Pak. J. Bot., 42(3): 1703-1711, 2010.

QUANTIFICATION OF GROWTH, YIELD AND RADIATION USE EFFICIENCY OF PROMISING COTTON CULTIVARS AT VARYING NITROGEN LEVELS

AFTAB WAJID [1], ASHFAQ AHMAD[1], TASNEEM KHALIQ[1], SARDAR ALAM[1], ABID HUSSAUN, KHALID HUSSAIN[1], WAJID NASEEM[1], MUHAMMAD USMAN[2] AND SHAKEEL AHMAD[3]

[1]*Department of Agronomy, University of Agriculture, Faisalabad, 38040, Pakistan*
[2] *Department of Irrigation and Drainage, University of Agriculture, Faisalaba, Pakistan*
[3]*Department of Agronomy, Bahauddin Zakariya University, Multan-60800, Pakistan*
Corresponding author's E-mail: aftabwajid@hotmail.com

Abstract

Cotton cultivars response to different doses of nitrogen for radiation interception, canopy development, growth and seed yield were studied in 2006. The experiment was laid out in randomized complete block design with split arrangement under the climatic conditions of Bahawalpur. Data on seed yield, total dry matter (TDM), leaf area index (LAI), fraction of intercepted radiation (Fi), accumulated radiation interception during the growth season (Sa) and radiation use efficiency (RUE) were taken into account. TDM pattern showed sigmoid growth curve for both cultivars and nitrogen levels and showed strong relationship (R^2 = 0.98) with the accumulated intercepted radiation (Sa) for the season. Mean maximum value of fraction of incident PAR (Fi) remained 90% at 120 days after sowing (DAS) harvest due to maximum crop canopy development. Cultivar NIAB-111 produced 0.81 g m^{-2} of TDM for each MJ of accumulated PAR and nitrogen @185 kg ha^{-1} statistically proved to be better in converting radiation into dry matter production.

Introduction

Nitrogen is generally considered to be a limiting factor for the growth, yield and radiation use efficiency of various cotton cultivars. (Nicholos *et al.,* 2004: Milroy & Bange, 2004). Its deficiency reduces vegetative and reproductive growth and reducing yield due to leaf senescence (Gerik *et al*., 1994; Tewolde & Fernandez, 1997). On the other hand, high N availability may shift the balance between vegetative and reproductive growth toward excessive vegetative development, thus delaying crop maturity and reducing seed cotton yield (Gaylor *et al*., 1983; Howard *et al*., 2001; Kohli & Morrill, 1976). Higher doses of N lead to more vegetative growth and causes delay in maturity and ultimately reduction in the crop yield (Howard *et al*., 2001). Effect of excess doses of N application on growth, yield and fruiting are less apparent than its deficiency (Jackson & Gerik, 1990). Lint yield response to increased N doses follows a diminishing return trend but total dry matter, accumulated radiation and its efficiency show linear response (Girme *et al*., 1998). It is well documented that yield of cotton vary among different cultivars. Boquet *et al*., (1994) found that cotton yield enhanced due to increase in boll weight by the application of nitrogen at various rates. Studies show that older cultivars have much lower yield and also poor response to N fertilization than modern cultivars. Meredith *et al*., 1997 and Wells & Meredith (1984 a, 1984 b, 1984 c) concluded that modern cotton cultivars were determinate and responded more strongly to N application than older cultivars. Yield losses of different cultivars were due to reduced boll number associated with less dry matter production (Bange *et al.*, 2003). Plants of different cultivars were unable to develop proper canopy thus reducing its leaf area index (LAI). Bange *et al.*, (2003) further concluded that plants were 35% less efficient in converting radiant energy into carbohydrate because of reduced leaf area and less dry matter production. Another direct impact of radiation interception on cotton production was defined by Pettigrew, (2001). Who concluded that 55% more radiation was intercepted by cotton cultivars due to more leaf area index.

In Pakistan no data are available on yield response of cotton cultivars to nitrogen and intercepted radiation. The present study was therefore undertaken to quantify growth, yield and radiation use efficiency of cotton cultivars at varying nitrogen levels under the climatic conditions of Bahawalpur.

Materials and Methods

The experiment was conducted during kharif season 2006 at the Experimental Area of Regional Agricultural Research Institute (RARI), Bahawalpur. Composite soil sample was analyzed for physio-chemical characteristics before sowing the crop. The soil was sandy loam with sand, 51.5%; silt, 23.5%; clay, 26.0%; pH 7.6; electrical conductivity, 2.5 dS m^{-1}; calcium carbonate, 2.7%; organic matter, 0.72%; total nitrogen, 0.05%; available phosphorus, 8.9 mg kg^{-1} and extractable potassium, 139 mg kg^{-1}.

Proposed study was conducted under Bahawalpur conditions to quantify the growth and yield response to radiation interception and its conversion efficiency of selected genotypes of cotton. The experiment was laid out in Split Plot Design with three replications having net plot size of 3 m × 8 m. The cotton cultivars (CIM-496, NIAB-111 and CIM-506) were tested at four nitrogen levels (85, 115, 150, 185 kg ha^{-1}) with cultivars in main plots and nitrogen levels in sub-plots. Crop was sown uniformly in 75 cm apart rows using 25 kg ha^{-1} seed rate with single row hand drill. Thinning was done keeping 15 cm plant-to-plant distance. All the other cultural practices such as hoeing, irrigation and plant protection measures were kept normal according to general recommendations for the crop. A net plot size measuring 1.5 m × 6.0 m was maintained for final yield and the rest of the plot was used for random sampling regarding the crop growth. Randomly three plants from each plot were harvested with an interval of 30 days from each plot during the season.

Following growth parameters were recorded from measurements of leaf area and dry weight. Leaf area index (LAI) was calculated as the ratio of leaf area to land area proposed by Hunt, (1978).

$$LAI = \text{Leaf area} / \text{land area}$$

Leaf area duration (LAD) was estimated according to Hunt (1978).

$$LAD = LAI_1 + LAI_2 \times (t_2 - t_1) / 2$$

where LAI_1 and LAI_2 are the leaf area indices at time t_1 and t_2 respectively.

Statistical analysis: Data recorded on growth, yield and radiation interception were statistically analyzed by using the Fisher's analysis of variance technique and Least

Significant Difference (LSD) test at 5% probability were applied to compare the significance of treatments means (Steel *et al.*, 1997).

Results and Discussion

Weather: Table 1 shows mean monthly weather data for the crop growth period. Average air temperature of May, June, July, August, September and October was 30.7°C, 36.5°C, 33.3°C, 32.9°C, 31.4°C and 27.1°C respectively. The maximum air temperature was recorded in the month of June (36.5°C) and minimum average temperature was recorded in the month of October (27.1°C). The average relative humidity first increased from May to July (maximum 70.3%) but after July it decreased minimum 44.2% in October. The maximum average rainfall was recorded in the month of July (84.3mm) and minimum in month of October (10 mm). The total rainfall throughout the growing season was 294.2 mm. Maximum net radiations were received in the month of June.

Seed cotton yield: Seed cotton yield is a combined effect of individual yield components under particular environmental conditions. It is evident from the Table 2 that seed cotton yields were significant among various cultivars. Cultivar CIM-506 produced more seed cotton yield of 3333 kg ha^{-1} and increase in yield was 19% and 26% higher over cv CIM-496 and NIAB-111, respectively. However, NIAB-111 produced lowest seed cotton yield (2460 kg ha^{-1}) due to more vegetative growth. Different doses of nitrogen linearly increased seed cotton yield from 85 kg ha^{-1} to 150 kg ha^{-1} then it declined at 185 kg ha^{-1} N application. Nitrogen application at 150 kg ha^{-1} produced maximum yield of 3275 kg ha^{-1} followed by 185 kg ha^{-1} in which 3023 kg ha^{-1} of seed yield was recorded. Minimum N fertilization (80 kg ha^{-1}) produced lowest seed cotton yield of 2239 kg ha^{-1}. Overall N application at optimum rate (150 kg ha^{-1}) enhanced yield by 32% over low dose of N (85 kg ha^{-1}). Constable, (1997) observed that four cotton cultivars produced 28 % more fruiting and 44 % seed cotton yield when sown in narrow rows. Milroy *et al*., (2004) studying on yield of cotton cultivars found that yield of early maturing varieties was maximum because they developed canopy earlier and harvested more light.

Total dry matter: Six harvests for TDM were recorded with an interval of 30 days starting from 30 days after sowing (DAS) to physiological maturity. Fig. 1 (a) & (b) show the time course curves of cultivars and nitrogen applications at different harvests during the growth of the crop. Total dry matter accumulation was less at first harvest (30 DAS) then it linearly increased till 120 DAS. Early harvest had slower vegetative growth and canopy development which yielded less dry matter but as the developmental stages progressed, DM accumulation response to nitrogen application became linear.

Perusal of the Table 2 shows data recorded for cultivars and nitrogen fertilization on dry matter production. Cv. NIAB-111 remained superior over other cultivars in dry matter accumulation due to its more vegetative and faster growth rate. CIM-496 showed 17 % less potential than NIAB-111 and 8% by CIM-506. Bange *et al*., (2003) observed that cultivar differences in TDM production was not pronounced which did not confirm the results of the experiment under study. Each increment of nitrogen application had significant effect on DM and it ranged between 874-1308 g m^{-2}. TDM remained 33 % higher with N fertilization at 185 kg ha^{-1} comparative to low dose of 80 N kg ha^{-1}. Kefyalew *et al*., (2007) concluded that N fertilization affected yield of different cotton cultivars in different combinations with P and K application.

Table 1. Meteorological data for cropping season 2006.

Month	Maxi Tem. (°C)	Mini Tem. (°C)	Mean Tem. (°C)	Relative humidity (%)	Rainfall (mm)	Net radiation MJ d^{-1}
May	40.4	20.9	30.7	59.4	13.0	3.70
June	**46.0**	**27.1**	**36.5**	**65.0**	**84.3**	**14.80**
July	40.2	26.3	33.3	70.3	74.3	14.20
August	39.2	26.7	32.9	60.2	37.9	13.92
September	37.4	25.4	31.4	51.8	74.6	14.63
October	35.2	19.0	27.1	44.2	10.0	13.59
Total	-	-	-	-	**294.2**	

Source: Agro-meteorological data collected at Regional Agriculture Research Institute Bahawalpur

Table 2. Effect of cultivar and nitrogen levels on seed yield, TDM, Fi, intercepted radiation and radiation use efficiency.

Treatments	Seed yield (kg ha^{-1})	TDM (g m^{-2})	LAI	LAD	Fi	Accumulated PAR	RUE (g MJ^{-1})
Cultivars							
V_1=CIM-496	2796 ab	1016.70 b	3.267 b	259.62 c	0.894 c	1403.738 c	0.721
V_2=NIAB-111	2460 b	1184.70 a	3.502 a	282.69 a	0.910 a	1457.290 a	0.810
V_3=CIM-506	3333 a	1093.80ab	3.406 a	269.99 b	0.904 b	1429.213 b	0.761
LSD 5%	633.10	144.30	0.129	8.119	0.002	22.73	0.00001
Significance	*	*	*	**	*	**	NS
Nitrogen levels							
N_1=80 kg ha^{-1}	2239 d	873.50 d	2.825 d	220.50 d	0.861 d	1130.417 d	0.656 d
N_2=115 kg ha^{-1}	2715 c	1022.40 c	3.209 c	255.94 c	0.894 c	1408.540 c	0.726 c
N_3=150 kg ha^{-1}	3275 a	1190.00 b	3.605 b	290.64 b	0.919 b	1470.905 b	0.809 b
N_4=185 kg ha^{-1}	3023 b	1307.70 a	3.929 a	316.47 a	0.936 a	1510.090 a	0.865 a
LSD 5%	184.40	19.95	0.063	3.845	0.001	18.83	0.0003
Significance	**	**	**	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS	NS
Mean	**2813**	**1098.43**	**3.392**	**270.893**	**0.903**	**1429.988**	**0.764**

Means having different letters differ significantly from each other by LSD (p=0.05)
*, ** = Significantly and highly significant respectively; NS = Non-Significant

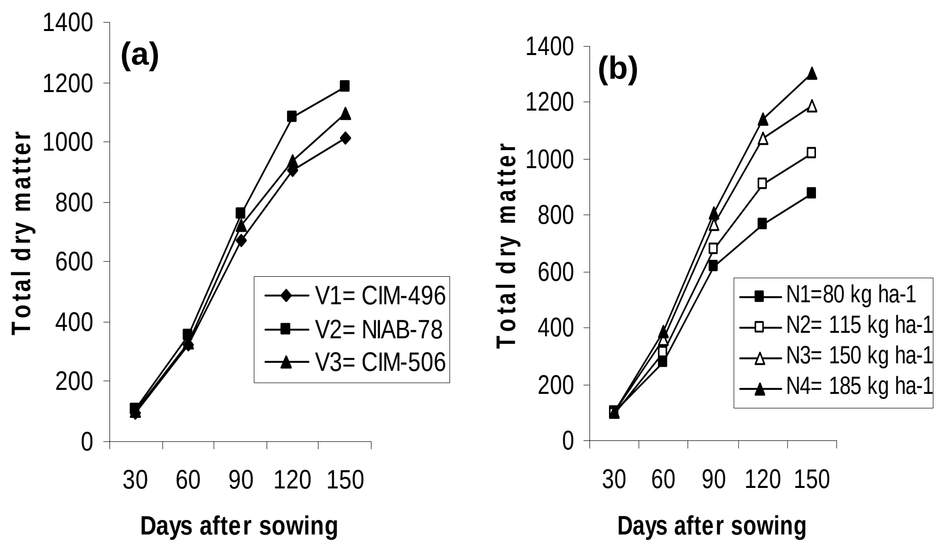

Fig. 1. Effect of (a) Cultivar (b) Nitrogen levels on temporal changes in total dry matter accumulation.

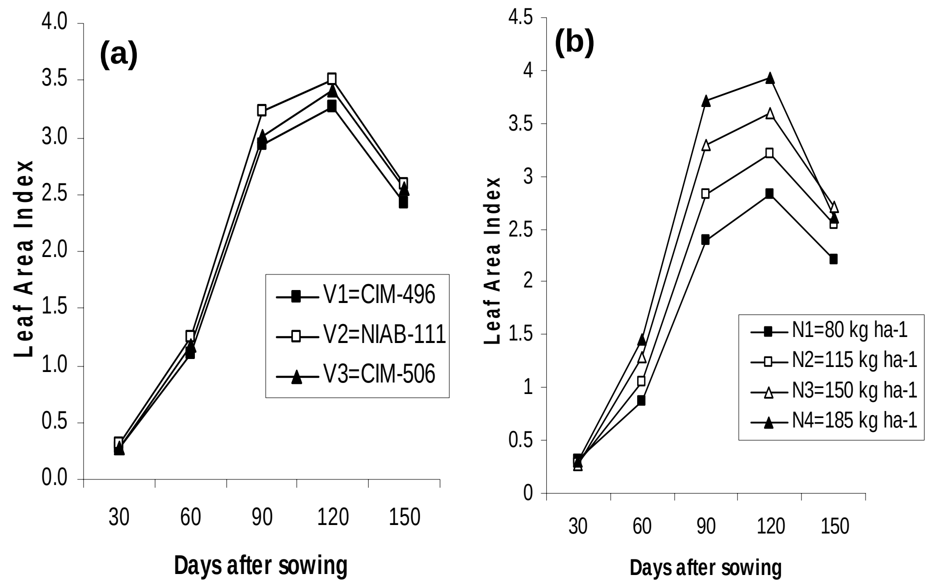

Fig. 2. Effect of (a) Cultivar (b) Nitrogen levels on temporal changes in Leaf Area Index.

Leaf area index: Leaf area index is the main physiological determinant of crop yield. Fig. 2 (a) & (b) depict development of canopy in the growing season for cultivars and nitrogen applications. LAI development in various cultivars was less early in the season because of slow growth then it progressed faster and reached its peak value 120 DAS and then declined in both cultivar and N application due to leaf senescence. Table 2 indicates that cultivar NIAB-111 developed its canopy at much faster rate than other cultivars and it remained at par with CIM-506 (3.5 vs 3.4). Bange *et al*., (2003) observed that leaf area index for closely grown cotton remained 3.02 and 2.52 for cv. S-324 and L-22 respectively. Low dose of N fertilizer (80kg ha^{-1}) had less contribution in leaf expansion and its value remained below 3 to intercept radiations properly. Felix *et al*., (2003) concluded that less LAI (2.5) was observed at 56 kg ha^{-1} N and value of 4 was attained with 168 kg ha^{-1} N Fertilizer.

Leaf area duration: Leaf area duration is the persistence of leaf canopy to remain photosynthetically active. A regression equation was derived between LAD and TDM. Fig. 3 shows positive and linear relationship between seasonal TDM and LAD ($R^2 = 0.98$ and r = 0.99**). Table 2 shows that more days (283 days) were taken by NIAB -111 to stay green comparative to cv CIM-506 and CIM-496. Data showed that persistency of leaves to remain active for CO_2 assimilation increased with nitrogen application. At higher doses of N (185 kg ha^{-1}) leaf tissues remained green for an extended period of 96 days over low dose of 80 kg ha^{-1}. During this period more assimilates were manufactured by the crop which ultimately accumulated more DM.

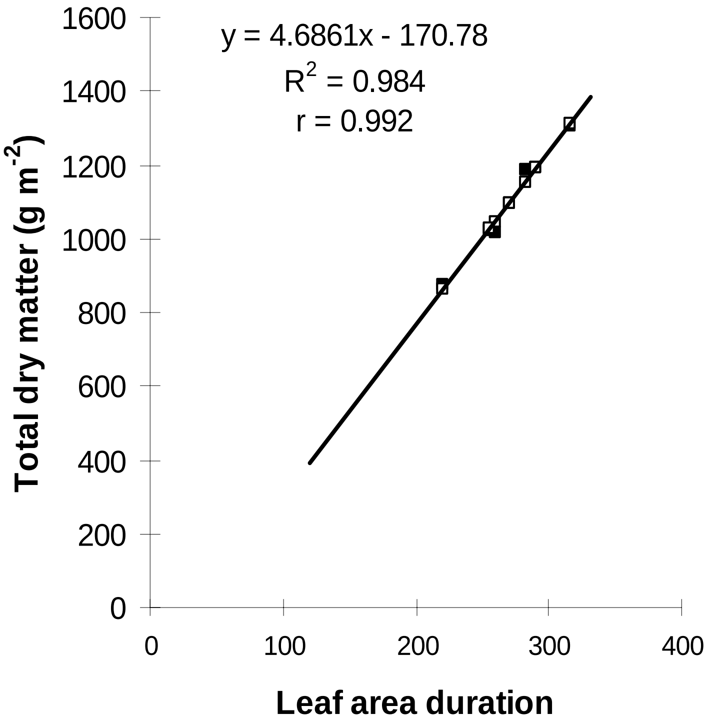

Fig. 3. Relationship between TDM and LAD

Fraction of radiation interception (Fi) and accumulated intercepted PAR (∑Sa): Abundant sunshine is available during the growth season of cotton crop in Pakistan and analytical approach shows that well husbanded crop can harvest more than 1700 MJ m^{-2} of light during the season. NIAB-111 showed maximum Fi 91% over two other cultivars CIM-506 and CIM-496 which produced Fi values of 90% and 89%, respectively. Higher N dose gave fraction of intercepted PAR 93% at 185 kg ha^{-1}, 91% at 150 kg ha^{-1}, 98% at 115 kg ha^{-1} and minimum 86% with 80 kg ha^{-1}. Among cultivars NIAB-111 accumulated radiation 1457 MJ m^{-2} followed by CIM-506 and CIM-496 which intercepted 1429 and 1403 MJ m^{-2} of light, respectively. Rosenthel & Gerik (1990) noted that cultivar response to different light harvest was due to change in fraction of intercepted PAR. Classical studies of Monteith (1977a) and Gallaghar & Biscoe (1978) found that the rate of DM production in a range of field crops was proportional to the amount of intercepted PAR. Fraction of intercepted PAR of crop increases hyperbolically with LAI (Jamieson *et al*., (1995) and LAI of 4-6 is sufficient to intercept more than 90% incident radiation to attain maximum growth rate (Monteith & Elston 1983). The relationship between TDM and accumulated PAR was highly positive and linearly correlated with intercepted PAR (R^2 = 0.97) (Fig. 4).

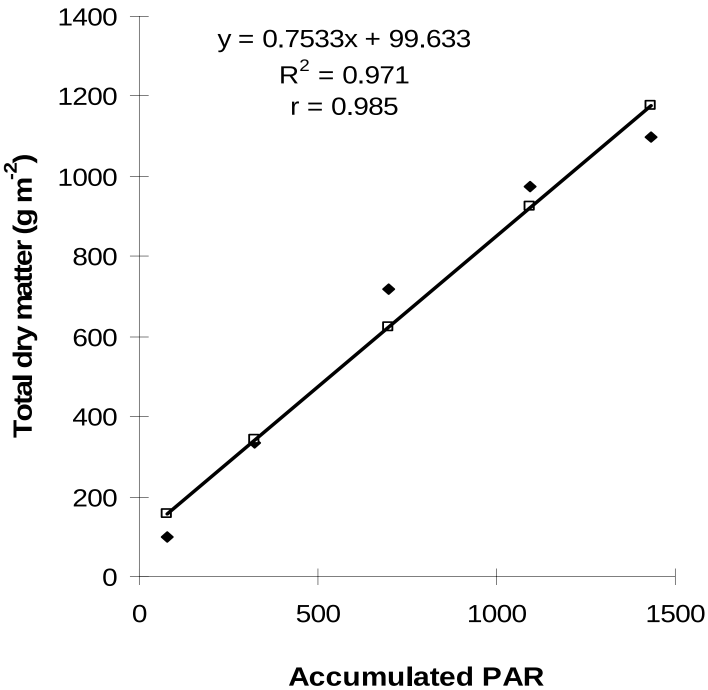

Fig. 4. Relationship between seasonal TDM and seasonal PAR.

Radiation use efficiency (RUE): Rosenthal & Gerik (1990) reported a crop canopy with greater LAI intercepts more radiation, which enhances RUE. Cultivar NIAB-111 proved to be more efficient in converting light into carbohydrates than other cultivars. It produced 0.81 g of seed cotton yield for each MJ m^{-2} of intercepted radiation. As regards N, 185 kg ha^{-1} gave more value of RUE 0.86 g for each MJ m^{-2} and this treatment was 25% more efficient in converting radiation into seed cotton yield than N applied at low dose of 80 kg ha^{-1}. Kefyalew *et al*., (2007) calculated RUE for cv. S-324 and L-22, 1.03g and 1.03g for each MJ of light, respectively.

Milroy & Bange (2004) explained that leaf N and light intensity is directly relating to photosynthesis, in turn intercepting more radiation and as a result higher radiation use efficiency is obtained. Milroy *et al*., (2004) concluded RUE increases up to 35% due to more accumulation of light.

Conclusion

It is concluded from the study that yields of different cultivars can be statistically different due to their architectural behavior and genetic make up. Cultivar may develop leaf area index earlier and intercept more radiation to manufacture DM production if properly fertilized. Boll shedding in cotton is well understood by nitrogen theory. It indicates that a normal leaf has 5% N and drops to 2.5 % as the crop progresses towards reproductive stage. Its internal retranslocation leads to boll shedding. To avoid much damage N-fertilization should be applied at 150 kg ha^{-1} (Reddy, 2004).

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(Received for publication 13 December 2009)