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MAIZE RESPONSE TO TIME AND RATE OF NITROGEN APPLICATION

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Abstract

To find out effective use of nitrogen (N) in autumn planted maize (*Zea mays* L.) hybrid, a field experiment was conducted during 2009 at Agronomic Research Area, University of Agriculture, Faisalabad. Three N split application timings depending upon various development stages were kept in main plots and five rates of N; N_1 (100 kg ha^{-1}), N_2 (150 kg ha^{-1}), N_3 (200 kg ha^{-1}), N_4 (250 kg ha^{-1}) and N_5 (300 kg ha^{-1}) were randomized in sub plots. Results revealed that maximum plant growth, number of kernels per cob (419) and grain yield (8.27 t ha^{-1}) were recorded in N_4 treatment. Contrary maximum days to maturity (103.3 days) and biological yield (16.56 t ha^{-1}) were recorded in N_5 treatment. Based on the results, it was concluded that application of N in three split (at V2, V16 and R1 stage) @ 250 kg ha^{-1} can be recommended for achieving optimum grain yield under semi arid environment of Pakistan.

Introduction

Maize is usually considered to have a high soil fertility requirement to achieve maximal yields (Paponov *et al*., 2005; Uribelarrea *et al*., 2009) and thus large quantities of N is required. Nitrogen being the most yield limiting nutrient, its stress reduces grain yield by delaying plant growth and development (Uhart & Andrade, 1995a). Similarly N fertilization and management practices remain significant agronomic practices for maize production to obtain high yield (Graham, 1984; Sattelmacher *et al*., 1994). Usually for optimum crop production N requirement has generally been determined from field experimentation keeping different rates of N fertilizer application (Muchow, 1998).

In agro ecological condition of Faisalabad, there is little data to show how soil N status early in the season affects maize growth while it response to delay N application. Jokela & Randall (1989) concluded that there was less response of maize to N when it was applied at V2 stage than V8 stage. Maize starts to take up N rapidly at the middle vegetative growth period (V10) and maximum rate of N uptake occur near to silking stage (Hanway, 1963; Settimi *et al*., 1998). Hence, application of N at V8-V10 stage should be one of the best ways of supplying N to convene this high demand. At low N supply, crop growth rate slows down causing reproductive structures to decline, as a result lower maize grain yield (and its components) as well as lesser harvest index and leaf area duration are achieved (Lemcoff &Loomis, 1986; Below *et al*., 2000; O'Neill *et al*., 2004; Ding *et al*., 2005; Monneveux *et al*., 2005). Similarly in maize during silking stage, the maintenance of N uptake is a critical aspect in minimizing the requirement for N remobilization from vegetative to reproductive stage, therefore decreasing green leaf area, and concurrently dry matter accumulation becomes low (Rajcan & Tollenaar, 1999). It is thus necessary to apply optimum dose of N at critical stages (Gungula *et al*., 2003).

Several researchers (Moser *et al*., 2006; Grant *et al*., 2002) attributed lower yield in maize when the crop was subjected to high dose of N, while time of N application improved N uptake and protects the soil environment (Power *et al*., 1998; Karlen *et al*., 1998). Similarly the deficiency of N is evident in the reduction of light interception by decreasing leaf area index which results in lower grain yield (Uhart & Andrade, 1995b). The existing recommended dose of 200 kg N ha^{-1} for maize production is low for Pakistani soils. Maize grain yield absolutely increases upto 300 kg ha^{-1} (Khaliq *et al.*, 2009). It has been clearly shown in the literature that applying optimum rate of N at proper time is considered to be the single most significant factor in improving crop productivity (Magdoff, 1991). Therefore, judicious N management optimizes grain yield and it reduces the potential for leaching of N beyond the rooting zone (Raun & Johnson, 1999; Subedi & Ma, 2005). The present study was conducted to optimize the dose and time of N application in maize hybrid under semi arid conditions of Pakistan.

Materials and Methods

A field experiment was conducted to study the effect of N application time and rates on growth and yield of maize hybrid at the Agronomic Research Farm, University of Agriculture, Faisalabad (31° 25′ N, 73° 04′ E) during autumn season 2009. Soil analysis of the experimental site samples illustrated that it had pH value at 7.48, N, P_2O_5 and K_2O was found 0.066 %, 6.90 and 187 ppm, respectively. The soil was sandy clay loam in texture with organic matter and total soluble salt at 0.96 % and 12.25 %, respectively. A split plot design was employed and each treatment was replicated thrice having net plot size of 3m x 6m. Application of N was based on growth stage; three N application timing: T_1 (1/3 N at seed bed preparation, 1/3 N at V6 and 1/3 N at VT stage), T_2 (1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage) and $T_{3:}$ (1/3 N at seed bed preparation, 1/3 N at V12 and 1/3 N at R2 stage) were kept in main plots and five N rates: N_1 (100 kg ha^{-1}), N_2 (150 kg ha^{-1}), N_3 (200 kg ha^{-1}), N_4 (250 kg ha^{-1}) and N_5 (300 kg ha^{-1}) were applied in sub plots of the experiment.

The crop was sown on August 1, 2009 with P x P distance of 20 cm and in 75 cm apart rows on ridges. The maize hybrid, Pioneer 31-R-88 was sown @ 25 kg ha^{-1}. Recommended dose of P_2O_5 and K_2O each @ 125 kg ha^{-1} and N was applied in three split doses according to treatments. The crop received eight irrigations according to its requirement, starting from 7 days after sowing. After 20 days of planting, one meter long row was harvested from each plot at ground level after 14 days interval. Fresh and dry weight of constituent fractions of plant was also determined separately and sub-sample from each division was taken to dry in an oven (Model: WFO-600ND) at 70ºC till constant weight. Total dry matter production was calculated by adding oven dry weights of leaves, stem, tassel and cob (as it developed) by using standard procedures at each harvest.

For measurements of crop development ten plants were randomly selected from the central rows in each plot and tagged. The numbers of days to tasseling and silking were noted at the appearance of tassel and silk respectively. The same ten tagged plants were kept under observations and the average numbers of days to maturity were calculated from the tagged plants; from days after sowing (DAS). In the same way from each plot ten g leaf was taken after fourteen days interval for the calculation of leaf area using leaf area meter (CI-202) then leaf area index (LAI) was calculated using formula given by Watson (1952).

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

Similarly, leaf area duration (LAD), crop growth rate (CGR) and net assimilation rate (NAR) were calculated by using the procedure given by Hunt (1978).

$LAD = (LAI_1+LAI_2) \times (t_2-t_1)/2$, where LAI_1 & LAI_2 were at time t_1 & t_2, respectively

$CGR = (W_2-W_1) / (t_2-t_1)$, where W_1 and W_2 were the total dry weights of harvested sample at times t_1 and t_2, respectively

$NAR = TDM / LAD$, where values of TDM and LAD were the values of final TDM and LAD, respectively

At maturity, an area 1.5m x 2m which had 20 plants was harvested for final yield and various yield components. All the data obtained were analyzed by employing "M-Stat C" statistical package. The response of yield and growth to N rates was also analyzed by using polynomial contrasts (linear, quadratic and cubic) within the analysis of variance structures. Differences among the treatments means were compared using least significant difference (LSD) test at 5% probability level (Steel *et al.*, 1997).

Vn, V= vegetative, n= number of leaves R= reproductive stage T= tasseling,1= silking, 2= blister

Results and Discussion

Both, the timing and rates of N did not significantly affect the number of days to emergence (Table 1) because sufficient food reserves in the cotyledons of seeds were available for initial growth of the newly emerged plants (Belfield & Brown, 2008). Similarly, during primary growth stages plants use residual soil inorganic N. However, on an average it took 3.22 to 3.56 days for germination in different treatments.

Data regarding days to tasseling was statistically significant (Table 1). The treatment T_2 (1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage) took higher number of days (51.29 DAS) to tasseling while minimum days (48.73 DAS) to tasseling was found in the treatment T_3 (1/3 N at seed bed preparation, 1/3 N at V12 and 1/3 N at R2 stage). Difference in number of days to tasseling between T_1 and T_3 were also significant. Nitrogen rates also showed highly significant effect on number of days to tasseling and this response of N application was linear and also highly significant (Table 1). Nitrogen @ 250 kg ha^{-1} delayed four days to tasseling from treatment N_1 (100 kg N ha^{-1}) and it was statistically at par with treatment N_5 (300 kg N ha^{-1}). Minimum days to tasseling (47.62 DAS) were observed in N_1 (100 kg N ha^{-1}) while mean day to tasseling was 49.63. The results indicated that the treatment which took maximum days for tasseling reached late to silking and physiological maturity as compared to others. Valero *et al*., (2005) concluded that maize crop took 47 days for tasseling when N was applied @ 130 kg ha^{-1} under semiarid condition. The association of days to tasseling with the other parameter was significant (Table 3) except days to emergence.

In the same way both timing as well as rates of N application significantly influenced the days to silking (Table 1). In treatment T_2 (1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage) more days to silking (56.29 DAS) as compared to T_1 and T_3 were observed. Effect of N application rate on days to silking was significant and response of N was linear (Table 1). Maximum days to silking (56.37 DAS) were taken by the crop when N dose was applied at the rate of 250 kg ha^{-1} (T_4), followed by N_5 (300 kg N ha^{-1}) while minimum days to silking (52.50 DAS) were observed for N_1 (100 kg ha^{-1}) treatment, mean days to silking was 54.62 DAS. The correlation coefficient of days to silking with different growth and yield parameters was significant and positive (Table 3). Amanullah *et al*., (2009) reported that maize took 56.6 days to reach at silking stage when N was applied @ 180 kg ha^{-1} in three split. Increase in N dose delayed phenological characteristics such as silking due to the LAD longevity. Finally, the phenological traits of the crop found to be extremely sensitive to the availability of N during growth period.

Effects of N application timing on days to maturity were significant. The treatment, T_1 and T_2 were statistically at par in days to maturity. The crop matured earlier when N was applied at initial stages and vice versa (Table 1). Moreover, it is worth noting that in general, late-maturing treatment tended to have longer duration from silking development (Ma & Dwyer, 2000). The effect of N rates also significantly influenced days to maturity; its response was linear and highly significant. Maximum days to maturity (103.3 days) were taken by the highest dose of N (300 kg ha^{-1}) and it was statistically at par with N_4 and N_3. Similarly, the lowest days to maturity (98.74) were recorded with the application of N @ 100 kg ha^{-1}. Overall, the mean days to maturity were 101.32. Akbar *et al.* (2002) observed that maize crop took 102 days to maturity when N was applied @ 200 kg ha^{-1}. The correlation coefficient of days to maturity with yield parameter (grain per cob, economic and biological yield) was found significant (Table 3). Maize crop accumulate more heat units (thermal time) to tasseling, silking and physiological maturity with increasing the rate of N and vice versa (Amanullah *et al.,* 2009). Increase in N rate might have increased the rate of photosynthesis in the plant (Oikeh *et al.,* 1997) that resulted in the leaf durability and delayed same phenological characteristics in the crop (Edemeades *et al*., 1993; Gungula *et al*., 2003).

Table 1. Influence of nitrogen on phenology and growth of maize hybrid.

Treatment	Days to emergence	Days to tasseling	Days to silking	Days to maturity	Maxi. LAI	LAD (day)
T_1	3.33	49.56 b	54.55 b	100.0 b	4.74 b	232.0 b
T_2	3.27	51.25 a	56.29 a	101.5 a	4.85 a	243.4 a
T_3	3.47	48.09 c	53.02 b	102.1 a	4.44 c	228.2 b
LSD 5%	0.24	1.52	1.74	0.54	0.13	6.48
Significance	NS	**	**	*	**	**
N_1	3.56	47.62 c	52.50 c	98.74 c	4.24 c	207.7 d
N_2	3.22	48.73bc	53.70 bc	101.1 bc	4.47 bc	225.5 c
N_3	3.44	50.13 abc	55.11abc	101.5 ab	4.74 ab	237.8 b
N_4	3.33	51.29 a	56.37 a	102.3 ab	5.06 a	258.4 a
N_5	3.22	50.39 ab	55.41 ab	103.3 a	4.76 ab	243.0 b
LSD 5%	0.50	2.51	2.68	2.45	0.34	6.20
Significance	NS	**	*	**	**	**
Linear	NS	**	**	**	**	**
Quadratic	NS	NS	NS	NS	**	**
Cubic	NS	NS	NS	NS	*	**
Mean	3.36	49.63	54.62	101.32	4.73	259.50
Interaction	NS	NS	NS	NS	NS	NS

Means sharing different letters in a column vary significantly at $p \leq 0.05$
LSD= least significant difference, *, ** = Significant at 5 % and 1%, respectively, NS= Non-significant,

Table 2. Influence of nitrogen on yield of maize hybrid.

Treatments	Mean CGR ($g\ m^{-2}\ d^{-1}$)	NAR ($g\ m^{-2} d^{-1}$)	Kernel per cob	Biological yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)
T_1	18.10 a	6.91	394 ab	15.96 a	6.88 ab
T_2	17.24 b	6.47	404 a	15.73 a	7.16 a
T_3	16.35 c	6.56	378 b	14.92 b	6.53 b
LSD 5%	0.60	0.45	20	0.78	0.37
Significance	**	NS	*	*	*
N_1	15.32 d	6.91 a	368 c	14.32 c	5.46 e
N_2	16.49 c	6.64 abc	378 c	14.93 bc	6.02 d
N_3	17.49 b	6.54 bc	389 bc	15.54 b	6.94 c
N_4	18.14 ab	6.33 c	419 a	16.36 a	8.27 a
N_5	18.71 a	6.83 ab	405 ab	16.56 a	7.61 b
LSD 5%	0.73	0.32	26	0.68	0.39
Significance	**	*	*	**	**
Linear	**	**	**	**	**
Quadratic	*	**	NS	NS	**
Cubic	NS	NS	NS	NS	**
Mean	15.38	6.65	391.88	15.54	6.86
Interaction	NS	NS	NS	NS	NS

Means sharing different letters in a column vary significantly at $P \leq 0.05$ **LSD**= least significant difference, ***, **** = Significant at 5 % and 1%, respectively, NS= Non-significant

Table 3. correlation coefficients between grain yield and explanatory variables

Characters	Grain yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)	Grain per cob	M CGR ($g\ m^{-2}\ d^{-1}$)	LAD (days)	Max. LAI	Dayto Maturity	Day to Silking	Days to Tasseling	Days to Emergence
Grain yield ($t\ ha^{-1}$)										
Biolog. yield ($t\ ha^{-1}$)	0.92^{**}									
Kernal per cob	0.988^{**}	0.91*								
M CGR ($g\ m^{-2}\ d^{-1}$)	0.86^{*}	0.98^{**}	0.83*							
LAD (days)	0.98^{**}	0.83*	0.98^{**}	0.74*						
Maxi. LAI	0.96^{**}	0.78*	0.94^{*}	0.71^{ns}	0.99^{**}					
Days to maturity	0.73^{*}	0.94^{*}	0.72^{*}	0.95^{*}	0.58^{ns}	0.52^{ns}				
Days to silking	0.98^{**}	0.86^{*}	0.95^{*}	0.81^{*}	0.98^{**}	0.98^{**}	0.62^{ns}			
Days to tasseling	0.98^{**}	0.86^{*}	0.95^{*}	0.82^{*}	0.78^{**}	0.98^{**}	0.64^{ns}	0.99^{**}		
Days to emergence	0.19^{ns}	0.047^{ns}	0.072^{ns}	0.001^{ns}	0.267^{ns}	0.38^{ns}	0.31^{ns}	0.37^{ns}	0.37^{ns}	

*, **; Significantly different from zero at $p \leq 0.05$ & $p \leq 0.01$ levels, respectively.

Leaf area index (LAI) has primary importance in increasing the yield of crop. The data showed that time of N application had significant effect on LAI (Table 1). When 1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage was applied as a result maximum LAI (4.85) was recorded at 62 DAS on the same time period and minimum with treatment T_3 (Fig. 1a). The periodic data illustrated that rate of N application had highly significant effect on LAI and this response of N rates cubic and significant. Maximum LAI (5.06) was observed with 250 kg N ha^{-1} and it was statistically at par with N_5 and N_3 treatment. Haghighi *et al*., (2010) were recorded 5.1 LAI with the application of 300 kg N ha^{-1}. Minimum value of LAI 4.24 was achieved with the application of N 100 kg per ha^{-1} these values were observed on 62 DAS when crop achieved maximum canopy cover. At this stage mean LAI was 4.73, thereafter it started to decrease till 104 DAS (Fig. 1b) due to start of leaf senescence as noted by Bu-Chong *et al*., (2007). Similarly Oscar & Tollenaar (2006) concluded that LAI of maize increased with the application of higher rate of N and decline in LAI was much prominent in low doses of N (Valero *et al*., 2005). Leaf expansion was improved in plants by giving optimum nitrogenous fertilizers and leaf expansion was illustrated in terms of leaf length and breadth but final numbers of leaves not affected by the time and rate of N application. Moreover sensitive period for LAI was between V12 and V 18 stage and it was not affected by earlier N stress and timing (Cox *et al*., 1993). The correlation coefficient of LAI was highly significant with days to tasseling and days to silking but non significant effect with days to emergence. Increase in LAI stay-green and maintain photosynthesis of green leaves during R1 stage (Tollenaar *et al*., 2004). Our results were also in corroboration with those of Turgut, (2000) and Akbar *et al*., (1999) who found that N rates and time of application have significant effects on maize phenology.

Leaf area duration (LAD) was statistically highly significant with time and rate of N application (Table 1). The crop achieved maximum LAD (243.4 days) when T_2 (1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage) was applied. Both T_1 and T_3 treatments effect was statistically alike. Similarly response of N application rates was cubic and significant. Increase in N rates illustrated that LAD of the crop was increased upto 258.4 days with application of 250 kg N ha^{-1} and was followed by N_5 and N_3 treatments. Leaf area duration gradually increased till maturity of the crop (Fig. 2, a&b). Minimum LAD was observed with application of 100 kg N ha^{-1} and mean LAD was (259.5 days). The correlation coefficient of LAD was highly significant with LAI, days to tussling and days to silking while it was non significant with days to maturity and emergence of the crop (Table 3). Valero *et al*., (2005) were recorded 147 to 255 days LAD in maize with the application of various N rates in a semiarid region of Castilla-La Mancha, Spain. Variations in dry matter production and grain yield may not be explained by agronomic treatments. Therefore differences in yield among treatments are some time accounted from LAD as the LAD becomes photosynthetic surface during crop growth period.

Mean crop growth rate (CGR) was significantly affected by various studied times of N application (Table 2). The results revealed that maize attained maximum mean CGR (18.10 g m^{-2} d^{-1}) by the application of 1/3 N at seed bed preparation, 1/3 N at V6 and 1/3 N at VT stage. Lowest mean CGR (16.35 g m^{-2} d^{-1}) was achieved by the crop when 1/3 N at seed bed preparation, 1/3 N at V12 and 1/3 N at R2 stage was applied (Fig. 3a). Delay in N application decreased CGR in maize. Nitrogen rates also showed highly significant effect on mean CGR (Fig. 3b) and response of the N rates to crop was quadric and significant. Mean crop growth rate was increased upto 18.71 g m^{-2} d^{-1} with the application of 300 kg N ha^{-1} and it was at par with application of 250 kg N ha^{-1}. The value of mean CGR was reduced gradually with reduction of N supply and lowest mean CGR (15.32 g m^{-2} d^{-1}) was calculated for the lowest N dose (100 kg N ha^{-1}). Effects of N on maize mean CGR has been reported by Khaliq (2008) who calculated 20.78 g m^{-2} d^{-1} mean CGR with application of 250 kg N ha^{-1}. The association of mean CGR with LAD, days to tasseling, silking and maturity was positive and significant but non significant with LAI and days to emergence (Table 3). In general, mean CGR was lower during the earlier crop stages and it increased to reach a peak at R1 stage then it declined continuously up to physiological maturity of the crop. The increase in value of CGR is responsible for similar TDM at the end of growing seasons. This behavior agrees with the findings of (Valero *et al*., 2005). Moreover increase in CGR rate with N was mainly due to larger LAI, since CGR is a product of the LAI and NAR.

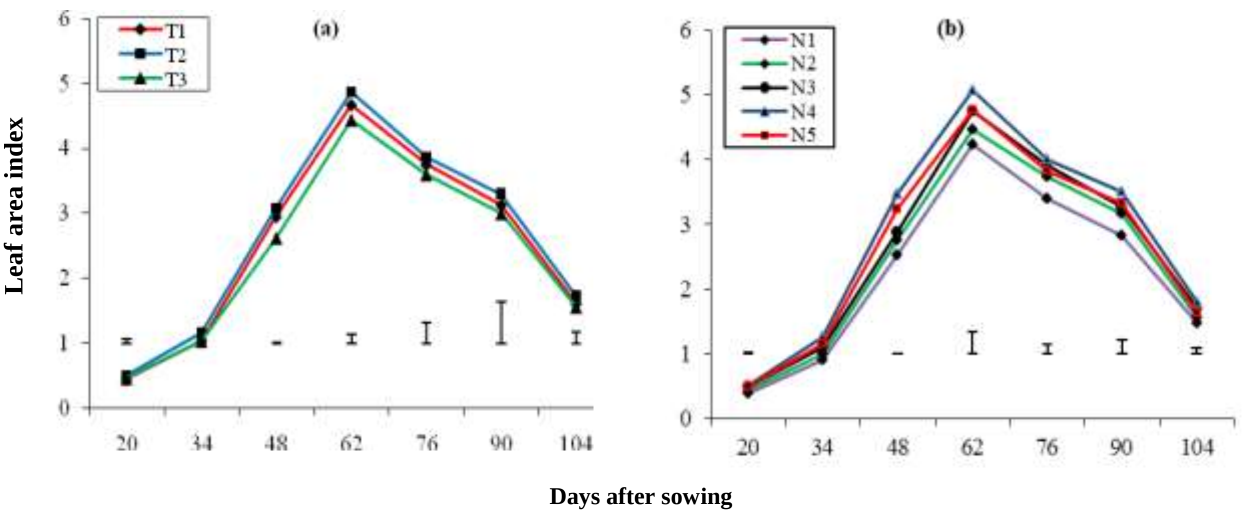

Fig. 1. Impact of nitrogen timing (a) and rates (b) on leaf area index; bars represent LSD at 5%.

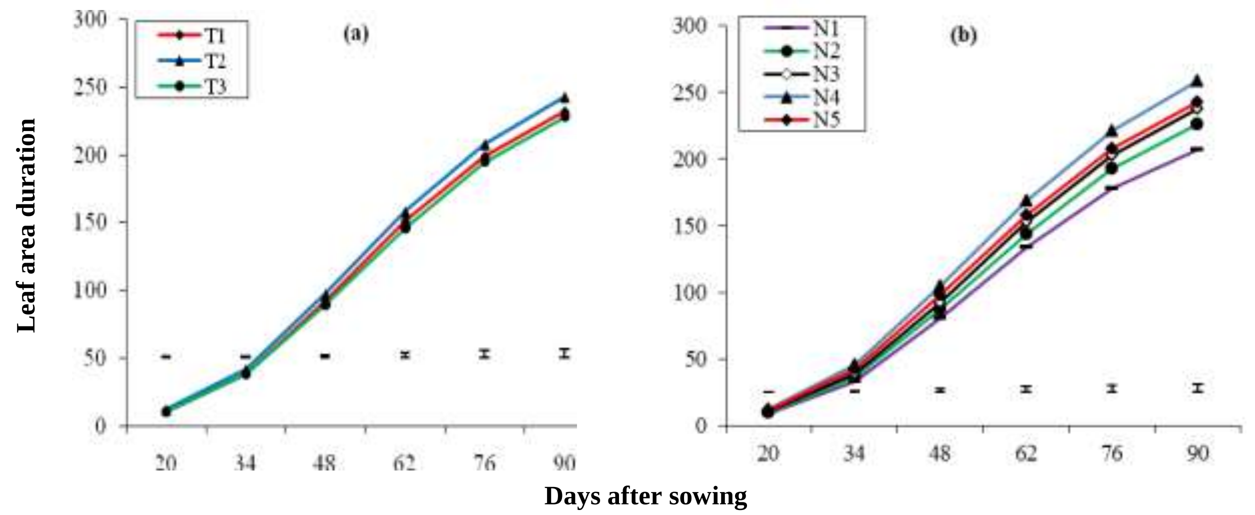

Fig. 2. Impact of nitrogen timing (a) and rates (b) on leaf area duration; bars represent LSD at 5%

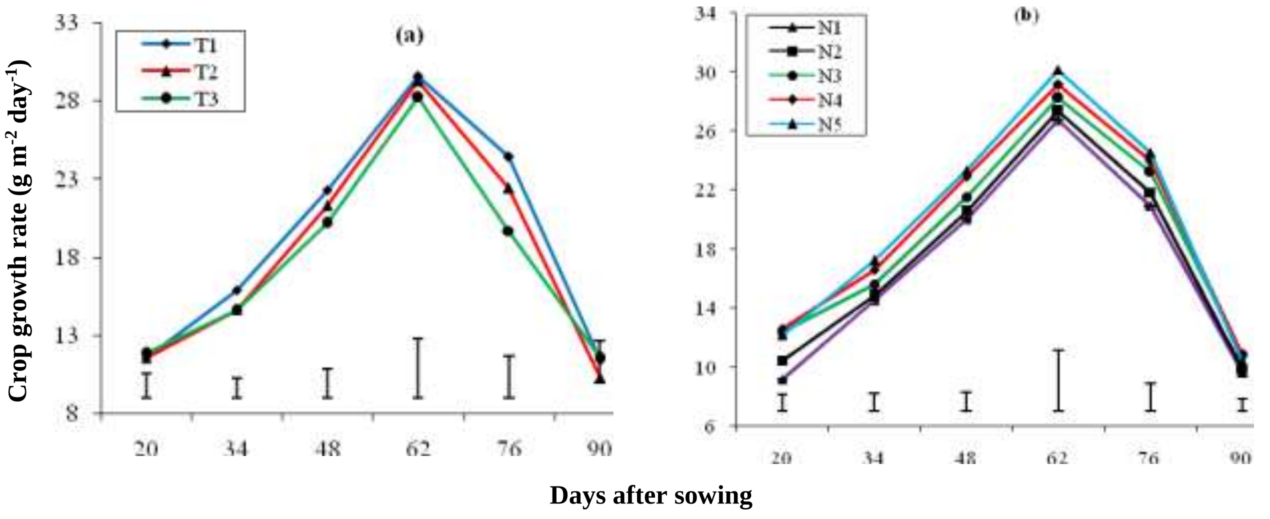

Fig. 3. Impact of nitrogen timing (a) and rates (b) on crop growth rate; bars represent LSD at 5%.

In this study, mean net assimilation rate (NAR) did not coincide with crop yield and there was little difference in NAR with changing timing of N application. However, various rates of N application showed significant effect on mean NAR and response of N application rates to the crop was quadric and significant (Table 1). Maximum mean NAR (6.91 g m^{-2} d^{-1}) was achieved by the application of 100 kg N ha^{-1} and further increases in N rates did not increase NAR. Haghighi *et al*., (2010) reported that there was no increase NAR with the application of N 35 DAS. Actually, at earlier growth stage maximum increase in stem growth occurred and maize plant accumulates more dry matter in that period then it decrease during several days, when the aerial vegetative organs stop growing.

Maize yield depends on number of kernels per cob. The data showed that number of kernels per cob was significantly affected by time of N application (Table 2). Maximum number of kernels (404) per cob was produced when 1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage was applied while the application of 1/3 N at seed bed preparation, 1/3 N at V12 stage and 1/3 N at R2 stage gave minimum number of kernels per cob (378). The rate of N application showed significant effect on number of kernels per cob. Nitrogen application response was linear and highly significant (Table 1). Maximum number of kernels per cob (419) was observed with the application of N @ 250 kg ha^{-1} and it was statistically at par with the application of N 300 kg ha^{-1}. Crop fertile with lower dose of N i.e., 100 kg ha^{-1} produced 368 kernels per cob. Moreover probable reason for lesser number of kernels was N deficiency which reduced biomass production traits of the plant which could be primarily relate to number of kernel per cob. Similarly, at crop level the responses to N supply is associated to enhance light interception and its use efficiency which lead to a higher CGR during tasseling, favorable to provide photoassimilate for kernel set (Uhart & Andrade, 1995a). Source sink relationship during tasseling stage seems to be critical for kernel numbers (Gambin *et al*., 2006). In maize number of kernels per cob was decreased by N stress (Uhart & Andrade, 1995b; Khan *et al.*, 1999). The correlation coefficient of kernels per cob with grain yield was highly significant (R^2= 0.99 Fig. 4d). Our results were supported with evidence obtained by Melchiori & Caviglia, (2008).

The potential of a crop depends upon its biomass production. The response of time of N application showed significant effect and maximum biological yield (15.96 t ha^{-1}) was produced when 1/3 N was applied at seed bed preparation, 1/3 N at V6 stage and 1/3 N at VT stage and it was statistically similar to T_2 treatment. From the results it clear N availability must be adequate at vegetative stage to ensure the maximum biological yield. Nitrogen application rate showed highly significant effect on biological yield as well as its response was linear and highly significant. Maximum biological yield (16.56 t ha^{-1}) was obtained with the application of N @ 300 kg ha^{-1} and was statistically similar with application of N 250 kg ha^{-1}; it was followed by applying of 200 kg N ha^{-1}. Similarly, minimum biological yield (14.32 t ha^{-1}) was observed with application of 100 kg N ha^{-1}. The mean biological yield was 15.54 t ha^{-1}. Amanullah *et al*., (2009) achieved 14.70 t ha^{-1}, biological yields in maize with application of N at the rate of 180 kg ha^{-1}. The correlation coefficient of biological yield was highly significant with all growth and yield parameter except days to emergence (Table 3). Patrick *et al*., (2004) found positive relationship of biological yield with grain yield under various N rates. The increase in TDM with higher rate of N was due to better CGR, LAI and accumulation maximum days to maturity by the crop which ultimately produced more biological yield.

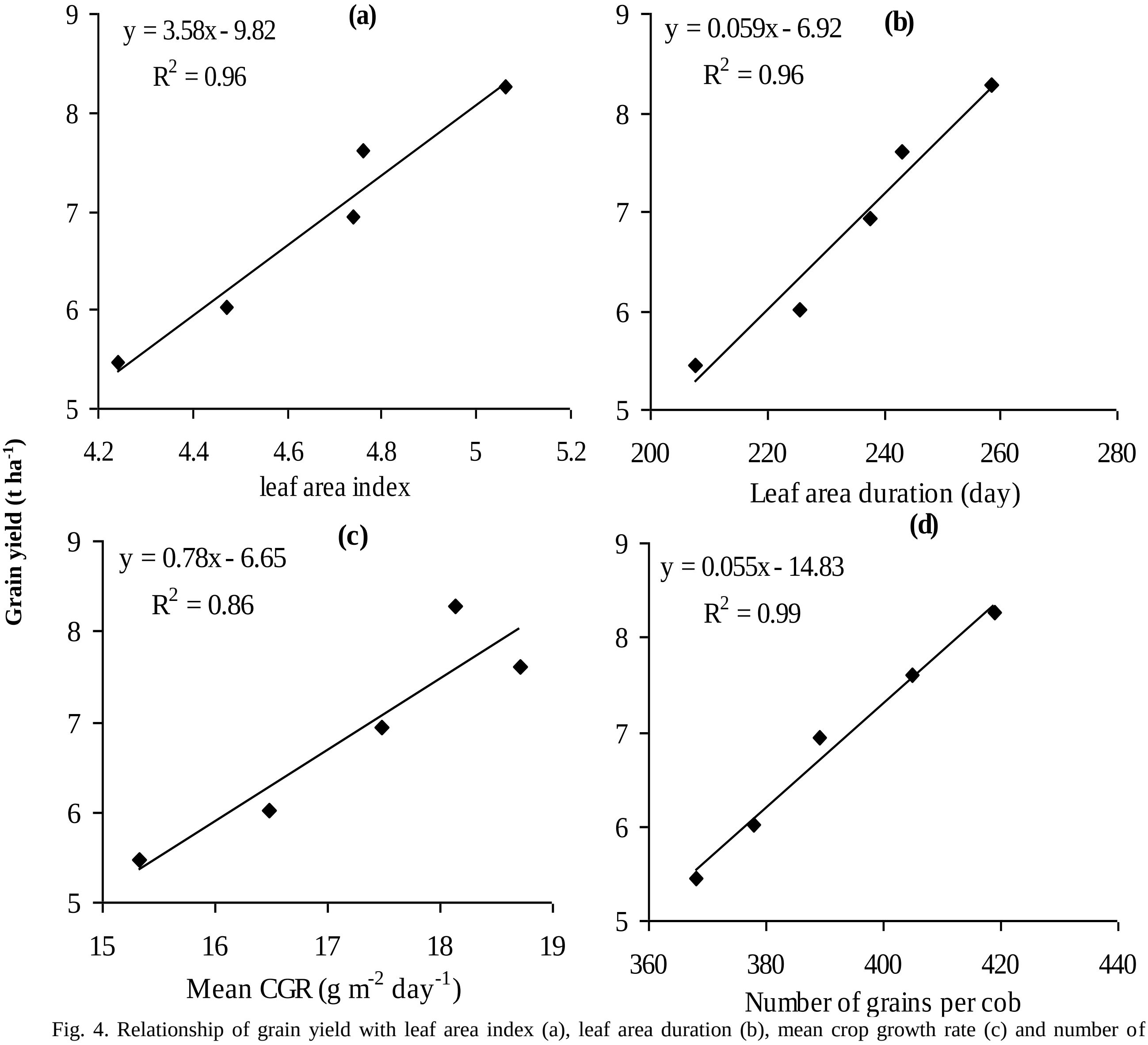

Fig. 4. Relationship of grain yield with leaf area index (a), leaf area duration (b), mean crop growth rate (c) and number of grains per cob (d).

Grain yield was influenced with different times of N application and when 1/3 N at V2, 1/3 N at V16 and 1/3 N at R1 stage (T_2) was applied it resulted maximum grain yield (7.16 t ha^{-1}) and the treatment T_2 was statistically at par with treatment T_1 (N was applied at initial stages of the crop). This indicates maximum grain production could be obtained with application of N after crop emergence and before R1 stage. Similar results have also been reported by Binder *et al*. (2000). The rate of N application also showed highly significant effect on grain yield and the response was cubic and highly significant (Table 1). Maximum grain yield (8.27 t ha^{-1}) was achieved by the application of 250 kg N ha^{-1} compared to all other N application rates. This treatment produced also the highest LAI and grain yield of maize could be explained by variation of LAI and LAD of the crop (Mansouri-Far *et al*., 2010; Cheema *et al*., 2010). Minimum grain yield (5.46 t ha^{-1}) was obtained with the application of 100 kg N ha^{-1} and mean grain yield was 6.86 t ha^{-1}. These results substantiate the findings of Khaliq *et al*., (2009), who achieved 8.17 t ha^{-1} maize grain yields by using 300 kg N ha^{-1}. Grain yield strongly correlated with all growth and yield parameters which were studied except days to emergence (Table 3). The correlation coefficient of grain yield with LAI, LAD, mean CGR and number of grains was positive and linear (R^{-2} = 0.96, .96, 0.86 and 0.99; Fig. 4a, b, c and d, respectively). Otegui & Andrade, (2000) observed positive relationship of grain yield with same parameters. Variations in grain yield with N rates were mostly due to significant differences in growth parameters such as TDM production, maximum LAI, LAD and CGR values these differences lead to significant change in the grain yield.

Conclusion

Time as well as rate of N application influenced maize growth and yield. The rate of N had significant response in terms of linear, quadratic and cubic effects on crop growth and yield. The application of N @ 250 kg ha^{-1} in three splits at V2 V16 and R1 stages produced highest grain yield (8.27 t ha^{-1}) contrary biological yield increased application of N upto 300 kg ha^{-1}. Moreover correlation analysis indicated that grain yield was highly and positively associated with all the parameters except days to emergence, where relationship was negative.

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