INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2004/06–6–1119–1123
http://www.ijab.org

Effect of Sowing Date and Plant Density on Growth, Light Interception and Yield of Wheat under Semi Arid Conditions

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ABSTRACT

Growth and yield of wheat at different sowing dates (10 Nov., 25 Nov., 10 Dec.) with different plant densities (200, 300 and 400 plants m^{-2}) were analyzed in terms of solar radiation intercepted by the leaves during 1998-99 and 1999-2000. Leaf area index, radiation interception and biomass accumulation were measured throughout the growing seasons. The relationship between dry matter production and intercepted photosynthetically active radiation (PAR) was highly significant (r = 0.93**) and linear throughout the growing season for all treatments, and a common regression line (slope) represented a constant mean seasonal efficiency in the conversion of radiation into biomass. The radiation use efficiency (RUE) was 3.65 g MJ^{-1} for the pooled data. Results showed that the highest yields were obtained from early (November) sowings and a plant density of 300 plants m^{-2}; yield variations among treatments were caused by affecting both the amount of intercepted PAR and RUE.

Key Words: Sowing date; Plant density; Radiation use efficiency; Yield; Wheat; Pakistan

INTRODUCTION

Key to increasing the productivity of field crops is to maximize the amount of radiation they intercept (Monteith, 1977). Interception of radiations on leaf surface can not be controlled but can be manipulated for their maximum use by crop husbandry means. The fraction of radiation intercepted by crops increases hyperbolically with LAI; in many crops 80-85% is intercepted when LAI is between 3.0 and 4.0, and 95% when LAI reaches 5.0 (Scott & Jaggard, 1978; Milford *et al*., 1980).

Crop growth can be analyzed in terms of its efficiency to use intercepte radiatins. This approach has been applied to many field crops (Scott *et al*., 1973; Gallagher & Biscoe, 1978; Muchow, 1989; Hussain & Field, 1993; Hussain *et al*., 1998; Hussain *et al*., 1998, 1999, 2002). The relationship has been used as a basis for theoretical investigations into tropical crop productivity, modeling climate effects and the importance of light as a limiting factor in crop performance (Monteith, 1972, 1973, 1981).

Under adequate supply of water and nutrients, wheat yield has been shown to be closely related to the amount of radiation intercepted during the growing season. Gallagher and Biscoe (1978) showed that 3 g dry matter (DM) of wheat was produced by each mega joule (MJ) of photosynthetically active radiations (PAR) absorbed until ear emergence. For the whole season about 2.2 g DM was produced per MJ absorbed. Such measurements provide a useful index of the production efficiencies of crops in different regions. Scanty information is available on these aspects of productivity of wheat or other crops in Pakistan. This paper presents the effects of sowing date and planting density on growth, light interception and yield of wheat under semi arid conditions.

MATERIALS AND METHODS

The study was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, (31º.76´, 75º.06´, 104.4 m) during 1998-1999 and 1999-2000. The experiment was laid out in a randomized complete block design with split plot arrangement; sowing dates in main plots and seeding rates in sub-plots. There were three replications having a plot size of 1.6m x 10m. The treatments were three sowing dates (10 and 25 Nov., and 10 Dec.) and three planting densities (200, 300 and 400 plants m^{-2}). The seed was sown with the help of a single row hand drill. Nitrogen and phosphorus @ 120 and 100 kg ha^{-1}, respectively, were applied in both the years. Half of the nitrogen and full phosphorus was applied at sowing and remaining half of nitrogen was top dressed with first irrigation. All other practices such as hoeing, irrigation, weeding, etc. were kept uniform in both seasons.

Estimates of dry weight (oven dry) and leaf area were made weekly from harvesting 20cm long row from each plot at ground level. Leaf area was measured from a sub sample of 10 g of green leaf lamina by an area meter (Li-cor, Model 3100). Tube solarimeters were used to measure the radiation interception by the crop canopy. Accumulated intercepted radiation was calculated by summing the products of proportional interception values, and half of the total daily incoming solar radiation was considered as PAR (Szeicz, 1974).

At maturity an area of one meter square was harvested manually from each plot. Spikes were threshed manually and grains were separated and weighed. Then the grain yield was converted into kilograms per hectare.

RESULTS AND DISCUSSION

Weather. During both the growing seasons temperatures ranged between 12.9ºC – 28.4ºC during the crop-growing season (Nov. - April); March and April were warm by about 3ºC than the long term mean (Table I). Months of December and January were foggy in 1998-99 and radiations received were less by 35 and 42%, respectively in both the months. However, in 1999–2000, radiation receipts were normal throughout the growing period. Total rainfall was 34.6 mm in 1998-99 and 28.8 mm in 1999-2000, which was 57% less than the long term mean. Potential soil moisture deficit increased from 33 mm to 229 mm 1998-99 and 38 mm to 275 mm in 1999-2000 until the termination of experiments.

Leaf area index. In both seasons early sowing enhanced LAI over late sowing until 11 February; thereafter, 10 Dec. sowing significantly increased LAI over early sowing until final harvest (Fig. 1). In 10 Nov. sowing, LAI reached a maximum value of 5.0 on 11 Feb. in 1998-99 and 5.6 on 28 January in 1999-2000. In contrast, LAI reached a maximum value of 5.1 on 25 Feb. (2 weeks later) in 1998-99 and 6.2 on 18 Feb. (3 weeks later) 1999-2000 in 25 Nov. sowing. In late sowing crop (10 Dec.), maximum LAI reached at 5.1 on 5 March (3 weeks later) in 1998-99 and 5.5 (6 weeks later) in (1999-2000) on 12 March; thereafter it reduced rapidly in all the treatments.

In 1998-99, plant density at 400 plants m^{-2} significantly increased LAI over lower density (200- or 300 plants m^{-2}) until 31 Dec. (Fig. 2). Thereafter, the differences in LAI between plant densities became non-significant until 21 January. From this point onward the LAI was higher at plant density of 200- and 300 compared to 400 plants m^{-2} density until 18 Feb., but thereafter this difference became non significant among between densities. In 1999-2000, differences in LAI among densities were non-significant throughout the season, except at 21 Jan. and 18 Feb. harvests, when high plant density significantly increased LAI over lower density.

The growth curves of LAI provide a visual integration of changes in climatic conditions. During winter months (Dec.-Jan.), LAI development rates were low but from Feb. onward rapid rates of development occurred as temperature increased (Table I). The sharp decline of LAI after mid March was probably associated with senescence of leaves. Increases in LAI due to sowing date and plant density were positive, especially early in the season.

The general effect of sowing date and plant population on LAI was consistent with those of Khan (2000), who reported that early (Nov.) sowing and higher plant density increased LAI, especially early in the season. Maximum LAI value of >5.0 found noted here is comparable to that

Table I. Monthly mean weather data for the wheat growing seasons at Faisalabad.

Month	Temperature (ºC)		Solar radiation (MJ m^{-2})		Rainfall (mm)		PSMD (mm)	
	1998-99	1999-00	1998-99	1999-00	1998-99	1999-00	1998-99	1999-00
Nov.	19.5	19.8 (18.5)*	12.2	12.9 (13.6)*	0	0.2 (4.4)*	33.4	38.2
Dec.	13.5	14.8 (14.1)	5.3	11.3 (9.7)	0	0 (6.5)	29.1	38.3
Jan.	11.9	11.7 (11.8)	4.8	10.0 (10.1)	23.5	9.4 (10.4)	4.2	24.4
Feb.	15.8	14.1 (14.5)	14.1	16.0 (12.5)	4.7	11.8 (19.6)	47.0	43.3
March	21.0	19.9 (19.5)	16.5	18.7 (15.6)	6.4	1.4 (12.4)	86.0	97.1
April	28.6	29.1 (25.8)	21.9	21.24 (19.6)	0	0 (33.3)	29.9	34.4
Total					34.6	28.8	229.6	275.5

* = Figures in Parenthesis are long term average; PSMD = Potential Soil Moisture Deficit (Penman)

Table II. Effect of sowing date and plant density on growth, intercepted PAR and yield of wheat during 1998-99 and 1999-2000

Treatments	Grain Yield (kg ha^{-1})		Intercepted PAR (MJ m^{-2})		Crop growth rate(g $m^{-2}day^{-1}$)		Radiation use efficiency (g MJ^{-1}) (TDM)		(Grain yield)	
	1998-99	1999-00	1998-99	1999-00	1998-99	1999-00	1998-99	1999-00	1998-99	1999-00
Sowing date										
S1= 10 Nov.	3183^NS	5279a	371.5 a	503.1 a	13.0 b	11.8 c	3.6 b	2.9 c	0.85 b	1.05 a
S2= 25 Nov.	2970	4834b	337.1 b	489.6 b	15.1 a	16.4 b	4.3 a	3.3 b	0.88 b	0.89 a
S3= 10 Dec.	2995	3336c	295.9 c	420.1 c	13.0 b	17.5 a	4.2 a	3.9 a	1.01 a	0.79 b
LSD 5%	203	248	3.6	2.46	0.48	0.12	0.15	0.01	0.06	0.06
Contrast (S1+S2 vs S3)	NS	**	**	**	**	**	*	**	**	**
Plant density										
P1=200 Plants m^{-2}	3007^NS	4292c	325.6 c	452.1 c	13.5 ^NS	15.5 b	4.1 a	3.5 a	0.93 ^NS	0.94 ^NS
P2=300 Plants m^{-2}	3211	4489b	334.8 b	472.1b	13.9	15.6 a	4.1 a	3.4 b	0.97	0.94
P3=400 Plants m^{-2}	2929	4667a	344.2 a	488.6a	13.7	14.6 c	3.9 b	3.1 c	0.85	0.95
LSD 5%	446	139	1.4	2.3	0.42	0.07	0.11	0.01	0.13	0.01
Linear	NS	**	**	NS	NS	**	**	**	NS	NS
Quadratic	NS	**	NS	**	NS	**	*	**	NS	NS
Mean	3049	4483	334.8	470.9	13.7	15.2	4.0	3.4	1.92	0.94

Means Sharing Different Letters Differ Significantly at P< (0.05); NS = Non- Significant

Fig. I. Effect of sowing date on leaf area index during 1998-99 and 1999-2000; Bars represent LSD value at 5%

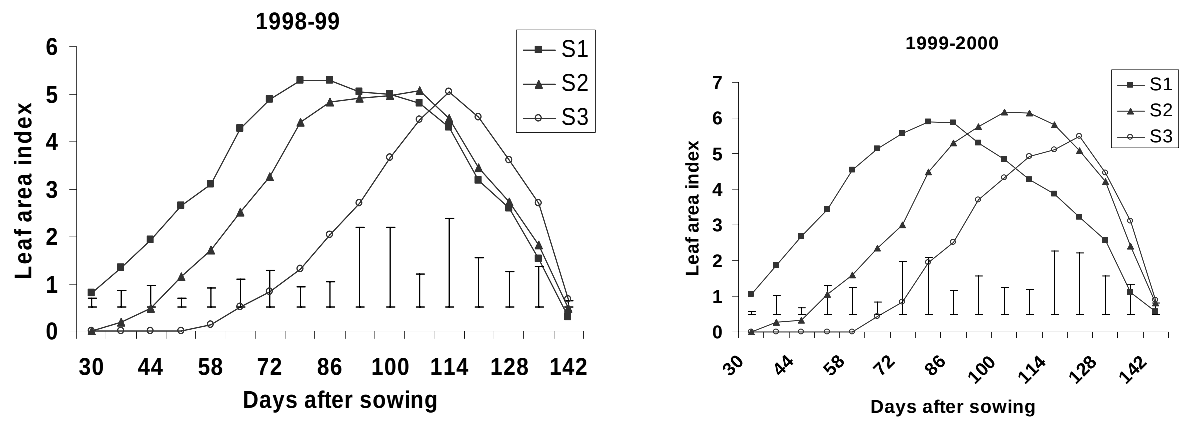


Fig. 2. Effect of plant population on leaf area index during 1998-99 and 1999-2000; Bars represent LSD value at 5%

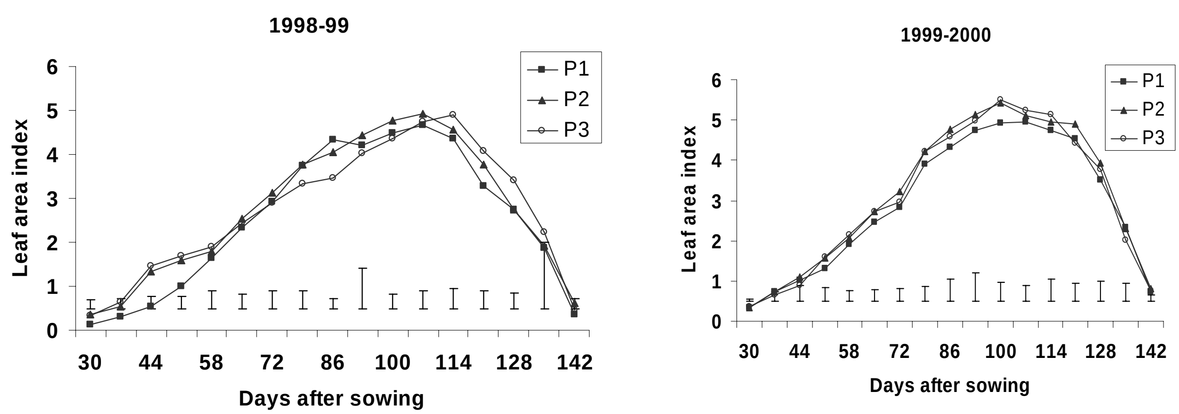
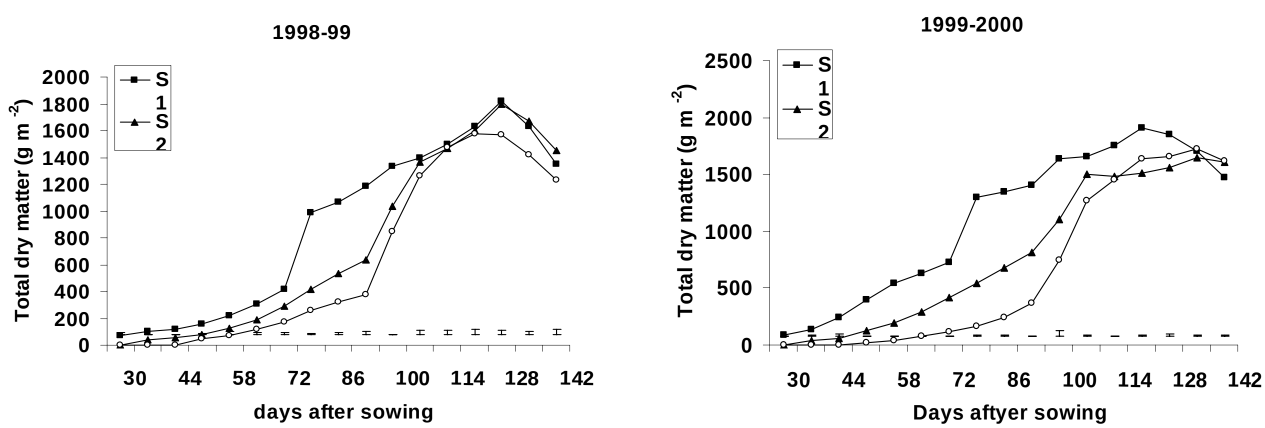


Fig. 3. Effect of sowing date on total dry matter during 1998-99 and 1999-2000; Bars represent LSD value at 5%



reported by others (Khan, 2000; Naeem, 2001). A sharp decline of LAI in the early sowing was typical and associated with the senescence of leaves.

Fig. 4. Effect of plant population on total dry matter during 1998-99 and 1999-2000; Bars represent LSD value at 5%

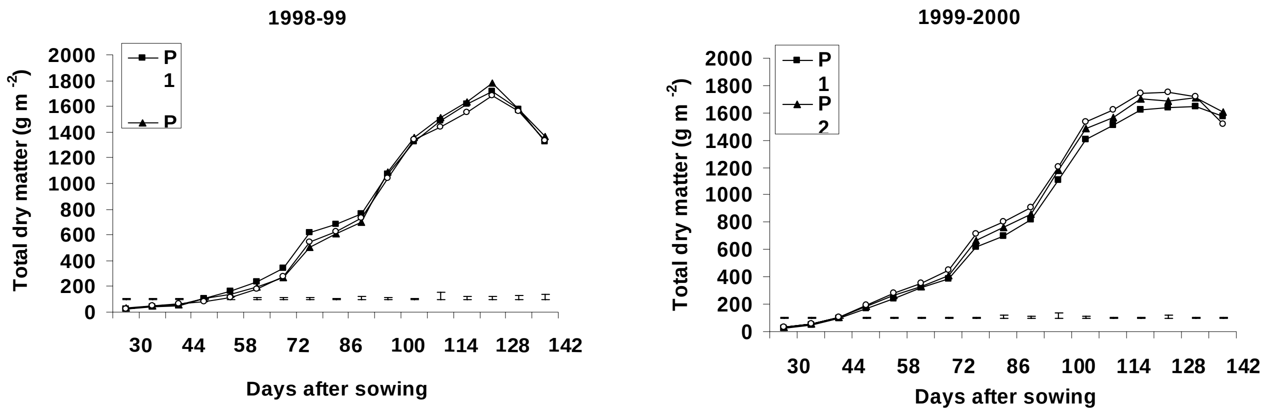
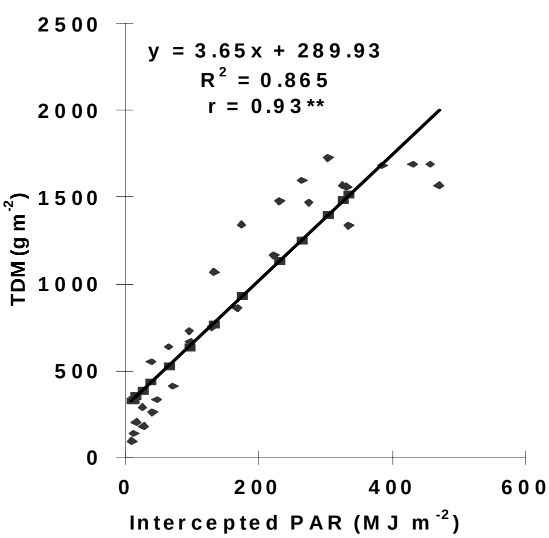


Fig. 5. Relationship between seasonal TDM and accumulated intercepted PAR for the pooled data



Dry matter accumulation. In both seasons, early sowing enhanced total dry matter (TDM) accumulation over late sowing until 18 March but slightly decreased till final harvest (Fig. 3 & 4). Accumulation of TDM was generally slow until 21 January in all the treatments, rose linearly till 18 March, and then declined slightly until final harvest in all treatments. In 1998-99, maximum TDM reached to 1816 g m^{-2} in 10 Nov. sowing, 1796 g m^{-2} in 25 Nov. sowing and 1567 g m^{-2} in 10 Dec. sowing. Maximum TDM in 1999-2000, reached at 1855 g m^{-2} in 10 Nov. sowing and 1560 g m^{-2} in 25 Nov. and 1658 g m^{-2} in 10 Dec. sowing on 18 March as well. Final TDM production was 1370 g m^{-2} in 10 Nov. sowing, 1448 g m^{-2} in 25 Nov. sowing and 1228 g m^{-2} in 10 Dec. sowing in 1998-99. Equivalent figures for 1999-2000 were 1470 g m^{-2} in 10 Nov. sowing, 1610 g m^{-2} in 25 Nov. sowing and 1620 g m^{-2} in 10 Dec. sowing.

Increasing plant density significantly and linearly increased TDM over lower density until 18 March harvest in both the seasons (Fig. 4). Thereafter, response became quadratic until final harvest in both the seasons.

Comparatively superior performance of 10 Nov. sowing and higher density in TDM production was associated with their higher LAI values (Figs. 1, 2) especially early in the seasons. The plants in these treatments intercepted more of the available radiation probably due to longer duration. Although the growth rate of the early sown crops may be slightly lower (Table. II), longer duration of growth offsets the effect of slower growth rate. Thus an early sown crop is expected to out yield a late sown crop (Biscoe & Gallagher, 1978; Monteith, 1981; Khan, 2000).

Intercepted PAR. In 1998-99 total amount of incident PAR was 699 MJ m^{-2}, out of which 335 MJ m^{-2} was intercepted. Equivalent figures in 1999-2000 were 969 MJ m^{-2}, out of which 470 MJ m^{-2} was intercepted (Table II). In 1998-99 the amount of intercepted PAR differed significantly between sowing dates; early sowing intercepted 25.7% more PAR (372, 337 vs. 296 MJ) than the late sowing. In 1999-2000, early sowing also had 19.8% more intercepted PAR (503, 490 vs. 420 MJ) than late sowing.

Higher plant density, in both the seasons, significantly increased intercepted PAR than lower (Table II), and the response was linear in both the seasons. When LAI exceeds 4-5, interception of light for most crops increases only slightly (Biscoe & Gallagher, 1977). On an average, about 45% of the incident PAR during the growing seasons was intercepted which is similar to the average value of 40%, as reported for a range of arable crops (Monteith, 1977).

Results showed that early sowing intercepted more PAR than the late sowing, probably due to longer duration. Results also showed that the magnitude of this response was greater with higher than the lower densities. These results agree with other workers (Khan, 2000; Naeem, 2001).

Radiation utilization efficiency (RUE}. There were significant differences in RUE in total DM for different treatments in both the seasons (Table II). Late sown crop indicated significantly increased RUE (4.8% in 1998-99 and 24.1% in 1999-2000) than early sowing. Differences in RUE between 25 Nov. and 10 Dec. sowing were also significant during 1999-2000. Averaged RUE for two seasons was 3.3, 3.8 and 4.0 g MJ^{-1} on 10 and 25 Nov., and 10 Dec. sowing, respectively. Plant density of 200 was also superior in RUE than that of 400 plants m^{-2} in both the seasons. Differences in RUE between 200- and 300 plants m^{-2} were also significant during 1999-2000. Average RUE of TDM was 4.0 and 3.4 g MJ^{-1} in 1998-99 and 1999-2000 respectively (Table II).

RUE for grain was differently affected by the sowing dates (Table II). In 1998-99, late sowing (10 Dec.) gave 16.0% higher RUE (0.85, 0.88 vs. 1.01) than early sowings (10 Nov or 25 Nov.). In contrast, in 1999-2000, RUE for grain yield was significantly higher at 10 Nov. sowing compared to 25 Nov. or 10 Dec. RUE for grain yield was also higher in 25 Nov. sowing over 10 Dec. Averaged over the seasons, RUE was 0.95, 0.95 g and 0.90 g MJ^{-1} for 10 and 25 Nov., and 10 Dec. sowing, respectively. Differences in RUE for grain yield among different plant densities were, however, non-significant in both the seasons.

There was a positive and linear correlation between intercepted PAR and seasonal TDM accumulation in both the seasons (r = 0.94 to 0.96 **), and the common regression line accounted for 86.5% variation in the data (Fig. 1). Similar relationships were also noted by others (Ali, 1999; Khan, 2000). Rinald (1991) reported that RUE for TDM in wheat was 2.5 g MJ^{-1}. Both Ali (1999) and Khan (2000) reported average RUE for TDM at 2.8 g MJ^{-1} (2.6 – 3.0 g MJ^{-1}) in wheat under Faisalabad conditions. Both of them also noted higher RUE in Dec. sowing as compared to Nov. sowing. These higher values of RUE in the late sowing were insufficient to compensate for the significantly lower amount of intercepted PAR, and thus production of reduced DM yields. Relatively smaller values of RUE in the early sowing were probably due to the decline in photosynthetic efficiency due to leaf age (Woolhouse & Jenkins, 1983).

CONCLUSION

There was a linear relationship between total biomass production and intercepted PAR. High yield thus require agronomic techniques that produce both a high level of radiation interception and a high rate of conversion of intercepted PAR to grain. Further increases in yield are more likely to come from techniques which promote earlier leaf expansion. Result provides a basis for diagnosing what factors are limiting for growth and yield. These relationships can be used to formulate growth models that are needed to predict regional and national yields of wheat crop.

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(Received 10 September 2004; Accepted 06 October 2004)