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Effect of nitrogen fertilizers on radiation use efficiency, Crop growth and yield in some maize (*Zea mays* L) genotypes

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Abstract

Nitrogen is the most important element required for plant growth and development. It is a key component in many biological compounds that play a major role in photosynthetic activity and crop yield capacity. Variation in nitrogen availability can affect plant development and grain production in maize. The effect of nitrogen availability on grain yield of maize can be assessed by physiological components such as the interception and efficient use of radiation and partitioning of nitrogen to reproductive organs. Nitrogen fertilization affects maize dry matter production by influencing leaf area development, leaf area maintenance and photosynthetic efficiency of the leaf area. The objective of this study was to determine the effect of high and low nitrogen levels on morpho-physiological traits, radiation use efficiency and yield behaviour in long and short duration genotypes of maize. Field experiments were conducted in two growing seasons at five nitrogen levels: recommended dose of nitrogen (RDN), RDN+25%, RDN+50%, RDN-25% and RDN-50%. Ecophysiological traits such as leaf area index (LAI), intercepted photosynthetically active radiation (IPAR), fraction of photosynthetically active radiation intercepted by plants (FRI) and radiation use efficiency (RUE) significantly improved with the application of 25 and 50% nitrogen higher than the recommended dose. At both high and low nitrogen level, hybrids PMH1 (long duration) and JH 3459 (short duration) showed higher efficiency for converting IPAR into dry matter. Also, hybrids were more responsive to variations in nitrogen supply than their female and male parents in various physiological traits. Correlation of different physiological traits and grain yield at recommended, high and at low nitrogen levels was positive and significant, while for phenological traits, it was negative and significant.

Keywords: maize, nitrogen, radiation use efficiency, hybrids, grain yield

Introduction

Nitrogen is the most important element required for plant growth and development. It is a key component in many biological compounds and plays a major role in photosynthetic activity and crop yield capacity (Cathcart and Swanton, 2003). Variation in nitrogen availability can affect plant development and grain production in maize. Maize grain yield is linked to both higher nitrogen uptake and higher ability to utilize nitrogen accumulated in the plant in yield production (Luque et al, 2006). Parameters such as leaf area index, longevity of leaf canopy and efficient use of incident light in maize are all increased by nitrogen (Muchow and Davis, 1988). Leaf nitrogen distribution within the canopy, with its consequences for photosynthesis is major determinant of the radiation use efficiency of a crop (Gastal and Lemaire, 2002). Crop growth rate depends upon its radiation use efficiency (RUE), which is the amount of intercepted photosynthetic active radiation (IPAR) and the efficiency of the crop to convert IPAR to aboveground biomass (Cirilo et al, 2009). IPAR is related to canopy size, canopy architecture and incident PAR (Maddoni et al, 2001) while RUE is species specific and is modified by stress factors. Therefore, light interception by crop canopies has direct implication on canopy physiological processes. A knowledge of regulatory mechanisms controlling plant nitrogen economy is vital for improving nitrogen use efficiency and for reducing excessive input of fertilizers while maintaining acceptable yield.

Materials and Methods

Seeds of six maize genotypes (hybrids and their parents) i.e., PMH1 (parents LM13, LM14) and JH3459 (parents CM143, CM144) were obtained from department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, India and raised as per recommended procedures (Anonymous, 2009) during two seasons, June till October (2009 and 2010, respectively). The mean daily temperature of June till September ranges between 28°C and 36°C while during October it is between 20°C and 27°C. Ludhiana represents the Indo-Gangetic alluvial plains and is situated at 36°-54°N latitude and 75°-48°E longitude at a mean height of 247 m above sea level. The genotypes used for this study had different rec-

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ommended dose of nitrogen (RDN) i.e. 125 kg N/ha for long duration genotypes (PMH1 and its parents LM13, LM14) and 87.5 kg N/ha for short duration genotypes (JH3459 and its parents CM143, CM144). The crop was raised in two sets. For long duration genotypes (PMH1, LM13, LM14), there were five levels of nitrogen: Recommended (RDN) (125 kg N/ha); RDN plus 50% (187.50 kg N/ha); RDN minus 50% (62.50 kg N/ha); RDN plus 25% (156.25 kg N/ha) and RDN minus 25% (93.75 kg N/ha). Likewise for short duration genotypes (JH3459, CM143, CM144), there were five levels of nitrogen: Recommended (RDN) (87.5 kg N/ha); RDN plus 50% (131.25 kg N/ha); RDN minus 50% (43.75 kg N/ha); RDN plus 25% (109.37 kg N/ha) and RDN minus 25% (65.63 kg N/ha). The crop was raised in split plot design with nitrogen levels in the main plot and maize genotypes in the subplot. The size of the main plot was 25.2 m^2. Each sub plot had 14 rows. The row to row spacing was 60 cm for all genotypes. The plant to plant spacing was 20 cm for PMH1 and its parents whereas it was 15 cm in case of JH3459 and its parents. Nitrogen was applied as DAP and urea in three equal splits: at the time of sowing, at knee high stage and at anthesis stage as per treatments. DAP and urea were applied at the time of sowing while for top-dressing only urea was used. The plots supplied with recommended dose of nitrogen (RDN) were taken as controls. Representative sample of the soil from 0-15 cm depth was collected at the time of sowing and after harvesting the crop during years 2009 and 2010 respectively. The soil samples were analysed for their physico-chemical properties, electrical conductivity (EC), organic carbon (OC), pH, available nitrogen, phosphorus and potassium content (Table 1). The time taken to phenological stages after sowing (Yi et al, 2008) were recorded by tagging three plants from each plot at random. Seedling emergence was recorded when the coleoptile was visible on the soil surface. The number of plants emerged were recorded at 5 and 10 days after sowing. Days to 9-leaf stage was recorded when the collar of ninth leaf was visible. Anthesis is defined as the beginning of pollen shed from the male inflorescence (tassel) and was recorded when at least one anther had dehisced and was liberating pollen. Silking was recorded when pollen-receptive stigmas (silks) were visible from surrounding husks on the ear. Anthesis-Silking Interval (ASI) is the temporal separation of male (anthesis) and female (silking) floral maturity and this was calculated as number of days between anthesis and silking date. Plant height was recorded from the same plants that had been tagged for recording phenological observations. The plant height was measured at each phenological stage using one metre long wooden scale from the base of the main stem to the base of the last unfolded leaf at the top at each stage and expressed in centimetres. Leaf area of the top most leaf and middle leaf (above the cob) were measured at the vegetative stage i.e. V9 (9-leaf) and reproductive stages (anthesis onwards). Lengths of fully opened leaf lamina were measured from the leaf base to the tip. Breadth was taken at the widest point of the leaf lamina. Leaf area was determined according to the formula given by Montgomery (1911):

Leaf area = L x B x k

where L = leaf length (cm), B = leaf breadth (cm), k = shape factor with value of 0.75 for maize. Leaf area index of the plant canopy was measured with PAR/LAI Ceptometer (Accu PAR Model LP-80, Decagon Devices, Pullman). Leaf chlorophyll content was reflected by Soil Plant Analysis Development (SPAD) value, which was determined by a chlorophyll meter (SPAD-502, Minolta). SPAD readings were taken at two-thirds of the distance from the leaf tip (without the midrib) towards the stem of the top-most leaf (before silking) and on leaf above ear, ear leaf and leaf under ear (after silking). Five leaves were measured at random in the plot and a mean SPAD value was calculated for each plot. Timing of leaf senescence was determined by counting the number of green leaves remaining below the ear on three tagged plants after anthesis stage.The fraction of incident photosynthetically active radiation intercepted by plots (FRI) was measured on clear days at noon with PAR/LAI Ceptometer (Accu PAR Model LP-80, Decagon Devices, Pullman). The fraction of PAR intercepted (FRI) was calculated by taking ten readings in rapid succession above the canopy (I_o) and ten readings just below the lowermost green leaf layer (I_t). The average of ten readings was taken for further calculations.

The following equations were used for calculating radiation use efficiency (RUE):

$$\mathrm{FRI}\ (\text{fraction of PAR intercepted by plants}) = 1-(\mathrm{I_t})/(\mathrm{I_o})$$

$$\text{Intercepted PAR} = \text{Incident PAR x FRI}$$

$$RUE\,(For\ vegetative\ period) = \frac{DM\,(v)}{Intercepted\ PAR\,(accumulated)}$$

$$RUE\,(For\ reproductive\ period) = \frac{DM\,(r)}{Intercepted\ PAR\,(accumulated)}$$

where, DM (v) and DM (r) are total plant dry matters at vegetative and reproductive stages, respectively. For grain yield, all the cobs in each plot were unsheathed, shelled and weighed and expressed as q ha^{-1}. The data were analysed using two way analysis of variance (Table 1 and 2).

Results

At 10 days after sowing (DAS), higher seedling emergence was observed in both the hybrids. A reduced rate of nitrogen fertilizer (RDN-50%) reduced the rate of seedling emergence by 19.33% in hybrid PMH1, while in female (LM13) and male (LM14) parents, this reduction was 8.82 and 10.97% respectively (Table 2).

Likewise, plots supplied with RDN-50% took sig-

Table 1 - Physico-chemical analysis of experimental field soil during crop years 2009 and 2010.

Soil property	At sowing		After harvesting		Method employed
	2009	2010	2009	2010	
Texture	Loamy sand		Loamy sand		Piper[1]
pH	8.6	8.1	7.6	7.5	Jackson[2]
EC (mm hos cm^{-1})	0.14	0.17	0.10	0.13	Jackson[2]
Organic carbon (%)	0.12	0.15	0.36	0.32	Subbiah and Asija[3]
Available N (kg ha^{-1})	130	145	141	149	Subbiah and Asija[3]
Available P (kg ha^{-1})	11.2	13.1	24.6	25.7	Oslen et al[4]
Available K (kg ha^{-1})	135	140	138	145	Jackson[2]

[1]Piper CS, 1966
[2]Jackson ML, 1967
[3]Subbiah BU, Asija GL, 1956
[4]Oslen SH, Cole CV, Watenable FS, Dean LA, 1954

nificantly more days to reach 9-leaf stage as compared with control (29.00 days, Table 2). These differences were significant (p=0.05) for genotypes which indicates genetic variability. The hybrid PMH1 was the earliest to reach 9-leaf stage at each nitrogen level and in its male parent (LM14), the stage was delayed as compared to female parent (LM13). The effect of genotypes-nitrogen levels interaction was not significant. Nitrogen levels and genotypes had significant effect on days to 9-leaf stage in second set of genotypes. Elevated rate of nitrogen reduced the number of days to reach 9-leaf stage. Among the three genotypes, JH 3459 took fewer number of days (22.31 days) to reach 9-leaf stage as compared to CM143 (24.67 days) and CM144 (28.36 days, Table 3).

There was an increase in leaf area with the advance in crop age, reaching the highest value at anthesis stage of the growth cycle and thereafter declined at grain filling stage in both long and short duration genotypes (Table 2 and 3). Various nitrogen-levels and genotypes (long duration) had a significant influence on leaf area. The interaction of genotypes (short duration) and nitrogen-levels showed significant difference in leaf area at the vegetative (9-leaf) and anthesis stages.

The LAI in both sets of genotypes (long and short duration) continued to increase from 9-leaf stage to anthesis and then declined towards the grain filling. However, LAI differed significantly in genotypes (long duration) at three phenological stages. The interaction between maize genotypes (long duration) and different nitrogen levels was found to be significant. For other set of genotypes (short duration), LAI was significantly affected by different nitrogen levels.

Leaf chlorophyll content was significantly affected by maize genotypes (long and short duration) and different nitrogen levels. SPAD reading values increased as maize growth proceeded from nine leaves towards anthesis. Under low nitrogen levels (RDN-50%), the reduction in chlorophyll content was more (17%) in case of hybrid PMH1 as compared to its parents (10%) at anthesis stage, where the leaf chlorophyll content is maximum.

The effect of various nitrogen levels (both high and low) on timing of leaf senescence was more pronounced at the silking stage but as the plants approaches maturity, the effect of nitrogen on senescence was reduced.In the genotype PMH1 (long duration), the number of green leaves below ear were more at high (RDN+50%) than at low (RDN-50%) nitrogen conditions. Timing of leaf senescence signifi-

Table 2 - Effect of different nitrogen levels on various physiological traits in long duration genotypes of maize.

Parameters	Hybrid (PMH1)					Female parent (LM13)					Male parent (LM14)					CD (5%)		
	RDN	RDN +25%	RDN +50%	RDN -25%	RDN -50%	RDN	RDN +25%	RDN +50%	RDN -25%	RDN -50%	RDN	RDN +25%	RDN -50%	RDN -25%	RDN -50%	G	N	GxN
Seedlings emerged per row	30.72	33.18	34.54	27.23	24.78	29.25	31.42	31.33	28.53	26.67	27.52	28.89	29.57	27.27	24.50	0.46	0.59	1.02
Days to 9-leaf	25.67	23.56	24.67	26.33	28.33	29.78	27.33	27.00	29.99	31.78	31.56	29.45	29.67	32.45	33.34	0.42	0.55	NS
Days to Anthesis	52.78	52.78	51.45	54.78	55.45	58.00	57.11	57.11	58.45	60.00	60.67	60.00	59.11	61.22	61.89	0.51	0.65	NS
Anthesis-Silking Interval	4.44	3.78	3.77	4.67	6.22	4.33	4.11	3.33	4.44	4.67	4.56	4.22	4.11	4.78	5.33	NS	0.59	NS
Plant height (cm)	130.17	130.44	136.07	122.32	118.40	108.21	111.00	116.97	105.52	101.86	101.06	106.07	108.42	95.85	93.74	1.53	1.98	NS
Chlorophyll content (SPAD)	53.0	55.7	57.7	48.5	45.4	46.3	48.9	52.9	44.3	42.4	44.4	45.5	47.8	42.9	39.9	0.96	1.24	2.16
No. of green leaves below ear	5.78	6.89	7.44	5.67	4.56	4.89	5.11	5.67	4.22	3.00	4.00	4.44	4.67	3.89	3.22	0.21	0.27	0.46
Leaf area (cm^2)	402.01	415.05	424.72	388.17	378.56	380.50	385.69	390.14	376.53	373.29	339.06	348.28	355.64	332.71	325.90	2.54	3.28	5.69
LAI	2.41	2.54	2.68	2.29	2.19	2.01	2.07	2.13	1.94	1.88	1.88	1.95	1.97	1.80	1.76	0.02	0.02	0.04
FRI (MJ MJ^{-1})	0.70	0.77	0.79	0.66	0.62	0.66	0.70	0.71	0.64	0.63	0.62	0.66	0.67	0.61	0.57	0.01	0.01	0.02
IPAR (MJ m^{-2})	267	275	280	255	249	230	235	236	227	223	228	235	237	225	222	1.68	2.17	3.76
RUE (g MJ^{-1})	2.68	2.75	2.86	2.61	2.48	2.16	2.18	2.22	2.15	2.13	2.14	2.16	2.18	2.11	2.09	0.01	0.01	0.02
Grain yield (q ha^{-1})	52.10	56.72	62.67	46.89	41.44	27.77	30.55	33.33	25.00	24.61	23.61	26.00	28.07	21.73	20.29	0.28	0.36	0.62

Table 3 - Effect of different nitrogen levels on various physiological traits in short duration genotypes of maize.

Parameters	Hybrid (JH3459)					Female parent (CM 143)					Male parent (CM 144)					CD (5%)		
	RDN	RDN +25%	RDN +50%	RDN -25%	RDN -50%	RDN	RDN +25%	RDN +50%	RDN -25%	RDN -50%	RDN	RDN +25%	RDN -50%	RDN -25%	RDN -50%	G	N	GxN
Seedlings emerged per row	25.75	30.22	34.00	23.42	20.97	23.22	25.08	27.35	21.17	19.57	21.58	24.03	25.85	19.80	18.12	0.73	0.94	1.62
Days to 9-leaf	22.00	21.00	19.89	23.67	25.00	24.89	24.00	22.55	25.56	26.33	28.89	26.22	25.22	29.78	31.67	0.37	0.48	0.82
Days to Anthesis	48.67	47.44	46.22	51.00	51.45	50.89	50.00	48.22	51.67	52.67	53.22	52.11	50.33	54.11	54.67	0.35	0.45	0.78
Anthesis-Silking Interval	4.67	4.56	3.66	4.78	6.11	4.33	4.00	3.89	4.33	4.56	4.56	4.22	3.89	4.67	5.44	NS	0.58	NS
Plant height (cm)	100.77	104.29	109.63	97.25	93.03	95.15	96.62	97.49	92.79	90.91	88.68	91.46	92.38	87.08	85.17	1.22	1.58	2.73
Chlorophyll content (SPAD)	55.2	57.1	58.5	50.2	47.4	46.0	47.1	51.4	43.9	40.8	41.6	44.6	46.7	36.9	34.7	1.16	1.49	NS
No. of green leaves below ear	5.11	5.78	6.44	4.89	4.22	3.78	4.22	4.44	3.89	3.11	2.78	3.11	3.55	2.56	2.22	0.19	0.25	NS
Leaf area (cm^2)	383.34	389.30	395.81	373.73	359.85	330.78	330.85	335.76	322.87	314.80	307.28	309.23	312.97	294.78	287.00	2.46	3.18	5.50
LAI	2.25	2.29	2.38	2.14	2.09	1.59	1.65	1.73	1.56	1.51	1.49	1.54	1.59	1.42	1.37	0.01	0.02	0.03
FRI (MJ MJ^{-1})	0.73	0.77	0.82	0.65	0.62	0.65	0.66	0.69	0.61	0.59	0.65	0.66	0.67	0.61	0.59	0.01	0.01	0.02
IPAR (MJ m^{-2})	273	280	286	264	254	212	225	228	212	210	218	222	224	216	211	1.76	2.27	3.93
RUE (g MJ^{-1})	2.79	2.85	2.91	2.63	2.48	2.19	2.21	2.24	2.15	2.12	2.16	2.16	2.19	2.12	2.09	0.01	0.01	0.02
Grain yield (q ha^{-1})	43.72	48.55	55.31	38.57	33.15	21.77	23.94	26.91	19.26	18.65	20.83	22.55	26.00	18.03	17.94	0.38	0.49	0.85

cantly varied with the treatments RDN and RDN+25% at silking, while at dough and grain maturity, there were no significant differences among these two nitrogen levels. The number of green leaves below ear was more in case of hybrid PMH1 than its parents at each nitrogen level. At all nitrogen levels, genotype JH3459 had more number of green leaves as compared with others (CM143 and CM144). Genotypes CM143 and CM144 produced statistically same number of green leaves at dough and grain maturity stages. The leaf senescence was delayed in case of hybrid JH3459 as compared to its parents (CM143 and CM144) which was evidenced by more green leaves at each nitrogen level (both high and low). The interaction of genotypes (short duration) and various nitrogen levels was non-significant for timing of leaf senescence (Table 3).

Data recorded on fraction of PAR intercepted by plants (FRI) revealed that long and short duration genotypes reached their maximum FRI at 9-leaf and anthesis stages respectively. Various levels of nitrogen significantly affected the FRI. The highest FRI was recorded in the treatment RDN+50% from the hybrid and minimum from the male parent at RDN-50%. The interaction effect of genotypes (long and short duration) and various nitrogen levels for FRI was significant.

Intercepted PAR (IPAR) was also significantly affected by various levels of applied nitrogen and genotypes (long and short duration). Hybrid PMH1 intercepted maximum PAR (409 MJ m^{-2}) as compared to its parents. Among nitrogen levels, the maximum IPAR was recorded in treatment RDN+50% followed by treatment RDN+25%. In case of interaction between genotypes (long duration) and nitrogen levels, a significant effect on IPAR was noted. Similarly, in short duration genotypes, hybrid JH3459 had maximum IPAR (397 MJ m^{-2}) as compared to its parents .The difference in IPAR values of female (CM143) and male (CM144) parent was non-significant. In the nitrogen treatments, maximum IPAR was recorded in RDN+50% treatment which was significantly higher than that of control (RDN) but it was statistically close to treatment RDN+25%. The minimum IPAR was recorded in treatment which receive 50% nitrogen lesser than the control (RDN) i.e. RDN-50% .The interaction effect between genotypes (short duration) and nitrogen levels was significant.

RUE was significantly affected by main and interaction effects of nitrogen levels and genotypes (both long and short duration). The treatments RDN+25% and RDN+50% did not produce significant effect on RUE in both male and female parents (LM13 and LM 4) over control (RDN), but it increased the RUE by 15% and 18% in hybrid PMH1. The increase in applied nitrogen fertilizer had significant effect on RUE in case of short duration genotypes. At RDN+50%, RUE was maximum, while minimum RUE was recorded in treatment RDN-50%. Genotype JH3459 had higher RUE at each nitrogen level than its parents CM143 and CM144. The difference between RUE of female (CM143) and male (CM144) parent was non-significant (Table 3).

The application of higher doses of nitrogen fertilizer led to a significant reduction in days to anthesis as compared to control. However, in long duration genotypes, there were no significant differences between RDN (125 kg N ha^{-1}) and RDN+25% (156.25 kg N ha^{-1}) treatments with respect to days to anthesis. In JH3459, nitrogen at the rate of RDN+50%, delayed anthesis by 2.66 days from control. Genotype CM144 took a significantly higher number of days (52.89 days) to anthesis followed by genotypes CM143 (50.69 days) and JH3459 (48.96 days).

In both long and short duration genotypes (Table 2 and 3), different rates of nitrogen application significantly influenced the days to silking. Maximum days to silking were taken by the genotypes when nitrogen dose was applied at the rate of RDN-50% followed by nitrogen rate of RDN-25%.

ASI was affected significantly by different nitrogen levels. However, no significant difference was found between treatments RDN+25% and RDN-25% as compared to control, but treatment RDN-50% significantly increased and treatment RDN+50% decreased the ASI in long duration genotypes. The high (RDN+50%) and low (RDN-50%) nitrogen supply caused a significant reduction and increase in the anthesis-silking interval, respectively in genotype JH3459 and CM144, while in genotype CM143, this effect was not significant. The interaction of genotype by nitrogen (GxN) had non-significant effects on ASI.

Plant height increased rapidly up to anthesis and thereafter slowly. In long duration genotype PMH1, various levels of nitrogen significantly affected the plant height. However, the interaction effect was not significant. Among the genotypes, the maximum plant height (174.48 cm) was observed in hybrid PMH1 followed by its parents LM13 (141.77 cm) and LM14 (137.62 cm), respectively. Different nitrogen levels (high and low) significantly affect the plant height of short duration genotypes. Hybrid JH3459 had a larger plant height at each nitrogen level than its parents (CM143, CM144). The plant height of hybrid JH3459 was reduced by 8% in the nitrogen-deficiency environment (RDN-50%) as compared to control (RDN) whereas this reduction was less in case of their parents i.e. CM144 (4.4%) and CM143 (5.1%), respectively. In the nitrogen levels, RDN+50% had more plant height (127.72 cm) than other treatments i.e. RDN+25% (125.09 cm); RDN (124.05 cm); RDN-25% (120.47 cm); RDN-50% (117.09 cm) respectively.

Grain yield was significantly affected by genotypes, nitrogen fertilizer levels and their interaction in both set of genotypes (long and short duration) (Table 2 and 3). Genotype PMH1 significantly produced maximum grain yield followed by LM13 and LM14. In the nitrogen treatments, RDN+50% and RDN+25% markedly enhanced grain yield than control (RDN; 125 kg N ha^{-1}) in all the three genotypes. RDN-50% produced the lowest yield (28.78 q ha^{-1}). In short duration genotypes, JH3459 genotype had significantly the highest grain yield while genotype CM144 had lowest yield. Among the nitrogen levels, levels of RDN+50% placed at the superior group as it produced the highest grain yield followed by RDN+25% (109.37 kg N ha^{-1}). The lowest grain yield resulted from the treatment which had 50% nitrogen less than control (RDN). Application of 25% less nitrogen (RDN-25%) tended to decrease grain yield significantly in case of hybrid JH3459 than their parents (CM143 and CM144).

Discussion

Application of higher dose of nitrogen produced maximum emergence in maize and also increased plant elongation and yield (Keskin et al, 2005; Siddiqui et al, 2006). The increase in plant height with the increase in nitrogen fertilizer level was due to the positive effect of nitrogen element on plant growth that leads to progressive increase in internode length and consequently plant height. Betran et al (2003) also reported consistently more plant height in hybrids than in inbred lines.

Leaf area influences the interception and utilization of solar radiation of crop canopies and consequently dry matter accumulation and ultimately the grain yield. Moreover, it is an important factor in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopy photosynthesis (Boote et al, 1996).Various nitrogen-levels and genotypes (long duration) had a significant influence on leaf area. These results are supported by those of Boonlertnirun et al (2010). Squire et al (1987) concluded that the main effect of nitrogen fertilizer was to increase the rate of leaf expansion which ultimately leads to the increased interception of daily solar radiation by the canopy. LAI is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery. It is the most important indicator of size of the assimilatory system in maize to maximize harvest of the incident solar radiation (Mahmood and Saeed, 1998). Oscar and Tollenaar (2006) reported that LAI increased with the application of higher rate of nitrogen. The increased LAI with increasing nitrogen supply may be due to the effect of nitrogen on the rate of growth of meristem and the appearance and development of leaves (Ahmad et al, 1993). Maize crop differs in its ability to maintain LAI and above ground dry matter production at different levels of nitrogen supply (Pandey et al, 2000).

Table 4 - Correlation analysis of different physiological parameters and yield in long duration genotypes of maize.

Sr.no.	Parameters	Low nitrogen (RDN-25%)	High nitrogen (RDN+25%)	Recommended (RDN)
1	RUE	0.99**	0.99**	0.98**
2	IPAR	0.99**	0.96**	0.99**
3	FRI	0.71*	0.89**	0.89**
4	LAI	0.99**	0.96**	0.96**
5	Leaf area	0.76*	0.89**	0.83*
6	Leaf senescence	0.99**	0.98**	0.91**
7	Chlorophyll	0.99**	0.98**	0.98**
8	Plant height	0.97**	0.98**	0.99**
9	ASI	0.06NS	-0.90**	-0.23NS
10	Days to silking	-0.93**	-0.94**	-0.97**
11	Days to anthesis	-0.95**	-0.93**	-0.97**
12	Days to 9-leaf	-0.96**	-0.96**	-0.98**

Table 5 - Correlation analysis of different physiological parameters and yield in short duration genotypes of maize.

Sr.no.	Parameters	Low nitrogen (RDN-25%)	High nitrogen (RDN+25%)	Recommended (RDN)
1	RUE	0.99**	0.99**	0.99**
2	IPAR	0.97**	0.99**	0.98**
3	FRI	0.90**	0.98**	0.93**
4	LAI	0.99**	0.99**	0.99**
5	Leaf area	0.95**	0.97**	0.96**
6	Leaf senescence	0.85*	0.91**	0.92**
7	Chlorophyll	0.89**	0.98**	0.95**
8	Plant height	0.86*	0.93**	0.85*
9	ASI	0.64NS	-0.89**	-0.55NS
10	Days to silking	-0.69*	-0.88*	-0.83*
11	Days to anthesis	-0.66*	-0.91**	-0.85*
12	Days to 9-leaf	-0.79*	-0.92**	-0.82*

Argenta et al (2004) speculated that nitrogen taken up by maize during early growth stages is used primarily to produce other plant structures (formation and expansion of leaves and stems) rather than chlorophyll early in the crop ontogeny. Because a fast establishment of such structures is useful to enhance light interception, leading to an increase in radiation use efficiency and grain yield (Marschner, 1995). In the present studies, various nitrogen fertilizer rates had an impact on leaf greenness at three phenological stages in case of long duration genotypes and the impact of nitrogen deficiency at photosynthetic maturity (anthesis stage) was greater in hybrid than its parents. Similar results have been reported by Zaidi et al (2003).

An adequate supply of nitrogen in the soil, plant maintain their chlorophyll content for long time, which resulted in slower leaf senescence and moreover, plant is able to supply its seeds with nitrogen and photoassimilates for a longer period which results in higher yields (Eghball and Power, 1999).

Senescence is the highly regulated last developmental phase of plant organs and tissues and is optimized to allow nutrient remobilization to surviving plant parts such as seeds of annual crops (Losak et al, 2010). Leaf senescence indicated the ability of a plant or genotype to intercept a higher fraction of incident light or to intercept light for a longer time (Wolfe et al, 1988a).

At maturity, the number of green leaves below ear were more in plants supplied with higher levels of nitrogen. This shows that higher nitrogen rates enhanced the vegetative growth of crop and increased the source capacity of plants by producing more number of green leaves.

Racjan and Tollenaar (1999) reported that leaf longevity was enhanced by an increase in soil nitrogen supply. In addition, reduced nitrogen availability accelerated post-flowering leaf senescence than at high nitrogen and maize inbred lines showed differences in their magnitude of response (Andrea et al, 2008). The reduction in nitrogen availability encouraged leaf senescence was also reported by Gangula et al (2005). In the present study, under nitrogen-deficient conditions (RDN-50% and RDN-25%) the hybrids had more number of green leaves below the ear than their parents. So, the hybrids had highest greening percentage at reduced nitrogen soil. Likewise, Hefny and Aly (2008) have also reported that the inbreds showed leaf greenness reduction more than hybrids when grown at nitrogen deficiency conditions. Moreover, the differences observed among the hybrids and their parents in number of green leaves indicate that the hybrids (PMH1 and JH3459) had more genetic potential to utilize the applied nitrogen to produce more green leaves.

In our studies, the traits related to light capture i.e. fraction of incident photosynthetically active radiation intercepted by canopy (FRI) at three phenological stages was more in case of hybrids than their parents. The nitrogen deficiency condition (RDN-50%) caused a significant reduction in FRI as compared to control (RDN) in both long and short duration genotypes and the negative effect of reduced nitrogen supply was larger on hybrids than their parents These results are in line with those reported by Andrea et al (2009).

Significant increase in radiation use efficiency (RUE) with increase in nitrogen application have also been reported by Cirilo et al (2009). The increase may be ascribed to a more green surface and a greater assimilate production (Diker and Bausch, 2003).

As maize is a nitro-positive crop, the reduction in number of days taken for anthesis with increasing levels of nitrogen may be attributed to higher leaf area index and dry matter accumulation which results in increased vegetative growth and influenced anthesis (Martin et al, 1976). In general, hybrids flowered earlier than their parents. The limited nitrogen supply increased the days required to reach anthesis stage for both hybrids and their parents. The impact of low-nitrogen stress was comparatively more pronounced on hybrids than their parents (Zaidi et al, 2003).

The phenological traits of the crop were extremely sensitive to the availability of nitrogen during growth period. In both the sets (long and short duration) of genotypes, comparison of delay in anthesis and silking days at low nitrogen supply revealed that days to silking were delayed more at reduced nitrogen supply as compared to days to anthesis. This led to an average prolongation of anthesis-silking interval.

Several reports have shown that the shorter ASI under stressful conditions is an indirect index for greater tolerance and biomass partitioning to the developing ear. Therefore, the shorter ASI reflects the adaptation to low-nitrogen stress.

The grain yield is a function of cumulative behavior of various yield components such as number of kernel rows per cob, number of kernels per cob and 100-kernel weight. Grain yield was higher in hybrids than their parents regardless of nitrogen availability. Grain yield decreased with low nitrogen conditions and hybrids were more responsive than their parents. Betran et al (2003) also reported that hybrids had larger negative response to reduced nitrogen supply as compared to inbreds for grain yield.

Correlation analyses between different physiological traits and grain yield at recommended, high and at low nitrogen levels indicated that grain yield was positively and significantly correlated with ecophysiological parameters i.e. RUE, IPAR, FRI, LAI at all the three levels of applied nitrogen for both long (Table 4) and short (Table 5) duration genotypes. However, the relationship of phenological traits i.e. days to 9-leaf, days to anthesis, and days to silking was negative and significant. The correlation of yield with ASI was non-significant at low and RDN but significant negative correlation at high levels of applied nitrogen for both sets of genotypes which means shorter the ASI, higher will be the yield (Tables 4 and 5).

Overall the study indicates an increase in traits related to light capture i.e. leaf area, leaf area index (LAI), fraction of PAR intercepted by plants (FRI), intercepted photosynthetically active radiation (IPAR), radiation use efficiency (RUE) and grain yield with higher doses of nitrogen. The higher nitrogen rates enhanced the vegetative growth of crop and increased the source capacity of the plants which is indicated by more number of green leaves below the ear in crop supplied with higher nitrogen. The high nitrogen supply also caused a significant reduction in the anthesis-silking interval (ASI) in both long and short duration genotypes.

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