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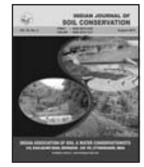

Sowing dates and irrigation regimes on growth, productivity and radiation use efficiency of winter maize (*Zea mays* L.)

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ABSTRACT

Phenological development, growth and yield of any grain crop are largely determined by availability of soil moisture, photo-thermal environments, intercepted photosynthetically active radiation (IPAR) and radiation use efficiency. Depending upon the harvesting period of previous rice crop, farmers sow winter maize in the region during November to January. Since development rate and duration of phenological stages are largely governed by prevailing temperatures; therefore, sowing date is one of the very important factors to obtain optimum productivity. Research was conducted to study phenological development rate, growth, yield, IPAR and radiation use efficiency of the winter maize under different photo-thermal environments and irrigation regimes, created by changing sowing dates and irrigation levels. The peak IPAR of 89.3, 87.6 and 85.5% were recorded by first, second and third sown crops, respectively and RUE of 1.55 to 2.02 g MJ^{-1} were achieved under different treatments. Development rate was significantly correlated with maximum and minimum temperatures during emergence to tasseling and tasseling to maturity stages of the crop. Day length was found to be significantly correlated with reproductive stage of the crop but its effect on the phenology development rate in vegetative stage was not evident. Significant variation in biomass, leaf area, IPAR and RUE occurred among irrigation treatments. The last sown (January) crop expressed lower negative stress degree day (SDD) due to more dryness and less availability of soil moisture; as a result crop growth and productivity were reduced significantly.

1. INTRODUCTION

The area under maize in India is 8.26 m ha with average productivity of 2893 kg ha^{-1} and now it ranks as the third most important food crop in the country. This area would grow further to meet future food, feed and other demands, especially in view of the booming livestock and poultry producing sectors in the country (Kar *et al.,* 2004; Kar *et al.,* 2005). Radiation (light), temperature and soil moisture are the major environmental factors which determine growth and productivity of any crop. In eastern India maize is sown in different seasons but growing of the crop in winter is getting popularity because of favourable photo-thermal environments. Depending upon the harvesting period of previous rice crop, farmers of the region sow winter maize during November to January. Since development rate and duration of phenological stages were largely determined by prevailing temperatures, therefore, sowing date is one of the very important factors to obtain optimum productivity. Sowing of the crop in early winter season is also advantageous to exploit carry-over residual soil moisture of rice field of previous season. Since in winter season, rainfall is erratic and meagre, irrigation water quantity and intervals play a great role to grow the crop successfully (Singh and Singh, 1995; Stone *et al.,* 2001; Igbadun *et al.,* 2008; Kumar *et al.,* 2011; Dobermann *et al.,* 2011; Painyuli *et al.,* 2013; Reddy *et al.,* 2013). Therefore, determining the optimum sowing dates with proper irrigation management during winter season is very much necessary for optimum maize productivity in the region.

Further, growth and yield of any grain crop are also largely determined by radiation interception, the efficiency of conversion of intercepted radiation to dry matter and partitioning of dry matter to grain. (Kar, 2005; Figuerola and Berliner, 2006). Therefore, productivity can be enhanced through efficient farming techniques that have better radiation and water use efficiency. Though radiation use efficiency (RUE) of grain crops are well established in different parts of the world from unstressed plots for wheat (Kiniry *et al.,* 1989; Gregory *et al.,* 1992), maize (Sivakumar and Virmani, 1984), barley (Gallaghar and Biscoe, 1978), pigeon pea (Robertson *et al.,* 2001), sunflower (Conner *et al.,* 1985). But still there is a paucity of such type of information in eastern India where maize is grown under both stressed and non-stressed conditions during wet as well as dry seasons.Adoption of good water management strategies and identification of proper sowing period for the crop for optimum utilization of photosynthetic active radiation (PAR) are still promising management recommendation in order to increase productivity of the crop in the region (Kar *et al.,* 2005).

Keeping the importance of above points in view, maize was sown in 3 dates with 3 irrigation regimes and effects of different sowing dates and irrigation were assessed on the duration of phenological stages, growth, biomass and RUE of the crop.

2. MATERIALS AND METHODS

Site Description

An on-farm experiment was carried out during two winter seasons (2007-08 and 2008-09) at Bhuasuni watershed of Dhenkanal district, Odisha, India (Latitude $20^0 60^/$ N and Longitude of $85^0 57^/$ E). The altitude of site is 69 m amsl. The mean maximum temperature varied from 27.0^0C in January to 36.7^0C in May, the minimum temperature ranged between 13.9^0C in December to 21.4^0C in May. Long term average rainfall and evaporation data of the study site are given in Fig.1. The average annual rainfall of the area is 1440 mm, out of which 72% occurs during

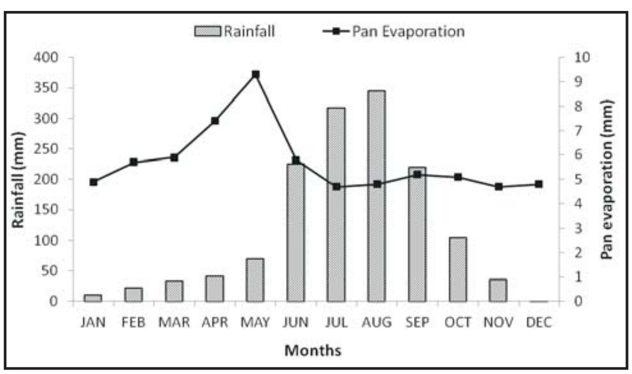

Fig.1. Normal weather parameters of the study area

southwest monsoon period and 30-40% goes off as runoff without any utilization. In winter season, rainfall is meagre and erratic, cropping is not possible without supplemental irrigations; therefore, the excess water of rainy season can be harvested and utilized to provide supplemental irrigation to the second crop in winter season.

Crop Management and Observations

For determining actual phenology, crop growth and yield under different photo-thermal environments, maize crop (*cv.* Navjyot) was sown in three dates in each season (25th November, 23rd December, 25th January in 2007 and 22nd November, 24th December and 23rd January in 2008) under 3 irrigation regimes. The crop was sown on 0.60 m spaced ridges keeping plant to plant distance of 0.30 m using a seed rate of 25 kg ha^{-1} and with fertilizer dose of N:P:K as 120:80:80. The on-farm experiment was laid out in split plot design with three replications. The treatments were three above sowing dates in main plots and three irrigation regimes (I_1= irrigations at tassel initiation and grain filling, I_2= irrigations at early vegetative, tassel initiation and grain filling, I_3= irrigations at early vegetative, tassel initiation, silking, grain filling) in sub-plots (Table 1). This method of varying irrigation regimes by withholding irrigation at some growth stages of the crop was similar to that used by Ritchie and Hanway (1982) and Pandey *et al.* (2000). The crop growth duration was divided into four stages similar to those of Doorenbos and Kassam (1979). The crop growth stages include the following: Establishment stage [planting to eight leaves formation (023 DAP)]; Vegetative stage [crop establishment to tassel formation (2455 DAP)]; Flowering stage [tassel formation to silking (5566 DAP)] and grain filling stage [milk, dough, and dent stages of grain filling to physiological maturity (66112 DAP)]. The lengths of growth stages were based on field observations of the crop development. The experimental treatment variation started at the vegetative growth stage. Irrigation was not skipped in any treatment during the establishment growth stage so as to allow the crop to be established before being subjected to moistures tress. Each irrigation consists of a metered amount of 70 mm depth of water applied through gated pipe. The dates of important phenological stages like emergence, 50% tasseling, 50% silking and maturity were recorded form each treatments.

Table: 1
Irrigation schedule for the field experiments during 2007-08 and 2008-09

Irrigation treatments	Crop establishment		Vegetative		Flowering		Grain filling		No. of Irrigations	Total water applied (mm)
					Tasseling	Silking				
I_1	30	30	X	X	70	X	40	40	5	210
I_2	30	30	30	40	70	X	40	40	7	280
I_3	30	30	30	40	70	60	40	40	8	340

I_1= irrigations at tassel initiation and grain filling, I_2= irrigations at early vegetative, tassel initiation and grain fling, I_3= irrigations at early vegetative, tassel initiation, silking, grain filling

Phenological developmental rate from emergence to tasseling and tasseling to maturity of the crop was 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) x f (p)

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.

Stress Degree Day, Intercepted Photosynthetically Active Radiation and Radiation Use Efficiency

The canopy temperature was measured at 9.00, 12.00 and 15.30 hrs at important phenological stages by infrared thermometer (AG 42, Telatemp) and the stress degree days (SDD) was calculated by subtracting the mid-day air temperature from mid day canopy temperature (Idso *et al.,* 1977). The relationship between dry matter production and yield with SSD was also established under different photo-thermal environments and irrigation regimes.

The percentage light interception or IPAR (400-700 nm) was derived measuring the incident radiation above the canopy and that transmitted to the ground below the canopy by a 1-m long quantum light bar (Light transmission meter, EMS-7) as per the following relationship:

$$I_i = I_o - I_{rc} - I_t + I_{rg}$$

Where, I_i (%) by the canopy = $(I_i/I_o)\times100$; I_i = Intercepted Photosynthetically Active Radiation (IPAR) by the canopy; I_o = Incident PAR on the canopy; I_{rc} = Reflected PAR by the canopy; I_t = Transmitted PAR through the canopy; and I_{rg} = Reflected PAR from the ground.

Measurements of radiation at ground level were taken by placing the linear sensor diagonally across the inter-row space with the ends of the sensor coinciding with the centre-line of the rows. All measurements were performed at 1000 h to 1400 h in a clear day at intervals of 714 days, depending on weather conditions.

The rate of increase of biomass density, B (g m^{-2}), is proportional to the absorbed photosynthetically active radiation, APAR (MJ m^{-2} d^{-1}) (Monteith, 1977).

$$\frac{dB}{dT} = \varepsilon \text{ APR}$$

Where, ε is the radiation utilization efficiency (RUE) (g MJ^{-1}), (Pitman, 2000).

The dry biomass at different stages were measured and corresponding accumulated photosynthetically active radiation (APAR) were computed to estimate radiation utilization efficiency (RUE) using the following relationship:

$$\varepsilon\ (\text{g MJ}^{-1}) = \frac{\text{Cumulative biomass (g m}^{-2})}{\text{Cumulative APAR (Mj m}^{-2})}$$

Daily intercepted solar radiation (MJm^{-2}) by the crop was obtained as the product of daily incident solar radiation, measured at the agro-meteorological station and the percentage of mid-day light interception. The mean daily values of intercepted photosynthetically active radiation was calculated by multiplying it with 0.48 following Kar *et al.* (2013).

Statistical Analysis

All the observed data obtained were analyzed for their statistical significance using SAS 9.2 software. Differences among treatment means were compared by the least significant difference (LSD) test at 1% and 5% probability levels and Duncan's Multiple Range Test (DMRT).

3. RESULTS AND DISCUSSION

Weather and Soil

The photo-thermal environments (maximum temperature, minimum temperature, day length, solar radiation) of two crop seasons (2007-08 and 2008-09) at different phenological stages of the crop for three sowing dates are presented in Table 2. The pattern of average temperature was similar in both the years, average maximum temperatures ranged between 27.5 to 28.9^{o}C in

Table: 2
Photo-thermal environments during crop growth period as influenced by different sowing dates

Sowing dates	Maximum temperature (^{0}C)			Minimum temperature (^{0}C)			Day length (hrs)			Solar radiation (MJ m^{-2})			Rainfall (mm)		
	Phenological stages														
	V_T	T_S	S_M	V_T	T_S	S_M	V_T	T_S	S_M	V_T	T_S	S_M	V_T	T_S	S_M
S1:															
2007-08	28.9	27.5	27.8	14.4	15.5	16.3	11.5	10.7	11.1	18.2	20.8	21.9	10.1	2.5	3.9
2008-09	28.1	27.9	28.6	14.1	15.2	16.4	11.7	10.9	11.5	17.4	19.2	20.5	5.5	0.0	0.0
S2:															
2007-08	29.9	29.1	30.8	15.1	17.9	18.1	12.2	11.5	11.6	17.2	18.3	20.5	12.2	5.0	4.8
2008-09	28.7	29.4	30.3	16.4	17.4	17.9	12.1	11.2	11.2	18.4	17.5	21.0	5.4	0.0	0.0
S3:															
2007-08	29.7	33.7	33.5	18.5	18.5	22.3	12.9	12.7	12.2	20.2	21.3	24.8	5.0	3.8	4.5
2008-09	30.6	32.4	34.0	18.1	18.6	22.1	12.8	12.6	12.3	21.1	20.8	23.9	0.0	0.0	7.1

V_T: Vegetative to tassel initiation, T_S: Tassel initiation to silking, S_M: Silking to maturity, S_1 First sowing; S_2 = Second sowing; S_3 = Third sowing first sown crop, then gradually increased during growth period of second (28.7 to 30.8^{O}C) and third sown crop (29.7 to 34.0^{o}C). Similar trend was observed in case of minimum temperature with the average values being 14.4-16.4, 15.1-18.1 and 18.1-22.3^{O}C during growth period of first, second and third sown crops, respectively. The incoming solar radiation ranged from 17.4 to 21.9 MJ m^{-2}day^{-1} during crop growth period of first sown crop. During crop growth period of second and third sown crops, solar radiation varied from 17.2 to 24.8 MJ m^{-2}day^{-1}. The average day length ranged from 10.7 to 11.7 hrs in case of first sowing. The rainfall was erratic and meagre during growth period of both the seasons and total rainfall of 2007-08 season was 16.5, 22.0 and 13.3 mm for first, second and third sown crops, respectively. The total rainfall was 5.5, 5.4 and 7.1 mm in 2008-09 in 3 respective sowing treatments. The soils within the experimental area was found to be relatively homogeneous and soil texture was sandy loam to clay loam in nature where clay content varied from 21.9% (0.30-0.45 m) to 34.5% (0.90-1.20 m).

Phenology as Influenced by Irrigations and Sowing Dates

The effects of treatments on number of days to emergence, 50% tasseling, silking and maturity are presented in Table 3. Though irrigation effects were non-significant on days to 50% tasseling, silking and maturity for all the sowing dates but effects of sowing dates on these phenophases were found to be highly significant. Statistically minimum days to 50% tasseling (46.1) were taken by plants of third sown crop (S_3). First and second crops sown took maximum number of days to 50% silking (56.8 and 54.1 days, respectively) whereas, statistically minimum days (50.3 days) to 50% silking were taken by last sown crop (S_3). Average numbers of days to maturity were also more in case of first and second sown crops (111.5 and 108.6 days, respectively) but was less (100.6 days) in third sown crop. For different growth and yield attributes. The interaction effect between sowing dates and irrigations were found to be statistically non-significant.

The relationship between phenological development rate (PDR) during different stages (emergence to tasseling and teaseling to maturity) and photo-thermal environments (maximum temperature, minimum temperature, day length) were established (Fig. 2 and Fig. 3). Data shows that the development rate was significantly correlated with maximum and minimum temperatures during emergence to tasseling and tasseling to maturity stages of the crop. Day length was significantly correlated with vegetative phase of the crop but its effect on the PDR in reproductive stage was not evident.

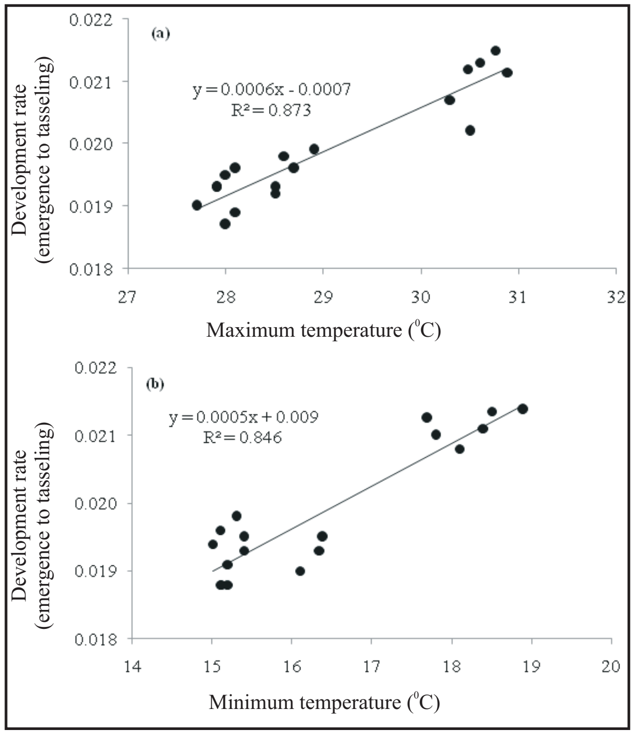

Fig. 2. Phenological development rate as influenced by (a) maximum and (b) minimum temperature

Table: 3
Duration of important phenological stages as influenced by sowing dates and irrigation regimes (Pooled data of 2 years)

Factors	Days to emergence	Days to 50% tassel initiation	Days to 50% silking	Days to maturity
I. Sowing dates				
S_1	7.00^A	51.83^A	56.83^A	111.50^A
S_2	6.67^A	49.97^B	54.10^B	108.67^B
S_3	6.00^B	46.17^C	50.33^C	100.67^C
Significance	*	*	*	*
II. Irrigation levels				
I_1	6.67^A	49.90^A	55.00^A	108.17^A
I_2	6.67^A	49.75^A	54.83^A	107.20^A
I_3	6.33^B	49.10^A	54.17^A	107.00^A
Significance	**	NS	NS	NS

*Significant at 5% probability level, **Significant at 1% probability level, NS = Non significant**,** The values in the column followed by same letters are not significant at 5% level of significance based on Duncan's Multiple Range Test (DMRT).
S_1= First sowing; S_2= Second sowing; S_3= Third sowing, I_1= irrigations at tassel initiation and grain filling, I_2= irrigations at early vegetative, tassel initiation and grain fling, I_3= irrigations at early vegetative, tassel initiation, silking, grain filling

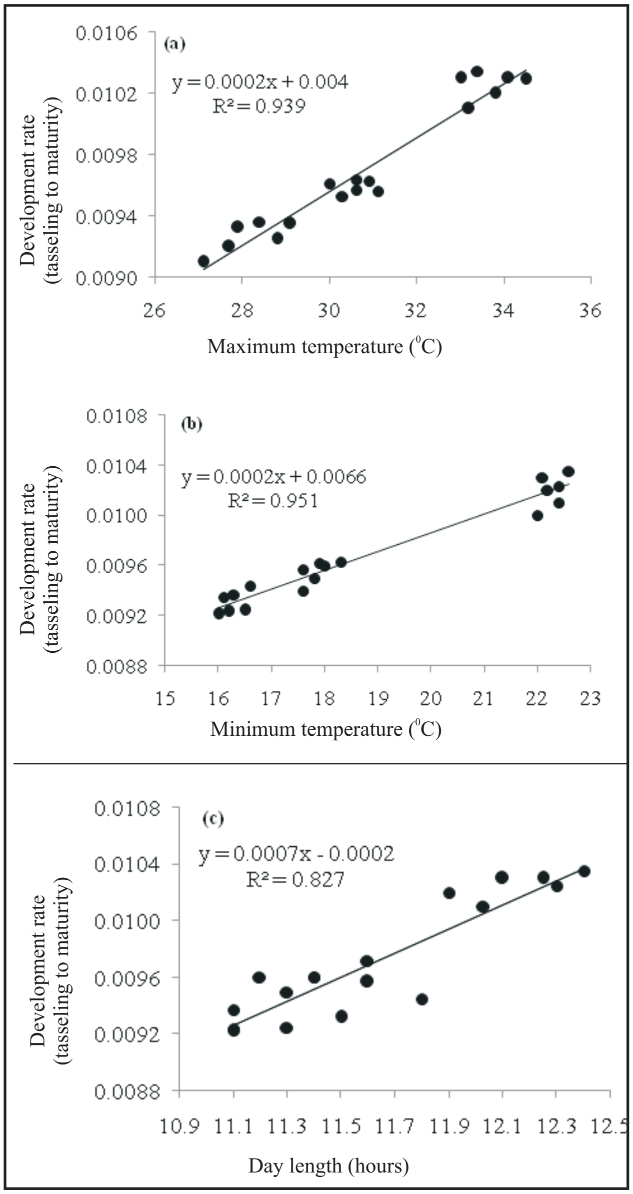

Fig. 3. Phenological development rate as influenced by (a)maximumtemperature,(b)minimum temperature and (c) day length during tassel initiation to maturity

Crop Growth, Productivity, Light Interception, Radiation Use Efficiency as Influenced by Irrigations and Sowing Dates

Total above ground dry biomass (AGDB) production increased steadily after crop establishment until maturity in all the treatments. Sowing dates significantly affected AGDB, first and second sown crop accumulated statistically higher AGDB as compared to third sown crop (Table 4). Averaged over irrigation treatments, maximum AGDB at final harvest was 12367 kg ha^{-1} by first sown crop followed by second (11169 kg ha^{-1}) and third (10180 kg ha^{-1}) sown crops. AGDB production responded positively to irrigation application also. Averaged over sowing dates, maximum AGDB accumulated to value of 12930 kg ha^{-1} in I_3 followed by I_2 (11374 kg ha^{-1}) and I_1 (9856 kg ha^{-1}) treatment which were statistically significant. The plants with I_3 treatment gave maximum plant height, LAI and ultimately produced more biomass.

LAI values steadily increased and reached at maximum value at 55 DAS for first and second sown crops and 48 DAS for last sown crop which coincided with tasseling to silking stage of the crop; thereafter, LAI declined in all the treatments. The year had no significant effect on maximum LAI for all the sowings but sowing dates within the season were significant on maximum LAI development (Table 4). Maximum LAI was significantly affected by irrigation levels for all sowings. Averaged over sowing dates, peak LAI reached to a value of 6.14 at 55 DAS in the I_3 followed by I_2 (5.30) and I_1 (4.27) treatments. Greater leaf expansion in maize was ascribed to more soil moisture availability for I_3 treatment.

Averaged over sowing dates, the highest grain yield (5433 kg ha^{-1}) was recorded in case of I_3 (4 irrigations) followed by I_2 (4621 kg ha^{-1}) and I_3 (3731 kg ha^{-1}). Harvest index shows the physiological efficiency of plants to convert the fraction of photosynthates assimilates to grain yield. Results also showed that sowing date's effects on

Table: 4
Crop growth, productivity and IPAR of maize as influenced by sowing dates and irrigation regimes (Pooled data of 2 years)

Factors	Maximum above ground dry biomass (kg ha^{-1})	Peak LAI	Grain yield (kg ha^{-1})	HI	1000 grain weight (g)	No. of grains/m^2	IPAR (%)
I. Sowing dates							
S_1	12367^{A}	5.66^{A}	4968^{A}	0.40^{A}	243^{A}	2038^{A}	89.33^{A}
S_2	11169^{B}	5.09^{B}	4738^{B}	0.41^{A}	240^{B}	1870^{B}	87.67^{B}
S_3	10180^{C}	4.76^{C}	4387^{C}	0.41^{A}	235^{C}	1502^{C}	85.50^{C}
Significance	**	**	**	NS	**	**	**
II. Irrigation levels							
I_1	9856^{C}	4.27^{C}	3731^{C}	0.38^{C}	239^{C}	1485^{C}	84.10^{A}
I_2	11374^{B}	5.30^{B}	4621^{B}	0.41^{B}	240^{B}	1882^{B}	88.67^{B}
I_3	12930^{A}	6.14^{A}	5433^{A}	0.42^{A}	244^{A}	2143^{A}	90.38^{C}
Significance	*	*	*	*	*	*	*

*Significant at 5% probability level, **Significant at 1% probability level, NS= Non significant, The values in the column followed by same letters are not significant at 5% level of significance based on Duncan's' Multiple Range Test (DMRT).

harvest index (HI) of maize were non-significant, however crop had an average harvest index of 0.42, 0.41 and 0.38 in I_3, I_2 and I_1, respectively and these variations were statistically significant. Irrigation levels response was highly significant on number of grain/m^2, 1000 gm weight and grain yield (Table 4). Average over sowing dates, maximum number of grains m^{-2} (2143) were produced in I_3 treatment (four irrigations) followed by I_2 (1882) and I_1 (1485). Irrigation effects on grain yield were significant for all the sowings but the interaction effect between sowing dates and irrigations was found to be statistically non-significant for different growth and yield attributes.

The IPAR was measured at different phenological stages and peak values are depicted in Fig. 4. Study revealed that IPAR (%) was higher in silking stage which coincided with maximum leaf area index. Generally IPAR values steadily increased and reached maximum value during silking stage (at 55-60 DAS in different sowings); thereafter it slightly declined in all the treatments and reached its minimum values at about 45-60% towards the maturity period. The peak IPAR was higher (89.3%) in first sown (S_1) crop which might be attributed to higher biomass, LAI and crop height in this treatment. The IPAR of 87.6 and 85.5% were recorded by second and third sown crop, respectively.

Among irrigation treatments, highest RUE of 2.02 g MJ^{-1} was obtained in case of I_3 followed by I_2 (1.77 g MJ^{-1})

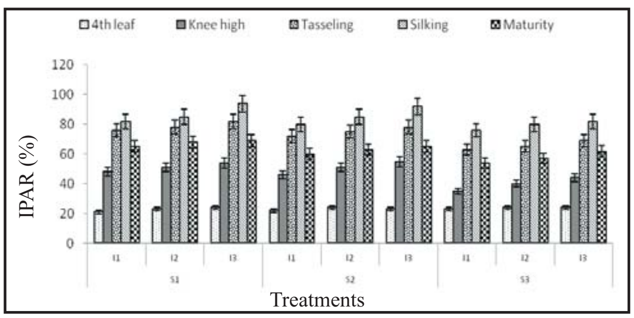

Fig. 4. Variation of IPAR (%) with sowing dates and irrigation levels at different phenological stages. (Pooled data of two years)

S_1= First sowing; S_2= Second sowing; S_3= Third sowing ; I_1= irrigations at tassel initiation and grain filling, I_2= irrigations at early vegetative, tassel initiation and grain filling, I_3= irrigations at early vegetative, tassel initiation, silking, grain filling.

and I_1 (1.55 g MJ^{-1}). Averaged over irrigation treatments, RUE of 1.97, 1.85 and 1.60 g MJ^{-1} were recorded in S_1, S_2 and S_3, respectively. Interaction between irrigation and nitrogen treatment was found to be non-significant on IPAR and RUE also.

Biomass and Yield in Relation to Canopy Temperature and Stress Degree Days (SDD)

The stress degree day (SDD) which is the difference between canopy temperature and air temperature was estimated at different growth stages based on the observation of 12.00 hr and are depicted in Table 5. Higher degree of negativity in SDD indicates less canopy temperature with a low water stress. In this study, higher negative values of SDD were observed for first sown (S_1) crop because of occurrence of less stress due to lower temperature and more soil moisture availability. The last sown (S_3) crop expressed lower negative SDD due to more dryness and less availability of soil moisture. Whereas, second (S_2) sown crop registered moderate negative value of SDD. In regard to relationship between SDD and irrigation regimes, I_3 plots registered more negative values than that of I_1 and I_2 irrigation treatments, which might be attributed to occurrence of more stress in I_1 (Table 5). By correlating the biomass and grain yield of the crop with ambient temperature, canopy temperature and SDD of different phenological stages it was found that the crop attributes were significantly correlated with thermal environments at 5% probability level (Table 6).

Table: 5
Effects of sowing dates and irrigations on stress degree days in maize (based on observation of canopy temperature at 12.00 hr)

Treatments	Phenological stages				
	Early vegetative stage	Tasseling	Silking	Grain filling	Maturity
I. Sowing dates					
S_1	-3.24	-3.78	-3.96	-3.41	-2.98
S_2	-2.21	-2.30	-2.67	-2.09	-0.98
S_3	-1.01	-1.12	0.74	0.90	1.11
II. Irrigations					
I_1	-1.76	-1.98	0.64	0.10	0.41
I_2	-2.29	-2.12	-2.19	-2.34	-1.65
I_3	-2.53	-3.07	-3.48	-3.45	-2.32

Table: 6
Relationship between SDD, dry matter and yield of maize

Growth stage	Correlation coefficients					
	Ambient temperature (^{0}C)		Canopy temperature (^{0}C)		Stress degree days	
	TAGDB	Yield	TAGDB	Yield	TAGDB	Yield
Early vegetative	-0.73*	-0.70*	-0.76*	-0.70*	-0.63*	-0.61*
Tassel initiation	-0.67*	-0.73*	-0.64*	-0.67*	-0.76*	-0.72*
Silking	-0.72*	-0.81*	-0.72*	-0.71*	-0.69*	-0.73*
Grain filling	-0.68*	-0.71*	-0.70*	-0.58*	-0.70*	-0.68*
Maturity	-0.71*	-0.72*	-0.69*	-0.71*	-0.72*	-0.72*

TAGDB = Total above ground dry biomass, *Significant at 5% probability level

4. CONCLUSIONS

The study revealed that there was a progressive decrease of crop biomass (9.6-17.6%) and yield (4.6-11.7%) when sowing gets delayed under limited irrigation scheduling. Temperature exerted a major effect on the rate at which plants developed and increase in temperature shortened the crop duration from planting to physiological maturity, retarded growth and decreased yield. Development rate was significantly correlated with maximum and minimum temperatures during emergence to tasseling and tasseling to maturity stages of the crop. Day length was significantly correlated with vegetative phase of the crop but its effect on the PDR in reproductive stage was not evident. Significant reduction in biomass, leaf area, IPAR, RUE was also occurred in water stress plots. The last sown (S_3) crop expressed lower negative SDD due to more dryness and less availability of soil moisture; as a result crop growth and productivity were reduced significantly. Therefore, to get the advantage of better photo-thermal environments under limited water availability, farmers are recommended to sow the crop in rice fellow within November. Growing period of the first crop rice may be adjusted accordingly.

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