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EFFECTS OF VARIABLE NITROGEN SOURCE AND RATE ON LEAF AREA INDEX AND TOTAL DRY MATTER ACCUMULATION IN MAIZE (*Zea mays* L.) GENOTYPES UNDER CALCAREOUS SOILS

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ABSTRACT

Leaf area index (LAI) and total dry matter are important growth and yield-determining factors in maize (*Zea mays* L.). Field experiment was conducted to investigate the impact of different N-fertilizer sources [urea, calcium ammonium nitrate (CAN) and ammonium sulphate (AS)] and rates (50, 100, 150 and 200 kg ha^{-1}) on mean single leaf area (MSLA), number of leaves plant^{-1} (NLPP), LAI and total dry matter (TDM) of maize genotypes "Local cultivars (Azam and Jalal) vs. hybrid (Pioneer-3025)". The experiment was conducted at the Agriculture Research Farm of The University of Agriculture Peshawar during summer 2008-10. The results indicated that all the experimental plots treated with N produced higher MSLA, NLPP, LAI and TDM than control (N not applied). The MSLA, NLPP, LAI and TDM increased with higher N rates (150 and 200 kg N ha^{-1}). Application of CAN and AS produced higher MSLA, NLPP, LAI and TDM than urea in the 1st year, but no significant differences were observed in the 2nd year. The hybrid (P-3025) produced higher MSLA, NLPP, LAI and TDM than Azam and Jalal. The increase in MSLA and NLPP showed positive relationship with LAI. The TDM increased with increase in LAI. Application of N either as CAN or AS at the rate of 200 kg ha^{-1} was recommended for the high yielding hybrid maize but 150 kg N ha^{-1} was most suitable for the low yielding local cultivars in the study area.

Key words: maize, *Zea mays* L., genotypes, N levels, N source, leaf area index, total dry matter

INTRODUCTION

Leaf area index (LAI) is a measure of leafiness per unit ground area and denotes the extent of photosynthetic machinery. Leaf area index influences the interception and utilization of solar radiation, and consequently growth and yield (Amaullah et al., 2007 and 2008). According to Fageria et al. (2006), LAI is an important yield-determining factor for field crops because LAI is a major determinant of light interception and transpiration. Rapid leaf area expansion is a desirable trait in the early growth stages of cereal crops grown in low-rainfall areas, because it leads to rapid canopy closure, thereby reducing the evaporation from the soil surface, and thus increasing crop water-use efficiency (Richards et al., 2002). In more favorable conditions, fast canopy development will make the crop more competitive with weeds for light interception (Lemerle *et al.*, 2001). Moreover, Boogaard et al. (1996) showed, in a controlled-environment study, that a fast leaf area expansion rate in wheat was positively correlated with above-ground biomass and grain yield. Our previous research on maize (*Zea mays* L.) indicated that increase in nitrogen (N) rate and number of splits led to an increase LAI (Amanullah et al., 2007), light interception (Amanullah et al., 2008); grain yield (Amanullah et al., 2009a), leaf area and total biomass (Amanullah et al., 2009b), net returns (Amanullah et al., 2010a) and dry matter portioning (Amanullah and Shah, 2011). Breadth of the area per leaf profile decreased under high soil nitrogen level and high plant density but leaf area, LAI and grain yield increased with higher rate of N (Oscar and Tollenar, 2006).

Efficient use of N for maize production is important for increasing grain yield, maximizing economic returns and minimizing NO_3 leaching to ground water (Gehl et al., 2005). Site-specific N application to maize is a way of maximizing yield potential while minimizing fertilizer cost (Kahabka et al., 2004). Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt et al., 2001). For the efficient management of N in the cropping systems, adequate rate, appropriate source and timing of application during crop growth cycle play an important role (Fageria et al., 2006). Urea, calcium ammonium nitrate (CAN) and ammonium sulfate (AS) urea are the three main N fertilizer sources for crop production in Pakistan. But there is no research work on the profitability of these N-fertilizers sources. However, our recent research work (Amanullah et al., 2012) reported the profitability of different phosphorus phosphatic fertilizers sources. Applications of either DAP (di-ammonium phosphate) or SSP (single super phosphate) was more profitable in terms net returns as compared to nitrophos (NP) and control plots (P not applied). The selection of fertilizers by the growers commonly depends upon price-the least costly fertilizer per kilogram of plant food is the one commonly selected (Plaster, 1992). Though the existing maize genotypes have a high yield potential, soil and climatic conditions of Pakistan are very ideal for its production, yet yield per hectare is very low particularly in the Northwest Pakistan (2000 kg ha^{-1}). The causes of yield gap include injudicious use of N fertilizer and growing of low yielding maize genotypes by the growers. In order to bridge this gap in maize productivity, the package of latest production technology involving the use of high yielding maize hybrids and low cost N fertilizers at appropriate level needs to be find out and used to increase maize productivity and profitability. There is lack of research on the interactive effects of maize genotypes, level and source of N fertilizers. For sustainable maize production, research on the interactive effect of genotypes into N-fertilizer source (NS x G), genotypes into N rates (NR x G) and N source into N rates (NS x NR) is indispensable. This experiment was therefore designed with an objective to investigate impact of different N fertilizer sources applied at various levels on the MSLA, NLPP, LAI and TDM of maize hybrid (Pioneer-3025) in comparison with the two local cultivars (Jalal and Azam) as checks.

MATERIALS AND METHODS

Site description

Field experiment was conducted at the Agriculture Research Farm of the University of Agriculture Peshawar during summer 2008 and 2010. The experimental farm is located at 34.01^o N latitude, 71.35^o E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from river Kabul. Soil texture is clay loam, low in organic matter (0.87 %), extractable phosphorus (6.57 mg kg^{-1}), exchangeable potassium (121 mg kg^{-1}), and alkaline (pH 8.2) and is calcareous in nature (Amanullah et al., 2009a). Weather data for the maize growing periods in the two years are given in Table 1.

Table 1. Weather data of maize growing periods in 2008 and 2010 at Peshawar- Pakistan.

Weather Data	**Growing season 1st year**				**Growing season 2nd year**			
	July	August	Sept.	Oct.	July	August	Sept.	Oct.
Mean Temperature ^{0}C	31	30	28	25	31	29	24	24
Max Temperature ^{0}C	36	35	34	32	34	33	34	32
Min Temperature ^{0}C	26	25	22	19	26	26	21	19
Precipitation(mm)	37	274	38	1	409	125	4	0
Mean Humidity (%)	66	71	63	60	75	80	63	65

Experimentation

A field experiment was conducted in a randomized complete block (RCB) design with split-plot arrangement using three replications. Factorial experimental treatments were four N (nitrogen) rates [N_1 = 50 kg $ha^{-1,}$ N_2 = 100 kg $ha^{-1,}$ N_3 = 150 kg ha^{-1} and N_4 = 200 kg ha^{-1}] and three N-fertilizer sources [S_1 = Urea {$CO(NH_2)_2$ having 46% N}, S_2 = Calcium Ammonium Nitrate {($CaCO_3.NH_4NO_3$) having 26% N and 10% Ca)} and S_3 = Ammonium Sulphate {(NH_4SO_4) having 21% N and 24% S}] applied to main plots, while three maize genotypes [G_1 = Jalal, G_2 = Azam and G_3 = Pioneer-3025] were kept in sub plots. One control plot (N not applied) was also used in each replication as check. A sub-plot size of 4.2 m by 5 m, having 6 rows, 5 m long and 70 cm apart was used. A uniform basal dose of 60 kg P ha^{-1} as single super phosphate (18% P_2O_5), and 60 kg K ha^{-1} as sulphate of potash (50% K_2O) was applied and mixed with the soil during seedbed preparation. Nitrogen in the form of urea, calcium ammonium nitrate (CAN) and ammonium sulphate (AS) were applied in two equal splits i.e. 50 % at sowing and 50 % at 2nd irrigation (30 days after emergence). Numbers of leaves of five plants in each treatment were counted and then average number of leaves per plant (NLPP) was worked. Then leaf lengths and widths of the three middle leaves of each five plants in each treatment were measured and average length and width was calculated. Data on mean single leaf area (MSLA), and leaf area index (LAI) were calculated according to the following formulae:

Mean single leaf area (MSLA) = *Leaf length x leaf width x 0.75* (cm^2)

Leaf area plant^{-1} (LAPP)= *MSLA x leaves plant^{-1}*(cm^2)

Leaf area index (LAI) = *LAPP x plants m^{-2}* (no unit)

At harvest maturity, the four central rows were harvested; the material was dried up to constant weight and weighed, and then converted into kg ha^{-1} using the following formula:

Total dry matter (TDM) = *Dry matter* m^{-2} *x 10,000 (kg* ha^{-1}*)*

Statistical analysis

Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel et al. (1997), and means between treatments was compared by least significant difference ($P \leq 0.05$). The analysis of variance for the two years data is given in Table 2. The mean values are given in Table 3, while different significant interactions are reported in figures.

Table 2 . Analysis of variance table for statistical analysis of the data during the two years at Peshawar-Pakistan.

Source of variance	**Degree of freedom**	**Probability ($P \leq 0.05$)**							
		1st year				**2nd year**			
		MSLA cm^2	NLPP -	LAI -	TDM kg ha^{-1}	MSLA cm^2	NLPP -	LAI -	TDM kg ha^{-1}
Replications	2	-	-	-	-	-	-	-	-
Treatments	12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N sources (NS)	2	0.004	0.000	0.000	0.000	0.443	0.551	0.333	0.161
N rates (NR)	3	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000
NS x NR	6	0.002	0.073	0.005	0.004	0.000	0.117	0.001	0.152
Control vs. rest	1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Error I	24								
Genotypes (G)	2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NS x G	4	0.422	0.049	0.167	0.234	0.008	0.843	0.096	0.921
NR x G	6	0.050	0.000	0.000	0.005	0.000	0.064	0.000	0.071
NS x NR x G	12	0.714	0.344	0.695	0.112	0.000	0.209	0.000	0.494
Error II	52								
Total	116								

Where:
MSLA=mean single leaf area in cm^2
NLPP=number of leaves plant^{-1}
LAI=leaf area index
TDM=total dry matter in kg ha^{-1}
ns=non significant

Table 3. Control (N not applied) vs. rest (all N applied plots), N rate, N source and genotypes influence on MSLA, NLPP, LAI and TDM in maize grown on calcareous soil (mean effects).

Treatments	**1st Year**				**2nd Year**			
	MSLA cm^2	**NLPP -**	**LAI -**	**TDM kg ha^{-1}**	**MSLA cm^2**	**NLPP -**	**LAI -**	**TDM kg ha^{-1}**
Control	298.89	10.11	1.97	6429	320.33	11.11	2.35	8814
Rest	380.06	13.40	3.38	9962	417.06	13.70	3.79	11379
N rate (kg ha^{-1})								
50	353.15	11.78	2.72	8575	367.62	13.22	3.18	9729
100	335.11	13.00	2.86	9883	398.00	13.63	3.60	10929
150	418.37	14.48	3.97	10543	450.68	14.07	4.22	12187
200	413.59	14.33	3.96	10846	451.96	13.89	4.16	12669
LSD ($P \leq 0.05$)	**23.48**	**0.43**	**0.22**	**456**	**21.17**	**0.48**	**0.25**	**985**
N Fertilizer Source								
Urea	375.33	13.11	3.26	9472	414.81	13.72	3.78	11050
CAN	400.56	13.89	3.68	10352	423.62	13.81	3.87	11839
AS	364.28	13.19	3.20	10062	412.77	13.58	3.71	11247
LSD ($P \leq 0.05$)	**20.33**	**0.37**	**0.18**	**395**	**ns**	**ns**	**ns**	**ns**
Maize Genotypes								
Azam	349.03	12.13	2.80	8980	361.26	12.28	2.88	10123
Jalal	352.42	12.36	2.85	9651	401.47	12.58	3.30	11173
Pioneer-3025	438.72	15.53	4.48	11254	488.46	16.25	5.19	12841
LSD ($P \leq 0.05$)	**24.18**	**0.38**	**0.22**	**237**	**13.47**	**0.38**	**0.15**	**639**

Where:
MSLA = mean single leaf area in cm^2
NLPP = number of leaves plant^{-1}
LAI = leaf area index
TDM = total dry matter in kg ha^{-1}
ns = non significant

RESULTS AND DISCUSSIONS

Year effects

Mean single leaf area (MSLA), number of leaves per plant (NLPP), leaf area index (LAI), and total dry matter (TDM) were higher in 2nd than the 1st year (Table 3). The lower MSLA, NLPP, LAI and TDM of maize in first year could be due to less precipitation (350 mm in 2008) during the time of emergence and early growth stage of maize (Table 1). Moreover, irrigation water was not available in the first year of the experiment during the early growth of maize, and only less irrigation water was applied from the tube well. On the other hand, in the second year, the higher amount of rainfall during the early growth stage of maize (409 mm in July, 2010) had positive impact on the maize that might have been resulted in the higher MSLA, NLPP, LAI and TDM of maize in the second year. Aliu et al. (2009) in their field experiments found the highest value of LAI for maize inbred L7 (3.9) in 1st year and 4.0 in 2nd year, whereas the lowest LAI was noted for maize inbred L10 (2.52) in 1st year, while in 2nd year the lowest LAI (2.6) was obtained for inbred L8. Amanullah et al. (2007) found significant increase in LAI of maize “Azam” in 2002 (4.22) as compared to LAI in 2003 (3.79) because of the fluctuation in the precipitation of the two years. Lloyd et al. (1997) noted that increase in yield with N application at all sites. But at three sites (B6, B8 and C7), yield was greater with ammonium nitrate, while at two sites (B9 and C13) yield was greater with application of urea. Wang et al. (2007) earlier reported that understanding concepts of ideal soil fertility level and response to nutrient management provide practical guidelines for improving nutrient management under the variable rainfall conditions. While, Okalebo et al. (2006) suggested that site specific recommendations are needed for maize because of its differential response to nutrient inputs which varied widely within and across agro-ecological zones. According to Harold et al. (2006) maize N availability varied greatly from year to year based on weather conditions.

Nitrogen rates effects

Nitrogen rates had significant effects on all parameters under study in both years (Table 2). All the experimental plots treated with N had higher LAI than the control plots (N not applied) in both years (Table 3). Nitrogen application on N deficient soil increased both MSLA and NLPP of maize that resulted in the higher LAI as well as TDM. In both years, the MSLA, NLPP, and LAI increased significantly ($P \leq 0.05$) with increase in N rate up to 150 kg N ha^{-1} and further increase in N up to the highest 200 kg N ha^{-1} did not increased the parameters under study (Table 3). However, the highest TDM was obtained with the highest rate of 200 kg N ha^{-1} in both years. Although, the differences in TDM at 150 and 200 kg N ha^{-1} in both years were significantly not different from each other. Similarly, the differences in MSLA at 150 and 200 kg N ha^{-1} in 2nd year were significantly not different from each other. Our previous published research (Amanullah et al., 2007; Amanullah et al., 2009b) indicated that on N deficient soils in Northwestern Pakistan, the MSLA, NLPP, LAI and TDM in maize increased with application of higher N rates (120 and 180 kg ha^{-1}) as compared to the lower N rate (60 kg ha^{-1}). The increase in N level increased LAI (Amanullah et al., 2007) and showed positive relationship with increase crop growth rate and light interception (Amanullah et al., 2008). The increase in NLPP and leaf area $plant^{-1}$ increased TDM in maize (Amanullah et al., 2009b).

Nitrogen source effects

Nitrogen sources had significant effects on all parameters in 1st year but had no significant effects in 2nd year (Table 2). Application of CAN (calcium ammonium nitrate) produced significantly higher MSLA, NLPP, LAI and TDM than urea and AS (ammonium sulphate) in the 1st year (Table 3). The higher MSLA, NLPP, LAI and TDM produced with CAN than other two fertilizers in 1st year probably may be due to the less rainfall (345 mm) because CAN was better N-fertilizer source under moisture stress condition than other two N-fertilizers. In the 2nd year, the higher rainfall (538 mm) probably had the same positive impact on the performance of all three N-fertilizers sources and so the differences in all the parameters under study were statistically not different from each other. According to Chien et al. (2011), AS is the best N-fertilizer source which contains frees sulfur and had many potential agronomic and environmental benefits over urea and ammonium nitrate. In Northwestern Pakistan where most of the soils are calcareous in nature, AS because of its free sulfur content, could be the most beneficial N-fertilizer in terms of reducing soil pH and increasing seed oil content (data not shown). However, because of its (AS) highest N cost (1.43 and 1.91 USD kg^{-1} N in 1st and 2nd year, respectively; one USD = 100 PKR) as compared to other sources of N i.e. CAN (0.77 and 0.97 USD kg^{-1} N in 1st and 2nd year, respectively) and urea (0.44 and 0.56 USD kg^{-1} N in 1st and 2nd year, respectively) the poor maize growers in the region can’t afford to use AS. Moreover, the transportation charges of AS was more than urea and CAN. Lloyd et al. (1997) reported that urea (200 USD per ton) is a less expensive form of N fertilizer than ammonium nitrate (260 USD per ton). However, urea has been considered to be less effective than other N fertilizers, due to N loss by ammonia volatilization, especially when used on soils of high pH or low CEC (Terman, 1979). Our previous research work (Amanullah et al., 2010b) on maize regarding the MSLA, NLPP and LAI response to phosphorus (P) fertilizers sources indicated that plots applied either with DAP (Di-ammonium phosphate) or SSP (single super phosphate) were better in terms of LAI and TDM accumulation as compared to the application of nitrophos (NP) and control plots (P not a). The increase in the LAI and TDM in maize was attributed to the increase in the leaf area with application of SSP or DAP as compared to smaller leaf area with application of NP (nitrophos) and in the zero-P control plots. Lloyd et al. (1997) noted that increase in yield with N application at all sites. But at three sites (B6, B8 and C7), yield was greater with ammonium nitrate, while at two sites (B9 and C13) yield was greater with application of urea. In some area with higher soil pH, AS because of its residual acidity, has been discontinued, and therefore not recommended (Kurtz, 2004). The advantages of AS include its low hygroscopicity and source of both N (21%) and S (24%), and strongly acid forming reaction in soil can be advantageous in high pH soils and can be more economical N fertilizer source where S is required (Halvin et al., 2009). In some other areas, the most widely used N source was CAN, due to its very low residual acidity, and calcium content (10 %) which particularly, in the savanna areas helps to neutralize soil acidity (Sas, 2006). Amanullah et al. (2013) reported that all foliar application of various N-sources (urea, CAN, and AS) had significantly produced higher biomass yield (TDM) than control (water spray only). But among the N source, urea (9283 kg ha^{-1}) and AS (9254 kg ha^{-1}) produced higher biomass yield than CAN (8703 kg ha^{-1}) and control (7973 kg ha^{-1}).

Genotypes effects

The maize hybrid (P-3025) had significantly ($P \leq 0.05$) higher MSLA, LAPP, LAI and TDM than the two local cultivars (Azam and Jalal) in both years (Table 3). Between the two local cultivars, Jalal had relatively higher MSLA, NLPP, LAI and TDM than Azam, but the differences were statistically not different. The possible reason of higher LAI and TDM in case of P-3025 was attributed to its more MSLA and NLPP. Moreover, the P-3025 had delayed maturity, taller plants and higher leaf area $plant^{-1}$ than the two local cultivars (unpublished data). This two years study confirmed that maize hybrid was more efficient in terms of LAI and TDM accumulation because its more NLPP, higher MSLA, leaf area $plant^{-1}$ and its more DM partitioning than the local cultivars. Difference in the LAI of maize genotypes were earlier reported by Aliu et al. (2009) and Subedi and Ma (2005). Fageria et al. (2008) suggested that in the 21st century, nutrient efficient plants will play a major role in increasing crop yields compared to the 20th century, mainly due to limited land and water resources available for crop production, higher cost of inorganic fertilizers, declining trends in crop yields globally, and increasing environmental concerns. Baligar et al. (2001) reported that efficiency of acquisition, transport and utilization of nutrients varies with crop species and genotype/cultivar within species, and their interactions with the environment. Differential response of maize genotypes regarding leaf area index has also been reported earlier by Azadgoleh and Kazmi (2007) and Luque *et al.* (2006). Differences in N use efficiency, harvest index, economic yield and net returns in different maize genotypes was also reported by Mkhabela et al. (2001) and (Hokmalipour et al., 2010). The cultivar Korduna which had the highest harvest index, kernels number/row, kernels number/ear and weight of 1000 kernels gained the highest NUE. In Brazil, Carvalho et al. (2012) concluded from their study on 21 maize genotypes, the three promising genotypes viz. GEN 03, GEN 10 and GEN16 were considered the most efficient genotypes in terms of agronomic N use efficiency and yield.

Nitrogen source x rates

Interaction of NS x NR (N source into rates) had significant effects ($P \leq 0.05$) on MSLA, in both years (Table 2). The MSLA increased to maximum with CAN at N1, and with urea at N3 in both years (Fig 1a). At N4, the MSLA increased with AS in both years, while CAN in the 1st year (Fig 1a). The NLPP were not affected by NS x NR in both years (Table 2) which is clear from Fig 1b. Interaction of NS x NR had significant effects ($P \leq 0.05$) on LAI in both years (Table 2). Likewise MSLA, the LAI increased with CAN at N1 in both years (Fig 1c). Urea and CAN increased LAI than AS when applied at N4; on the other hand, urea and CAN were best in terms of LAI at N3 (Fig 1c). The TDM varied significantly only in the first year but not in the second year (Table 2). In year one, CAN and AS had higher TDM than urea at N1 and N2, and CAN at N3 and N4 (Fig 1d). The increase in TDM with application of CAN and AS may be due to the increase in MSLA and LAI. Abayomi et al. (2006) reported that N application had greater improve leaf growth and hence yield of maize. Fageria et al. (2011) found that the higher and lower N rate of AS produced higher LAI and most of the plant growth and yield components, while the intermediate N rates (125 to 275 mg N kg^{-1}) of urea was slightly better compared to AS for grain production. The discrepancies in our results and that of Fageria et al. (2011) was due to the differences in the crop species used, amount of N sources applied, and the climatic conditions.

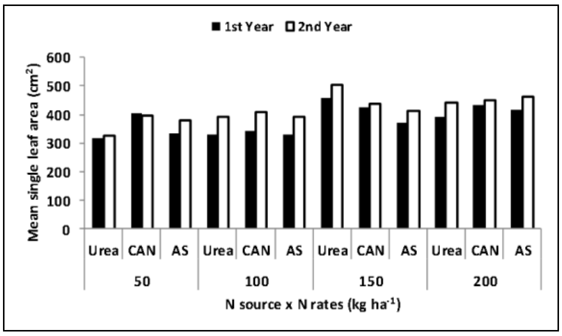

Figure 1a. Interactive effects of N source x N rates on the mean single leaf area (cm^2) of maize grown on calcareous soil

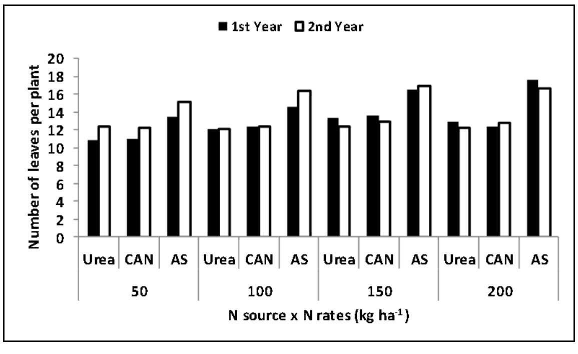

Figure 1b. Interactive effects of N source x N rates on the number of leaves $plant^{-1}$ of maize grown on calcareous soil

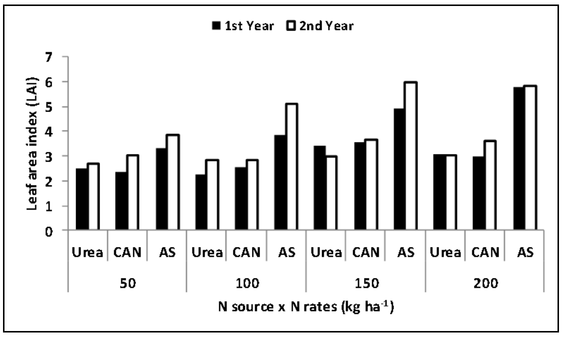

Figure 1c. Interactive effects of N source x N rates on the leaf area index of maize grown on calcareous soil

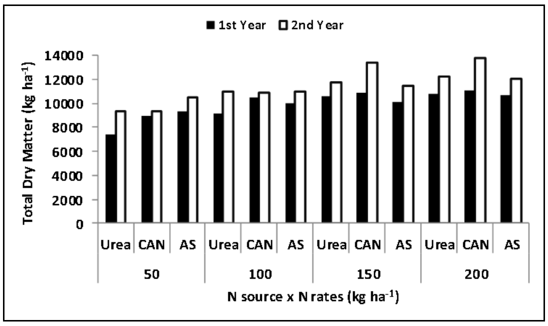

Figure 1d. Interactive effects of N source x N rates on the total dry matter (kg ha^{-1}) of maize grown on calcareous soil

Nitrogen Rates x Genotypes

Interaction of NR x G (N rates into genotypes) had significant effects ($P \leq 0.05$) on MSLA in both years (Table 2). The MSLA increased to maximum in genotype (P3025) at all four levels of N as compared with the two local cultivars (Fig 2a). The MSLA in the local cultivars increased up to N3 and further increase in N decreased it. On the other hand, the MSLA increased with N4 than N3 in year one, but it was statistically at par with each other in year two when applied with N3 or N4 (Fig 2a). The NLPP were significantly affected by NR x G in year one but not in year two (Table 2). In year one, the NLPP in the local cultivars increased up to N3 and further increase in N decreased it. On the other hand, the NLPP increased significantly with N4 than N3 in the 1st year, but it was statistically the same with each other in the 2nd year when applied with N3 or N4 (Fig 2b). Interaction of NS x NR had significant effects ($P \leq 0.05$) on LAI in both years (Table 2).

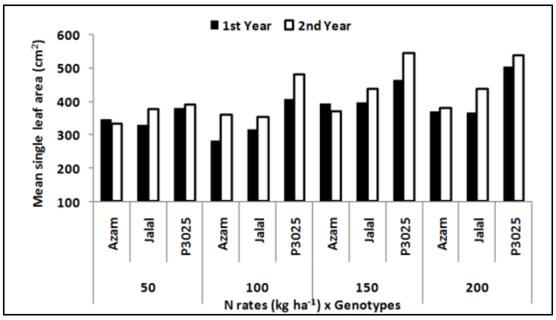

Figure 2a. Interactive effects of N rate x genotypes on the mean single leaf area (cm^2) of maize grown on calcareous soil

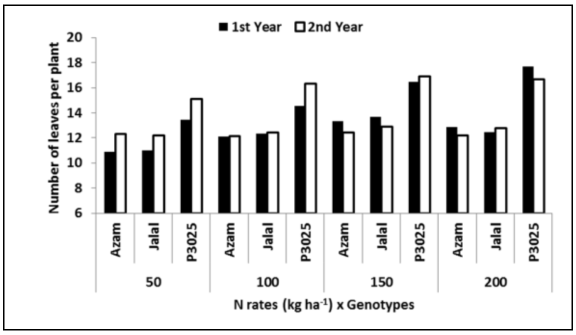

Figure 2b. Interactive effects of N rate x genotypes on the number of leaves plant^{-1}of maize grown on calcareous soil

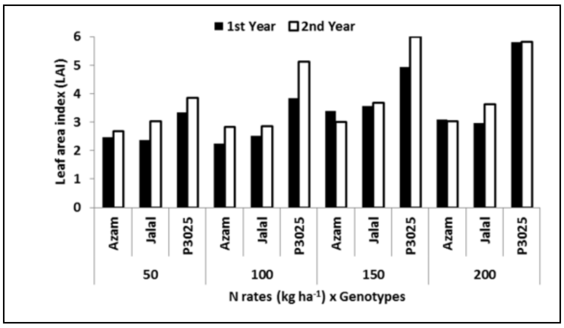

Figure 2c. Interactive effects of N rate x genotypes on the leaf area index of maize grown on calcareous soil

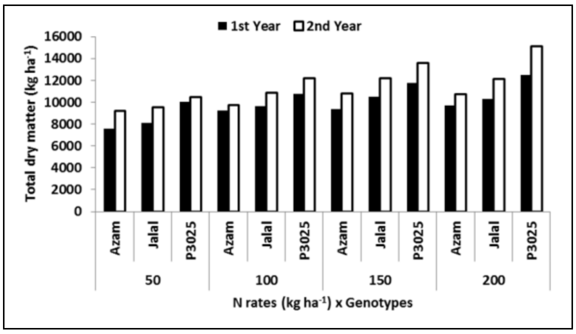

Figure 2d. Interactive effects of N rate x genotypes on total dry matter (kg ha^{-1}) of maize grown on calcareous soil

Likewise MSLA and NLPP, the LAI increased to maximum in genotype (P3025) at all four levels of N as compared with the two local cultivars (Fig 2c). The LAI in the local cultivars was highest at N3 and further increase or decrease in N decreased LAI. In the 1st year, the LAI in P3025 increased significantly wit increase in N rate up to N4, but in the second year the LAI in P3025 increased up to N3 and then decreased with further increase in N up to N4 (Fig 2c). Interaction of NS x NR had significant effects ($P \leq 0.05$) on TDM in year one and not in year two (Table 2). The TDM was generally higher in the 2nd year than 1st year and showed positive relationship with MSLA, NLPP and LAI. In the 1st year, the P3025 had higher TDM than the two local cultivars at all four levels of N. At the two lower N rates (N1 and N2) the TDM of the two local cultivars was almost the same, but at the two higher rates (N3 and N4) the TDM of Jalal was greater than Azam (Fig 2d). Frank et al. (2004) found a significant cultivar × N rate interaction at all sites for turfgrass visual quality and color, and that these ratings decreased with decrease in N rates. Amanullah et al. (2012) reported that the higher average yield in the Punjab Province than Khyber Pakhtunkhwa Province in Pakistan is due to the use of hybrid maize and efficient fertilizer use by the farmers in Punjab than Khyber Pakhtunkhwa. Wu et al. (2010) reported that the higher rates of N were not necessary for the tall fescue [*Schedonorus phoenix* (Scop.) Holub] that resulted in increased nitrate leaching.). In Indonesia, among the four genotypes tested showed significant interaction of genotypes into N rates on N uptake efficiency was observed and the highest N uptake efficiency was attained by Bisma, followed by Pioneer and Arjuna, while Madura local had the least N uptake efficiency in all rates of N fertilizer (Rahman and Koentjoro, 2011). Thus, genotypes with differences in yield potential may have differences in N accumulation and NUE (Sinclair and de Wit, 1975). Abayomi et al. (2006) found that N rates had greater impact on the yield of maize than genotypes effects. They reported that yield increased while increasing N rates among all maize genotypes, and the increase was more due to the increase in leaf growth with increasing N rates.

Nitrogen source x genotypes

Interaction of NS x G (N source into genotypes) had significant effects ($P \leq 0.05$) on MSLA in the 2nd year and not in the 1st year (Table 2). The MSLA increased to maximum in genotype (P3025) at all three sources of N as compared with the two local cultivars (Fig 3a). In the 2nd year of the experiment, the MSLA in the P3025 was statistically the same with each other at all three sources of N. The local cultivar “Jalal” had higher MSLA than “Azam” when applied with CAN. There were no significant differences in the MSLA of Azam and Jalal with application of urea and AS (Fig 3a). Amanullah et al. (2013) reported that foliar application of various N-sources (urea, CAN, and AS) had no significant effect on the MSLA of maize. In contrast to MSLA, the NLPP were significantly affected by NR x G in the 1st year but not in the 2nd year (Table 2). The NLPP increased to maximum in genotype (P3025) at all three sources of N as compared with the two local cultivars (Fig b. The two local cultivars “Jalal and Azam” produced similar NLPP at all three sources of N (Fig 3b). Interaction of NS x G (N source into genotypes) had no significant effects ($P \leq 0.05$) on LAI in both years (Table 2). The LAI increased to the highest level in genotype (P3025) at all three sources of N as compared with the two local cultivars (Fig 3c).

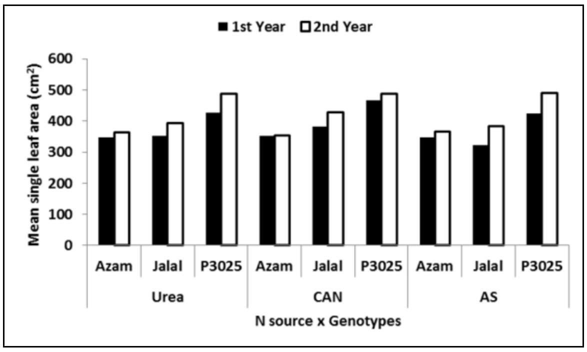

Figure 3a. Interactive effects of N source x genotypes on the mean single leaf area (cm^2) of maize grown on calcareous soil

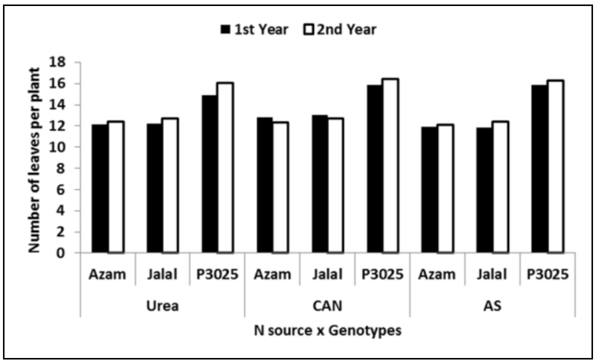

Figure 3b. Interactive effects of N source x genotypes on the number of leaves plant^{-1} of maize grown on calcareous soil

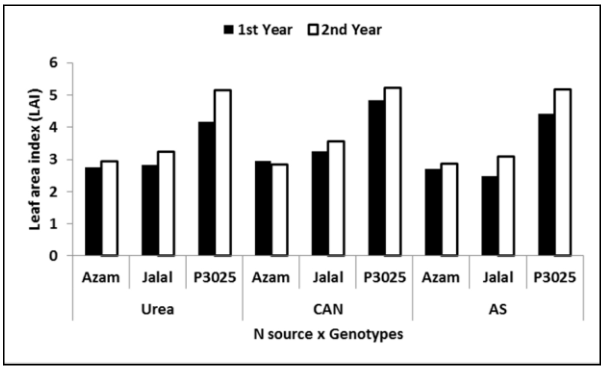

Figure 3c. Interactive effects of N source x genotypes on the leaf area index of maize grown on calcareous soil

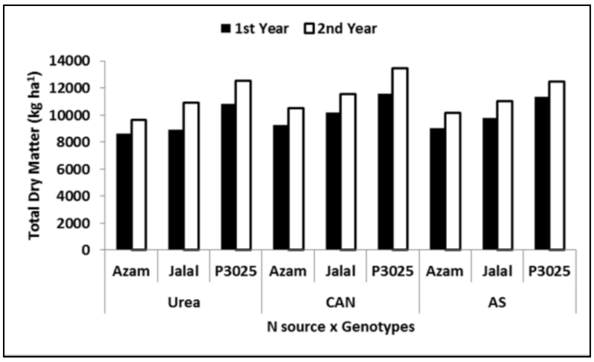

Figure 3d. Interactive effects of N source x genotypes on the total dry matter (kg ha^{-1}) of maize grown on calcareous soil

In the 2nd year of the experiment, all the genotypes produced higher LAI with different N sources than in 1st year (Fig 3c). Interaction of NS x G (N source into genotypes) had no significant effects ($P \leq 0.05$) on TDM in the two years (Table 2). However, the TDM increased to the highest level in genotype (P3025) at all three sources of N as compared with the two local cultivars (Fig 3d). The TDM was generally higher in the 2nd year than in 1st year (Fig 3d). Frank et al. (2004) found a significant cultivar × N rate interaction at all sites for turf grass visual quality and color, and that these ratings decreased with decrease in N rates. Wu et al. (2010) reported that among the N sources, slow-release N fertilizers were better for the tall fescue because of less nitrate leaching than the fast-release N sources. The higher TDM in the hybrid maize in this study was attributed to its higher LAI than the two local varieties. Amanullah et al. (2008) reported that the higher LAI in maize intercepted more light and increased the biomass in maize.

CONCLUSIONS

The results of this study confirmed the existence of significant variability in MSLA, NLPP, LAI and TDM accumulation among different maize genotypes depending on the base of their inheritance, differences in N-fertilizer source and rates as well as differences in the weather conditions in the two years. The decline in price of AS could make it most profitable and beneficial N-fertilizer source on calcareous soils with high pH because its free available sulfur (24 % S) is important for improving crop growth, increasing LAI and TDM. The decline in CAN price could also make it more beneficial N fertilizer source for improving growth and yield on acidic soils and/or soils having Ca deficiency. However, the favorable manufacturing, handling, storage, low transportation charges, marketing, easy availability and low N cost make urea the most competitive and beneficial N fertilizer source in terms highest net returns (unpublished data). Growing maize hybrid could increase maize productivity, grower's income, and N use efficiency (unpublished data) due to its higher MSLA, NLPP, LAI and TDM. The higher LAI of maize hybrid in this study was attributed to increased MSLA and NLPP indicating that leaf characteristics are the most important criteria for selection maize genotypes for higher LAI and TDM accumulation. The variation LAI and TDM in the two years of studies was attributed to the fluctuation in weather conditions. This problem poses a challenge for the development of technical recommendations targeted for diverse environments. In the light of the research results, ammonium sulphate was considered the most suitable N-fertilizer source for improving growth and total dry matter of maize under calcareous soils. Application of N at the rate of 200 kg ha^{-1} was recommended for the high yielding hybrid maize but 150 kg N ha^{-1} was most suitable for the low yielding local cultivars in the study area.

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