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Influence of Planting Geometry on Photosynthetically Active Radiation Interception and Dry Matter Production Relationships in Pearl Millet

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ABSTRACT

*A field experiment was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Center, Patancheru, India to study photosynthetically active radiation (PAR) interception and dry matter production relationships in pearl millet (*Pennisetum americanum *(L.) Leeke). Two pearl millet genotypes, BJ 104 (G_1) and ICH 226 (G_2) were sown at three planting geometries obtained by using combinations of row and plant spacings (S_1: 37·5 cm × 26·6 cm; S_2: 75·0 cm × 13·3 cm; S_3: 150·0 cm × 6·6 cm) such that plant population was constant at 100 000 ha^{-1} in all treatments. Cumulative intercepted PAR was maximum (330 MJ m^{-2}) in G_2S_2 and minimum (268 MJ m^{-2}) in G_1S_3. Conversion efficiency values ranged from 1·87 g MJ^{-1} in G_1S_2 to 2·32 g MJ^{-1} in G_2S_3. Final above-ground dry matter followed the pattern of cumulative intercepted PAR and maximum dry matter (7·22 Mg ha^{-1}) was produced by G_2S_2 while G_1S_3 produced minimum dry matter (4·97 Mg ha^{-1}).*

Key words: pearl millet, planting geometry, leaf area index, photosynthetically active radiation interception, extinction coefficient, conversion efficiency, dry matter.

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INTRODUCTION

Solar radiation interception and use by crop canopies is useful information for the assessment of crop productivity. Growth of crops is increasingly analyzed in terms of radiation interception by crops,[1-4] which provides a more rational analysis of crop growth than does classical growth analysis.[5] In recent years, information on photosynthetically active radiation (PAR) use efficiency has been used in crop-modelling research.[6] Such information is available for crops like soybean, sorghum, wheat, barley, fababean, peanut, etc. General information is available for pearl millet (*Pennisetum americanum* (L.) Leeke), which is a prominent crop of the semi-arid tropics. The present study was undertaken in order to understand PAR interception and dry matter production relationships in pearl millet under three planting geometries.

MATERIALS AND METHODS

Site and soil

The experiment was conducted during the rainy season (June–September) of 1982 at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center at Patancheru, near Hyderabad, India (17°32′N, 78°16′E). The soil of the experimental field was a medium-deep Alfisol. The field was laid out in a 150-cm broadbed-and-furrow system and the width of beds was 120 cm, separated by 30-cm furrows as described by Kampen.[7]

Treatments

The treatments consisted of two pearl millet hybrids, BJ 104 (G_1) and ICH 226 (G_2), and three planting geometries obtained by using combinations of row and plant spacings (S_1: 37·5 cm × 26·6 cm; S_2: 75·0 cm × 13·3 cm; S_3: 150·0 cm × 6·6 cm) such that plant population was constant at 100 000 plants ha^{-1} in all treatments. The experiment was laid out in a randomized block design with three replicates. Plot size was 20·0 m × 10·5 m, each plot having seven beds 20 m long.

Crop culture

The field was cultivated and beds were reshaped on 19 June 1982. Basal doses of nitrogen and phosphorus (P_2O_5) were applied (32 kg ha^{-1} each) using a compound fertilizer. Hybrids were sown on 20 June at 3–4 cm depths and emergence occurred on 24 June. The crop was thinned to 100 000 plants ha^{-1} on 9 July and nitrogen (28 kg ha^{-1}) was top-dressed using urea at 22 days after emergence (DAE). Weeds were controlled by hand weeding. No insect pest infestation was observed on the crop; however, slight incidence of rust (*Puccinia pennisetii*) occurred on lower leaves at the end of the growing season. Hybrids were harvested on 15 September.

Observations

Leaf area and dry matter

Plants from an area of 1·5 m × 1·0 m were pulled out of the soil at 7–10-day intervals from each plot, leaving borders. Roots were separated from top growth by cutting plants at the point on the stem which was at the soil surface. Leaves of all the sampled plants were detached from stems and their area was measured with a leaf area meter (LI-3100, LI-COR, Inc, Lincoln, NE, USA).† After measuring leaf area, plant material was chopped and placed in muslin cloth bags in a forced draft even at 65°C for drying to constant weight.

PAR interception

Measurements for PAR interception were made at weekly intervals using a PAR interception measurement frame,[8] with tracks for three quantum sensors (LI-190, LI-COR, Inc). The steel frame (Fig. 1) securing the sensors conformed to the 150-cm bed width. The frame was placed in each treatment such that crop rows in a 150-cm bed were centred in it. Site of placement was chosen when the crop was very small and the frame was kept at the same site throughout the season. Sensors were always positioned with their bases level to soil surface during data collection.

Each sensor was moved across crop rows on the horizontal track provided by the 150-cm steel bar, which was marked at 10-cm intervals so that the sensor could be moved manually from one end to the other in 150 s and positioned at each mark for 10 s. Each sensor was attached to a read-out integrator (LI-510, LI-COR, Inc). After 150 s, the integrated reading was noted and the sensor moved back to its original position. Transmission of PAR for a particular treatment was taken as the average

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†Mention of commercial products does not imply endorsement or recommendation by the authors.

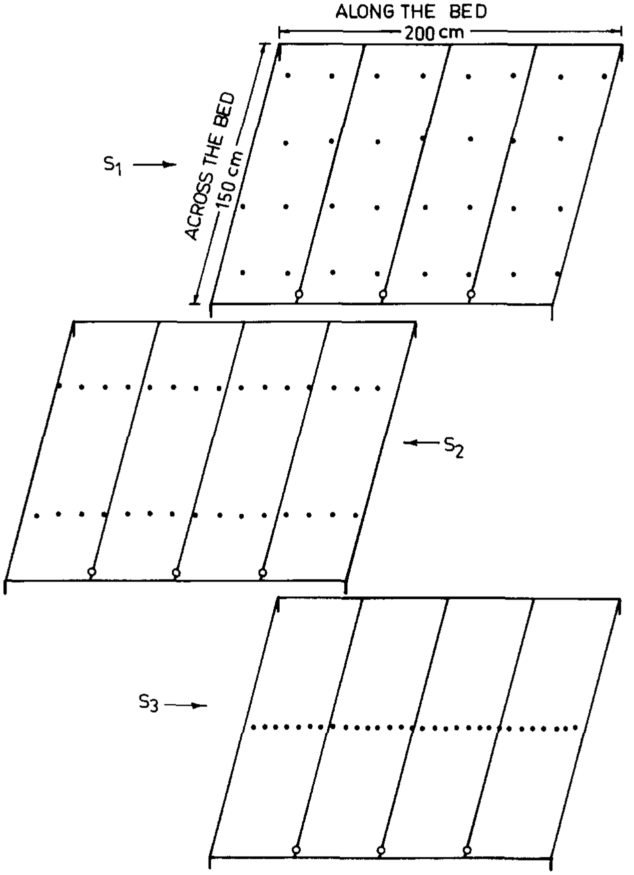

Fig. 1. Diagramatic sketch of PAR measurement frame and planting geometries. Circles and dots represent PAR sensors and plants, respectively.

of 30 readings, i.e. for 10 traverses of each of the three sensors. One quantum sensor was mounted 0·5 m above the canopy to record PAR incident on the canopy. The difference between incident and transmitted PAR was treated as intercepted PAR. These measurements were confined to midday periods to minimize the effect of solar altitude. Interception data recorded at weekly intervals during the growing season were plotted and interception for each day calculated.

Final total dry matter

An area of 45 m^2 was harvested from each plot. Harvested plant material was weighed and a sub-sample was drawn from each plot and dried. Dry matter yield of each plot was calculated and then converted to Mg ha^{-1}.

Statistical analysis

Statistical procedures were followed as given by Cochran and Cox,[9] and Smillie.[10]

RESULTS

Weather

Meteorological data for the growing season were obtained from the ICRISAT observatory (Table 1). Rainfall was well distributed except during the later part of the growing season when practically no rainfall was received over a span of two weeks (Weeks 34 and 35). Pan evaporation was fairly high and ranged between 36 and 62 mm week^{-1}. Except for a few cloudy days, solar radiation was high (more than 35 MJ m^{-2} day^{-1}) during the season.

TABLE 1
Meteorological Parameters[a] Recorded at ICRISAT Observatory during 1982 Rainy Season

Standard week[b]	*Rainfall (mm)*	*Evaporation (mm)*	*Temperature (°C)*		*Relative humidity (%)*		*Solar radiation (MJ m^{-2} day^{-1})*
			Max.	*Min.*	*0717 h*	*1417 h*	
25	24·2	46·9	31·8	23·1	88	60	36·46
26	29·1	58·5	33·4	23·4	78	51	36·46
27	9·2	61·5	34·2	23·6	76	42	45·35
28	27·1	41·6	30·3	22·1	89	65	36·21
29	18·9	40·7	29·9	22·4	87	62	29·80
30	50·0	46·1	30·2	22·5	88	62	36·38
31	74·4	46·1	30·4	22·3	89	62	43·38
32	24·9	37·8	30·0	22·8	88	62	35·01
33	14·4	36·6	28·8	22·4	88	67	26·99
34	3·4	39·6	29·9	22·4	85	58	31·17
35	0·8	43·8	31·5	22·3	80	51	40·39
36	59·1	40·4	30·5	21·8	90	58	37·74
37	40·7	24·4	28·2	22·0	96	73	28·10

[a] The data are weekly averages, except rainfall and evaporation which are totals.
[b] Planting and harvesting were done in Weeks 25 and 37, respectively.

Leaf area index (LAI)

In general, G_2 had a higher LAI than G_1 throughout the growing season (Fig. 2). The LAI was lowest under S_3 among planting patterns and highest under S_2. Leaf area index increased rapidly from 21 to 42 DAE in all treatments. Peak values of LAI for G_1 were 1·9, 1·8 and 1·6 under S_2, S_1 and S_3, respectively. Maximum LAI values for G_2 were 2·3, 2·0 and 1·7, respectively for S_2, S_1 and S_3.

PAR interception

Peak values of PAR interception for G_1 were obtained at 61, 40 and 54 DAE in S_1, S_2 and S_3, respectively (Fig. 3), with the highest value in S_1 (82%) and lowest in S_3 (72%). In G_2, S_2 usually had higher PAR interception which was maintained until 54 DAE when 88% PAR was intercepted which was also highest for the season. In S_3, the peak value of PAR interception (69%) was attained at 54 DAE. Averaged over plant

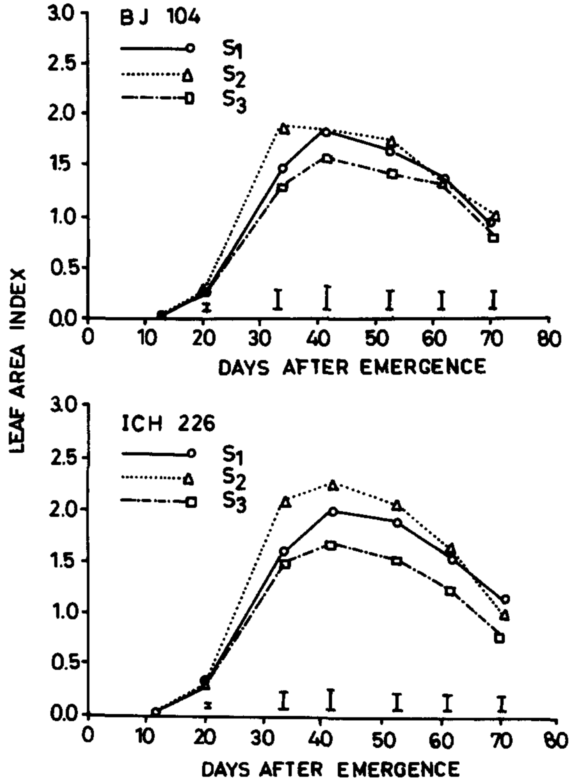

Fig. 2. Leaf area index as a function of time under three planting geometries of two pearl millet genotypes.

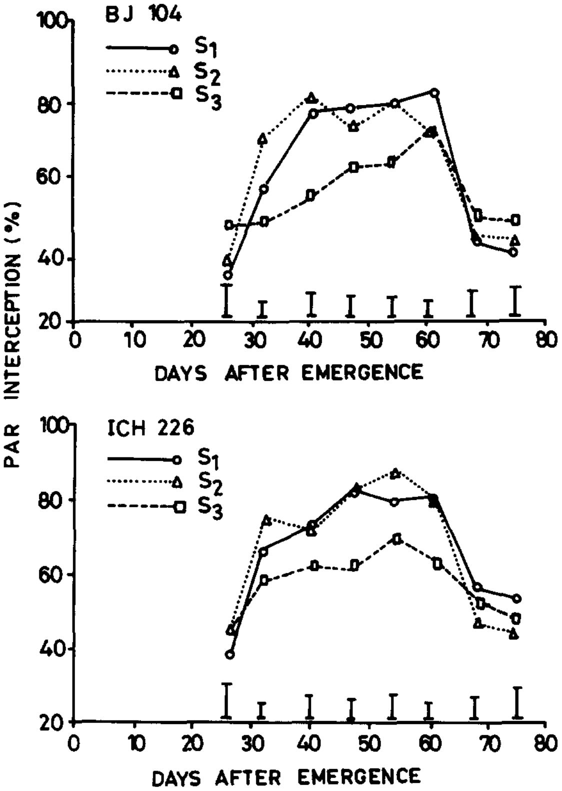

Fig. 3. PAR interception as a function of time under three planting geometries of two pearl millet genotypes.

geometries, PAR interception by G_2 was more than G_1. Cumulative PAR interception values for G_1 were 292, 298 and 268 MJ m^{-2} under S_1, S_2 and S_3, respectively. For G_2, the corresponding values were 320, 330 and 283 MJ m^{-2} for S_1, S_2 and S_3, respectively.

Extinction coefficient

The extinction coefficient[11] was determined using the relationship

$$\ln \frac{I_z}{I_0} = -KL$$

where

ln = natural log,
I_z = PAR density below a given LAI,
I_0 = incoming PAR density above the canopy,

K = extinction coefficient, and
L = LAI

Extinction coefficients for S_3 were low (Table 2) in both genotypes, suggesting less interception than in S_2 and S_1. This relationship further suggested that the LAI required to intercept the same amount of PAR was greater in S_3 (wide rows) than in S_2 and S_1.

TABLE 2
Extinction Coefficients Calculated for Two Pearl Millet Genotypes under Three Planting Geometries Using the Relationship $\ln(I_z/I_0) = -KL$

Treatment	*Extinction coefficient*
G_1S_1	0·64
G_1S_2	0·64
G_1S_3	0·38
G_2S_1	0·60
G_2S_2	0·50
G_2S_3	0·42

PAR interception versus dry matter production (conversion efficiency)

Linear relationships of the form $Y=bx$[10] were developed to determine above-ground dry matter production, on a seasonal basis, per unit of PAR absorbed. In the above relationship, Y = dry matter (g), b = conversion efficiency (g MJ^{-1}), and x = cumulative intercepted PAR (MJ). Maximum conversion (2·32 g MJ^{-1}) was obtained in G_2S_3 followed by G_2S_1 (2·16 g MJ^{-1}). Lowest dry matter (1·87 g) production per unit of intercepted PAR was in G_1S_2 (Table 3). Average values of conversion efficiency (b) were 2·01 g MJ^{-1} for G_1 and 2·19 g MJ^{-1} for G_2, whereas average values of conversion efficiency were 2·1, 1·98 and 2·22 g MJ^{-1} for S_1, S_2 and S_3, respectively.

Final total above-ground dry matter

Highest above-ground dry matter (7·22 Mg ha^{-1}) was produced by G_2S_2 (Table 4), which was significantly higher than the rest of the treatments. Lowest dry matter (4·97 Mg ha^{-1}) was produced by G_1S_3.

TABLE 3

Conversion Efficiency (Seasonal Basis) of PAR into Dry Matter (g MJ^{-1}) under Three Planting Geometries of Two Pearl Millet Genotypes

Treatment	*Equation*	*SE of estimate*	*r*
G_1S_1	$Y=2{\cdot}04x$	±0·13	0·94
G_1S_2	$Y=1{\cdot}87x$	±0·07	0·97
G_1S_3	$Y=2{\cdot}12x$	±0·16	0·92
G_2S_1	$Y=2{\cdot}16x$	±0·10	0·97
G_2S_2	$Y=2{\cdot}09x$	±0·08	0·98
G_3S_3	$Y=2{\cdot}32x$	±0·17	0·92

TABLE 4

Total Above Ground Dry Matter (Mg ha^{-1}) Produced by Two Pearl Millet Genotypes under Three Planting Geometries

	G_1	G_2
S_1	5·99	6·31
S_2	5·57	7·22
S_3	4·97	5·87
LSD (0·05)	0·37	

DISCUSSION

The ability to absorb and utilize PAR governs in part the plant productivity in a community. Interception of PAR by crop plants mainly depends on the amount of foliage represented by LAI, and orientation and distribution of foliage. The LAI values under S_3 (150·0 cm × 6·6 cm planting geometry) were lower for both the genotypes because of reduced number of tillers. Leaf area index of G_2 was more because of greater height and larger leaves.

Interception of PAR followed the pattern of LAI. Extinction coefficient (K) which is a function of foliage architecture, and is an indicator of PAR distribution within the canopy, was determined for all the treatments. While Squire *et al.*[12] have reported the value of K to be generally constant under wet conditions, it varied widely in the present study because of changed planting geometries which altered the distribution of foliage within a stand. Low values of K for S_3 suggested greater PAR transmission to the lower layers in the canopy and also to the ground resulting in low PAR interception.

Dry matter production has been shown to be linearly related to intercepted radiation.[13-15] Ong and Monteith[16] calculated this efficiency to be in the range of 2·0–2·5 g MJ^{-1} which was consistent with the observed values[17-19] in moist environments, while this efficiency was about 1·50 g MJ^{-1} in dry environment of Niamey (Niger).[20] Average values of conversion efficiency observed in this study were 2·01 and 2·19 g MJ^{-1} respectively for G_1 and G_2 over the planting patterns. Singh *et al.*[21] have also reported different values of dry matter production per unit of absorbed PAR in pearl millet. The differences in conversion efficiency among planting patterns were noted. Conversion efficiency of S_3 canopy was higher probably because of uniform distribution of PAR within the canopy as evidenced by its low extinction coefficient, and it might have taken more advantage of greater exposure to diffuse light and skylight at low solar angles.

Final dry matter production almost followed the pattern of cumulative intercepted PAR. Though conversion efficiency was less in G_2S_2, dry matter production was highest, and this was due to greater leaf area and increased PAR interception which was probably resultant of promoted plant competition in S_2.[22] High conversion efficiency alone of S_3 failed to bring up the level of total dry matter production because of considerably lower PAR interception. Thus, high conversion efficiency coupled with greater PAR interception could improve dry matter production. Among the genotypes, G_1 produced more dry matter at S_1, while in G_2 it was more at S_2. This indicates that a general conclusion regarding the planting geometries will be governed by the genotype in question.

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