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Light response and photosynthesis in sorghum under field conditions*

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सार — प्रकाश संश्लेषण (पी०) की दर में दैनिक परिवर्तन सहित प्रकाश संश्लेषी फोटॉन फलक्स घनत्व (पी० पी० एफ.० डी०), प्रकाश अनुक्रिया वक्रों के मॉडल तथा पी० पी० एफ़० डी० और P के मध्य संबंध का अध्ययन किया गया। यह अध्ययन पुणे के प्रायोगिक परिस्थितियों में दो मानसूनोत्तर (रबी) ज्वार जीनोटाइप्स, नामत: M35-1 तथा RSV-9R, के लिए किया गया। अर्ध उच्चिष्ट (मेक्सिमल) मान, अर्थात् पी० पी० एफ़० डी० स्तर जिस पर $P = P_{max}/2$ प्राप्त किया गया जो M35-1 और RSV-9R के लिए क्रमश: 1251 तथा 937 μmol $m^{-2}s^{-1}$ पाया गया। प्रकाश संश्लेषण की विभव दरें, 65.79 और 64.52 μmol $m^{-2}s^{-1}$ थीं, जबकि प्रायोगिक परिस्थितियों में वायु के तापमान के प्रभाव के कारण प्रकाश संश्लेषण की प्रेक्षित अधिकतम दर कम थीं। ये दरें M35-1 तथा RSV-9R के क्रमश: 40.93 और 46.66 μmol $m^{-2}mj^{-1}$ पाई गई। मॉडल से ज्ञात की गई प्रकाश संश्लेषण की अधिकतम दर विलंब से फसल बोने के कारण घटी। M35-1 और RSV-9R के लिए पी० पी० एफ़० डी० और प्रकाश संश्लेषण की दर में सहसंबंध गुणांक क्रमश: 0.794 और 0.708 पाया गया। प्राप्त पी० पी० एफ़० डी० और प्रकाश संश्लेषण की दर ज्वार की विलंबित बुआई के कारण कम हो गई।

ABSTRACT. The diurnal variation of rate of photosynthesis (P) with photosynthetic photon flux density (PPFD), model of light response curves and the relationship between PPFD and P were studied for two post-monsoon (*rabi*) sorghum genotypes, *viz.*, M35-1 and RSV-9R under field conditions at Pune. The half maximal values, *i.e.*, PPFD level at which $P=P_{max}/2$ obtained were 1251 and 937 μmol$m^{-2}s^{-1}$ for M35-1 and RSV-9R respectively. The potential rates of photosynthesis were 65.79 and 64.52 μmol$m^{-2}s^{-1}$, whereas, the observed maximum rates of photosynthesis were lower, 40.93 and 46.66 μmol$m^{-2}s^{-1}$ in M35-1 and RSV-9R respectively, due to effect of air temperatures under the field conditions. The maximum rate of photosynthesis determined from the model decreased with delay in the sowing of the crop. Correlation coefficients between PPFD and rate of photosynthesis were 0.794 and 0.708 for M35-1 and RSV-9R respectively. The PPFD received and rate of photosynthesis decreased significantly with delay in sorghum sowing.

Key words — PPFD, Rate of photosynthesis, Light response curves, Rectangular hyperbola, Sorghum genotypes.

1. Introduction

The varieties of a crop can be screened on the basis of their potential rate of photosynthesis (P_{max}) and their adaptability can be checked on the basis of their light saturation point. It is difficult to determine potential rate of photosynthesis under field conditions. Scientists have tried to estimate the rate of photosynthesis at known values of photosynthetic photon flux density (PPFD). Baker (1965) determined the equation $y = -1.99 + 1.736\ x - 0.0286\ x^2$, which was best fitted in the data of light and photosynthesis. Hesketh and Moss (1963) derived the equation of rectangular hyperbola

$$P = P_{max}K\ (I-I_0)/[1 + K\ (I-I_0)] \quad (1)$$

where, P — Rate of photosynthesis,

P_{max} — Maximum rate of photosynthesis when I is at saturation point,

K — Inverse of half maximal value, *i.e.*, PPFD at which $P=P_{max}/2$,

I_0 — Light compensation point.

This equation could be best used to determine the rate of photosynthesis at very high light intensities.

Many workers have studied photosynthesis under controlled conditions. However, very few studies have been conducted under field conditions (Singh & Sharma 1986 and Yadav *et al.* 1987). Thus two (*rabi*) sorghum genotypes, M35-1 and RSV-9R, were sown under field conditions to study the maximum rate of photosynthesis and to use the model for its prediction.

2. Material and method

The experiment was conducted in the post-monsoon season of the year 1989-1990, on the experimental field of Centre of Advanced Studies in

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TABLE 1

Influence of air temperature and PPFD on P_{max}

Genotype	Sowing date	Obs. P_{max} (μmol $m^{-2}s^{-1}$)	Air temp (°C)	PPFD (μmol $m^{-2}s^{-1}$)
M35-1	16 Sep	40.93	34.30	1751.25
	16 Oct	38.67	32.40	1533.50
	24 Oct	36.79	28.87	1510.50
	1 Nov	39.09	31.13	1563.50
RSV-9R	16 Sep	46.66	33.50	1857.27
	16 Oct	44.94	30.46	1540.57
	24 Oct	43.86	30.54	1461.28
	1 Nov	44.96	27.90	1586.00

Agricultural Meteorology, College of Agriculture, Pune. The experiment was laid out as a split plot design comprising of four sowing dates (16 September, 16 October, 24 October and 1 November) as main treatments and two post-monsoon (*rabi*) sorghum genotypes (M35-1 and RSV-9R) as subtreatments with four replications. The crop was sown with 45 × 15 cm spacing and one common pre-sowing irrigation was applied. The net plot size was 6.4 × 6.1 m. The soil of plot was medium black calcarious (vertisol) with a depth of greater than 90 cm.

The rate of photosynthesis of individual leaf of sorghum, PPFD and air temperature were measured by using LI-6200 photosynthesis system. Diurnal patterns of PPFD and photosynthesis were recorded at flag leaf stage (45-50 DAS). The third leaf from the top is physiologically more active (Estin 1972), hence, the rate of photosynthesis was recorded on it at an interval of one hour starting from 0700 to 1700 IST. The observations were also recorded at four important growth stages, *viz.*, flag leaf, boot, anthesis and soft dough. The data obtained at these stages were used to calculate correlation coefficient between light and photosynthesis. The equation of rectangular hyperbola (Hesketh and Moss 1963) $P = P_{max}K\ (I-I_0)/[1 + K\ (I-I_0)]$ was transformed in linear equation form :

$$\frac{1}{P} = \frac{1}{P_{max}} + \frac{1}{P_{max}K}\left(\frac{1}{I-I_0}\right) \qquad (2)$$

that is, $y=b+ax$, where $y=1/P$, $b=1/P_{max}$, $a = 1/P_{max}K$ and $x=1/I-I_0$. This equation was used to estimate the value of P at PPFD > 2000 $\mu mol m^{-2}s^{-1}$ because highest PPFD received in field was 1857.27 $\mu mol m^{-2}s^{-1}$ during the period of diurnal measurements (Table 1).

TABLE 2

Fitting the linear transformation of rectangular hyperbola

Genotype	Sowing date	I_0 (μmol $m^{-2}s^{-1}$)	$y=b+ax$	R^2	P_{max} (μmol $m^{-2}s^{-1}$) model	P_{max} (μmol $m^{-2}s^{-1}$) observed
M35-1	16 Sep	39.99	$y=0.0152+19.47x$	0.99	65.79	40.93
	16 Oct	20.00	$y=0.0166+24.66x$	0.99	60.24	38.67
	24 Oct	15.20	$y=0.0183+23.37x$	0.99	54.95	36.79
	1 Nov	10.10	$y=0.0189+17.47x$	1.00	52.91	39.09
RSV-9R	16 Sep	29.96	$y=0.0155+18.08x$	0.91	64.52	46.66
	16 Oct	20.05	$y=0.0167+15.14x$	0.99	57.14	44.94
	24 Oct	13.00	$y=0.0183+15.90x$	0.99	54.64	43.86
	1 Nov	5.00	$y=0.0191+16.28x$	0.99	52.35	44.96

3. Results and discussion

3.1. *Light compensation point* — For both the genotypes, the maximum rate of photosynthesis observed in the field during diurnal measurements at the flag leaf stage had a decreasing trend with decrease in PPFD received (Table 1). The optimum air temperatures followed the same trend. The results are supported by Sharpe (1983). The diurnal data was further used to plot light response curve. The light compensation point (I_0) was determined by interpolation at zero rate of photosynthesis (Table 2). It is found to vary with the genotype, PPFD and temperature at the time of measurements. Similar, results were obtained by Long (1983).

3.2. *Light response curve* — The values of $1/P$ and $1/(I-I_0)$ were fitted in the linear form $y=b+ax$ of the rectangular hyperbola and P_{max} was estimated at flag leaf stage (Table 2). The general equations of rectangular hyperbola obtained from pooled data for the two genotypes were :

$$P=0.047\ (I-I_0)/[1+0.000799\ (I-I_0)] \text{ for M35-1,} \qquad (3)$$

and

$$P=0.061\ (I-I_0)/[1+0.001067\ (I-I_0)] \text{ for RSV-9R.} \qquad (4)$$

It was observed that the half maximal values K^{-1}, *i.e.*, PPFD level at which $P=P_{max}/2$ were 1251

TABLE 3

PPFD and photosynthesis recorded at grand growth stages

Treatment	PPFD (μmol $m^{-2}s^{-1}$)				Photosynthesis (μmol $m^{-2}s^{-1}$)			
	Flag	Boot	Anthesis	Soft dough	Flag	Boot	Anthesis	Soft dough
16 Sep	972.97	1015.40	987.13	1034.63	35.65	37.94	40.03	42.15
16 Oct	980.82	981.95	922.19	992.52	35.92	36.27	38.61	39.21
24 Oct	925.56	913.04	924.77	943.07	32.24	33.49	36.19	38.11
1 Nov	895.47	886.48	896.16	908.28	30.97	32.83	34.39	35.81
SE ±	4.79	7.91	7.59	5.62	0.84	0.82	0.89	0.21
$CD_{0.05}$	15.32	25.28	24.27	17.99	2.68	2.62	2.86	0.69
M35-1	939.20	954.99	961.02	967.02	34.59	34.78	38.82	39.28
RSV-9R	948.22	943.45	939.10	972.23	32.79	35.49	35.79	38.68
SE ±	5.04	5.90	5.34	5.70	0.45	0.55	0.54	0.47
$CD_{0.05}$	NS	NS	NS	NS	1.40	NS	1.67	NS
Interactions $CD_{0.05}$	31.08	NS	32.93	NS	NS	NS	NS	NS

(1/0.000799) and 937 (1/0.001067) $\mu molm^{-2}s^{-1}$ for M35-1 and RSV-9R respectively. This indicated that M35-1 would be light saturated later than RSV-9R. The estimated maximum rate of photosynthesis (P_{max}) in M35-1 and RSV-9R were 65.79 and 64.52 $\mu molm^{-2}s^{-1}$ respectively; while those observed in the field conditions were 40.93 and 46.66 $\mu molm^{-2}s^{-1}$ respectively (Table 2). The value of maximum rate of photosynthesis in M35-1 was at par with earlier results but in case of RSV-9R, it was higher than the value (173 ng CO_2 $cm^{-2}s^{-1}$) recorded by Rawson *et al.* (1978). The maximum rate of photosynthesis determined theoretically from the model decreased with delay in sowing of the crop. Further, the observed values of photosynthesis are lower than the values determined from the model. This is because of effect of air temperatures under field conditions (Norcio 1976, Vong and Murata 1977).

3.3. *Relationship between photosynthesis and PPFD* — The correlation coefficients obtained between photosynthesis and PPFD were 0.794 and 0.708 for M35-1 and RSV-9R respectively (Table 3). These coefficients were less than those obtained by the other workers, previously, under the controlled conditions. The other micrometeorological parameters like air temperature, soil moisture and wind have an intervening effect on photosynthesis and PPFD relationship. The rate of photosynthesis and PPFD measured at four grand growth stages of the sorghum revealed that PPFD decreased significantly with delay in sowing at all growth stages (Table 3). However, there was no significant difference between 16 September and 16 October sowings at flag leaf stage. Consequently, the rate of photosynthesis also decreased significantly due to delay in sowing at all growth stages. However, there was no significant difference between 16 September and 16 October sowing and 24 October and 1 November treatments except at soft dough stage. There was no significant difference between PPFD and rate of photosynthesis of 16 October and 24 October sowings at anthesis. This clearly shows a trend of decrease in PPFD received and rate of photosynthesis with delay in sowing. The PPFD received at a particular growth stage did not vary significantly between genotypes, since the occurrence of growth stages in them varied only by two to three days. However, rate of photosynthesis did show significant difference between the genotypes at flag leaf stage and anthesis suggesting that M35-1 photosynthesized more at these stages and, therefore, would be light saturated later than RSV-9R. The interaction effects between sowing dates and genotypes showed no significant difference in the rate of photosynthesis irrespective of PPFD.

4. Conclusion

The half maximal values of PPFD were 1251 and 937 $\mu molm^{-2}s^{-1}$ for M35-1 and RSV-9R respectively. The potential rates of photosynthesis were 65.79 and 64.52 $\mu molm^{-2}s^{-1}$, whereas, the observed maximum rates of photosynthesis were lower, 40.93 and 46.66 $\mu molm^{-2}s^{-1}$ in M35-1 and RSV-9R respectively, due to effect of air temperatures under the field conditions. The maximum rate of photosynthesis determined from the model decreased with delay in the sowing of the crop. The PPFD received and rate of photosynthesis decreased significantly with delay in sorghum sowing.

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