H. 1967. Sunflower development at latitude ranging from 31 to 49 degrees. *Crop Sci.,* 7(2): 134-136.

Shen, Y., Zhang, Y., Kondoh, A., Tang, C., Chen, J., Xias, J., Sakura, Y., Liu, C. and Sun, H., 2004. Seasonal variation of energy partitioning in irrigated lands. *Hydrol. Process.,*18: 2223-2234.