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MAIZE HYBRIDS RESPONSE TO NITROGEN RATES AT MULTIPLE LOCATIONS IN SEMIARID ENVIRONMENT

T. KHALIQ[1*], A. AHMAD, A. HUSSAIN AND M.A. ALI[2]

[1]Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan
[2]Directorate of Agriculture (EXT. & AR), Agriculture House, Lahore, Pakistan.

Abstract

Productivity and resource use efficiency are critical issues in sustainable agriculture, especially in high-demand resource crops such as maize. The aim of this research was to compare maize hybrids and nitrogen fertilization rates, evaluating growth, yield and yield components under varying environments. Two year field experiments were carried out at Faisalabad, Sargodha and Sahiwal districts of Punjab, Pakistan. Three maize hybrids were subjected to five nitrogen levels (150, 200, 250, 300 and 350 kg N ha^{-1}). The results indicated a large yearly variability, mainly due to more rainfall during growing season 2005 at all sites. Maize hybrids had significant effect for all the variables under study, except for plant population. Hybrid Bemasal-202 out yielded at all sites by 23 to 35% than hybrid Monsanto-919. Nitrogen rates affected number of grains m^{-2}, 1000-grain weight, grain yield, total dry matter and harvest index with significant differences among nitrogen rates at all sites. The effect of nitrogen availability was amplified at 300 kg N ha^{-1}at all sites. The response of hybrids was different under varying environments. It was concluded that selection of best suited hybrid for each location can increase maize yield at 300 kg N ha^{-1} in semiarid irrigated conditions.

Introduction

The future prosperity and economic stability of Pakistan mainly depends upon the quantum of material resources and their judicious exploitation and utilization especially in agriculture. The population of Pakistan is increasing at an alarming rate of 2.6% per annum (Anon., 2008). Therefore, there is dire need for advanced planning and research to increase food production and improve quality in order to ensure food security of the country.

In Pakistan, maize occupies third position after wheat and rice and Punjab is the major producing province. It is grown on an area of 1017 thousand hectares with an annual production of 3088 thousand tons of grains, and average yield of 3036 kg ha^{-1} (Anon., 2008). This yield level is low compared to the biological potential of the existing maize hybrids.

Chemical fertilizers play an important role in maintaining and enhancing soil productivity in intensive agriculture. Amongst the nutrients, nitrogen is mostly deficient in cultivated soils of world while it plays a central role in plant growth as an essential constituent of cell components. Consequently a deficiency in the supply of nitrogen has a profound influence on grain yield. Numerous studies have shown the effects of N supply on leaf area index (LAI), plant height, shoot weight, plant N uptake, potential kernel set and grain yield (Muchow, 1988; McCullough *et al.*, 1994; Waraich *et al.*, 2007) and its application rates vary widely from field to field (Cerrato & Blackmer, 1991; Schmitt & Randall, 1994; Bundy & Andraski, 1995).

Corresponding author's e-mail: tasneem1056@hotmail.com: +92-333-8397076

Astute N management optimizes grain yield, farm profit and N use efficiency while it minimizes the potential for leaching of N beyond the rooting zone. Efficiency of use of applied N is variable, with a mean of only 33% of applied N recovered by cereal crops (Raun & Johnson, 1999). Nitrogen dynamics and crop response to N also vary with soil properties and weather (Eghball & Varvel, 1997; Sogbedji *et al.*, 2001; Kay *et al.*, 2006). Weather may influence availability of organic nitrogen, extent of leaching and denitrification, crop uptake and residual nitrogen at the end of growing season. Sogbedji *et al.*, (2001) found that variation in early season precipitation was the cause of yearly variation in yield response of maize to nitrogen fertilizer. Wienhold *et al.*, (1995) found that increasing nitrogen application enhanced 60% yield when the growing season was warm as compared cool weather. Derby *et al.*, (2005) reported that cool and wet years had poor productivity as compared to years with warm growing season.

The existing recommended dose of nitrogen 200 kg ha^{-1} for hybrid maize production is low for Pakistani soils, which are under high cropping intensity, very low in organic matter and deficient of nitrogen. High temperature in the area during maize cropping season also adds in volatilization losses of nitrogen. These recommendations are also much generalized. A better understanding of the factors affecting maize yield and crop response to N fertilizer is required for efficient use of nitrogen. Keeping in view this research was planned to provide an insight into the dynamic relations between climate and management options to assist in the optimization of N application for maize hybrids under different ecological zones of Pakistan.

Materials and Methods

Site and soil: A field study were conducted at Faisalabad (31.25°N, 73.04°E, 184.4m), Sargodha (32.04°N, 72.67°E, 188m) and Sahiwal (30.40°N, 73.06°E, 172m) districts of Punjab province during 2004 and 2005. Plains of Punjab fall in semiarid subtropical climatic zone and had world's largest canal irrigation system while its soils are deficient in nitrogen. Additional information regarding site and soil are given in Table 1.

Weather: Standard weather data were recorded for each site using nearest weather observatories set up in about one km area around the experimental sites. Each station recorded the daily maximum and minimum air temperature (ºC), rainfall (mm) and daily sunshine hours (h).

Soil analysis: Composite soil samples to a depth of 30 cm were obtained from the experimental sites with soil Auger prior to sowing of crop. Soil analysis showed that all the three sites had pH near 8.0 and were rated as deficient in the main elements like N, P and K, etc. At Faisalabad and Sargodha soils were sandy clay loam and silty loam in texture, respectively with well drained, moderately calcareous and alkaline characteristics, whereas at Sahiwal the soil was silt loam in texture, moderate to strongly calcareous and strongly alkaline in nature.

Design and treatments: The experiment was laid out in split plot design with four replications. The net plot size was 4.2 m x 10 m. Three maize hybrids i.e., Bemasal-202, Monsanto-919 and Pioneer 31-R-88 were planted in the main plots while 5 nitrogen levels 150, 200, 250, 300, 350 Kg N ha^{-1} were randomized in sub plots.

Table 1. Characteristics of experimental sites.

Location	Climatic zone	Soil series	USDA classification	Soil pH	OM (%)
Faisalabad	Dry semi-arid	Lyallpur	Coarse-silty, mixed, hyperthermic typic Calciargids	7.68	1.36
Sargodha	Arid	Bhalwal	Fine-silty, mixed, hyperthermic typic Calciargids	7.84	1.16
Sahiwal	Wet semi-arid	Khurrianwala	Coarse-silty, Mixed, hyperthermic Calcic Aquisalid	8.09	0.98

Table 2. Crop husbandry operations for the experiments during growing season.

Operations	Faisalabad		Sargodha		Sahiwal	
	2004	2005	2004	2005	2004	2005
Sowing dates	11.08.04	03.08.05	9.08.04	08.08.05	12.08.04	05.08.05
Cultivars	Bemasal-202, Monsanto-919, Pioneer-31-R-88					
Nitrogen (Urea)	Nitrogen was applied in three doses in all treatments					
1st Dose	11.08.04	03.08.05	09.08.04	08.08.05	12.08.04	05.08.05
2nd Dose	26.08.04	18.08.05	24.08.04	22.08.05	27.08.04	20.08.05
3rd Dose	30.09.04	24.09.05	28.09.04	27.09.05	02.10.04	27.09.05
Harvesting date	27.11.04	16.11.05	02.12.04	26.11.05	05.12.04	29.11.05

Crop husbandry: The seeds were planted during the month of August on 70 cm spaced ridges and a plant spacing of 20 cm, using a seeding rate of 25 kg ha^{-1}. Phosphorus and potassium were applied @100 kg ha^{-1} in all plots at time of planting as TSP and SOP, respectively. These fertilizers were broadcast and incorporated at the time of seedbed preparation. Nitrogen fertilizer i.e., Urea was applied in three equal splits. 1/3rd dose of each treatment was applied at time of planting. After 15 days of planting 2nd dose of nitrogen was applied to the crop, while third part of each treatment was applied at the time of tasseling (Table 2). At all sites crop was irrigated with canal water. First irrigation was applied just after planting the seeds and subsequent irrigations were applied on weekly bases up to flowering. Irrigation interval was enhanced to 15 days after flowering. All other cultural practices such as thinning, hoeing and plant protection measures were kept normal for the crop at all sites.

Sampling strategy: After 15 days of planting sampling was started. One meter long row from each plot was harvested at ground level after 10 days interval leaving appropriate borders. Plants were separated into components and fresh weight for each fraction (leaf, stem, tassel and cob) was determined. A sub-sample (10 g) of each fraction was taken and dried in an oven to a constant weight. Leaf area was recorded by taking 10g fresh leaves from harvested material at each 10 day interval. An area meter (Licor model 3100) was used for measurement. From these measurements of leaf area and dry weights, leaf area index and total dry matter (TDM; g m^{-2}) were calculated at each harvest. At final harvest two central rows with a length of 10 m for each plot were harvested. A sub-sample of 10 plants was taken to determine the yield components. All cobs including sub sample were thrashed mechanically to estimate grain yield (GY) of entire plot and converted into t ha^{-1}. To determine grain moisture, the sub sample of 250 g was weighed, dried and again weighed. Final yield was corrected to 0% moisture. Data collected on growth, yield and yield components were analyzed statistically and significance of treatment means was tested using least significant difference test at 5% probability level. Pooled analysis was carried out within location across years/seasons (Gomes & Gomes, 1984).

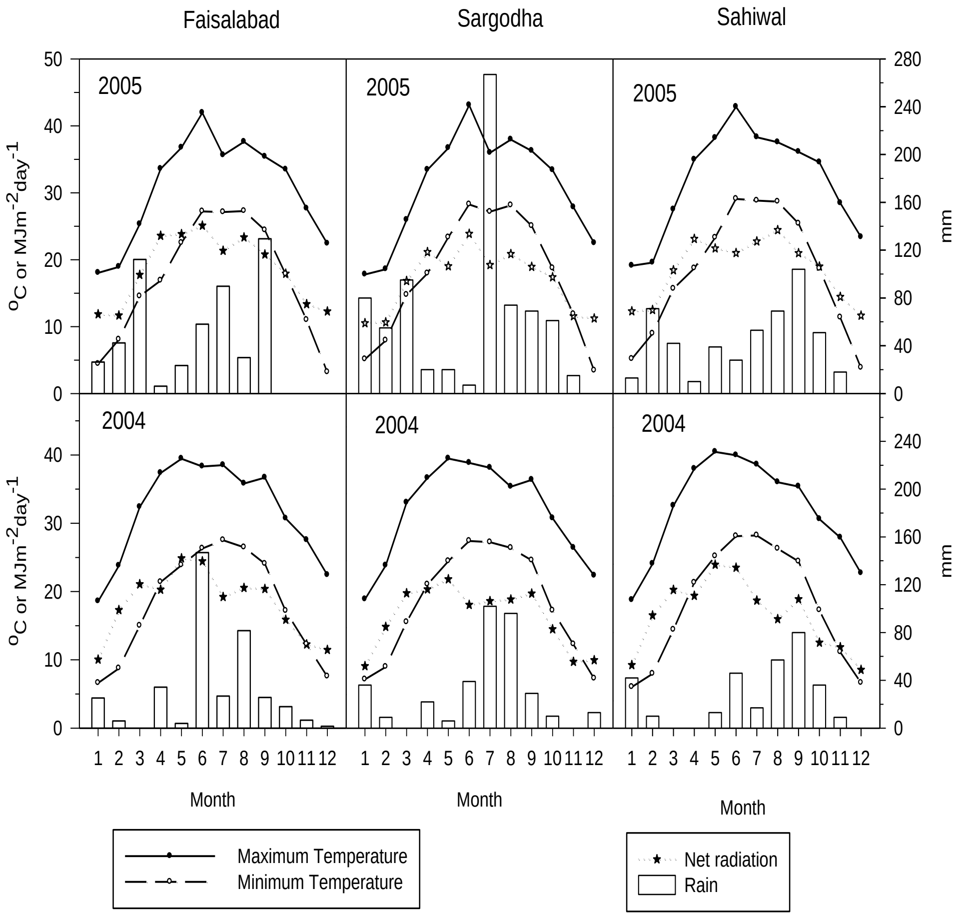

Fig. 1. Average monthly maximum and minimum air temperature, solar radiation and total monthly rainfall at the experimental sites.

Results and Discussion

A summary of weather data for 2004 and 2005 is presented in Fig. 1. During both growing seasons Sahiwal was relatively hotter than Sargodha and Faisalabad with a mean temperature of 1-2°C. Sargodha was slightly warmer than Faisalabad by 0.5-1°C. However, the temporal variation of the average temperature was similar for all three sites: the temperature was higher from August to October and then decreased towards maturity of the crop. Precipitation occurred during the monsoon from July to September and varied for all three sites during growing seasons: in 2004, rainfall for Faisalabad was lower e.g., 133.5 mm for Sargodha, e.g., 148 mm and Sahiwal, e.g., 182 mm. Comparable rainfall for Faisalabad was 159 mm, for Sargodha 219 mm and Sahiwal, 242 mm in 2005. Radiation levels were generally close to the long term means during both the seasons.

Leaf area index: LAI values steadily increased till 55 DAS at all the locations, thereafter LAI declined in all the treatments and reached its minimum values less than 2.5 by 105 DAS (Figs. 2 and 3). Such reduction in LAI was more pronounced at lower N levels (150 and 200 Kg ha^{-1}) than high N levels due to early senescence of leaves in former than the latter.

The season had significant effects on maximum LAI at all the locations, throughout the growth. Crop had greater LAI in 2005 as compared to 2004 and maximum values reached at 4.74, 4.66 and 4.60 at Faisalabad, Sargodha and Sahiwal, respectively. Equivalent LAI values were 4.70, 4.71 and 4.29, respectively (Figs. 2 and 3).

Cultivar differences in maximum LAI development were non-significant at Sargodha but were found significant at Faisalabad and Sahiwal. Averaged over locations the maximum LAI value (4.67) was registered from hybrid Pioneer-31-R-88 that was statistically at par with hybrid Bemasal-202 that had LAI 4.59. The minimum LAI (4.58) was recorded in case of Monsanto-919.

Maximum LAI was significantly affected by nitrogen levels at all sites. The trend was also similar at all sites (Figs. 2 & 3). Averaged over locations, peak LAI reached to a value 5.09 at 55 DAS in the N_4 (300 kg N ha^{-1}) treatments that was at par with N_5 (350 kg N ha^{-1}) treatments at all locations that gain maximum LAI (5.02). N_3 (250 kg N ha^{-1}) treatment had maximum LAI (4.73) that was statistically greater than N_2 (200 kg N ha^{-1}) the standard treatment producing maximum LAI (4.32). Statistically minimum value for peak LAI (3.93) was recorded in N_1 (150 kg N ha). Greater LAI could be attributed to significant increases in leaf expansion i.e., length and breadth due to high N levels. Greater leaf expansion in maize was ascribed to higher rate of cell division and cell enlargement by Wright (1982). Similar effects of N on maize LAI has been reported by D'Andrea *et al.*, (2006). Generally LAI increased up to 55 DAS when tasseling was started thereafter, LAI declined until final harvest (Figs. 2 and 3).

Overall, mean values of maximum LAI were 4.72, 4.69 and 4.46 at Faisalabad, Sargodha and Sahiwal, respectively. Higher LAI at Faisalabad was due to lower mean temperature and more rainfall as compared to other sites, during vegetative growth period (August and September) especially in 2005 (Fig. 1).

Seasonal dry matter accumulation: Total dry matter (TDM) production increased steadily after crop establishment until maturity in all the treatments (Figs. 4 & 5). Year effect on TDM accumulation of maize was significant. The crop accumulated more TDM during 2005 than 2004 (Table 4). Cultivars significantly affected TDM at all sites (Fig. 4). Hybrid Bemasal-202 and Pioneer 31-R-88 accumulated statistically non significant TDM through out the season, while hybrid Monsanto-919 accumulated statistically lesser TDM than other hybrids. Averaged over locations, maximum TDM was 1798 g m^{-2} accumulated by Bemasal-202 followed by Pioneer-31-R-88 that produced TDM 1758 g m^{-2} as compared to 1682 g m^{-2} by Monsanto-919 at final harvest (105 DAS).

Generally TDM production responded positively to N application. Figure 5 showed that averaged over locations, maximum TDM accumulated to a value 1891 g m^{-2} at 105 DAS in the N_4 (300 kg N ha^{-1}) treatment that was at par with N_5 (350 kg N ha^{-1}) treatment at all locations that accumulated maximum TDM (1868 g m^{-2}). N_3 (250 kg N ha^{-1}) treatment produced maximum TDM (1784 g m^{-2}) that was statistically greater than N_2 (200 kg N ha^{-1}) the standard treatment producing maximum TDM (1665 g m^{-2}). Statistically minimum value for final TDM (1524 g m^{-2}) was recorded in N_1 (150 kg N ha^{-1}). The increase in TDM with higher level of nitrogen was due to better crop growth, which gave maximum plant height, LAI and ultimately produced more biological yield.

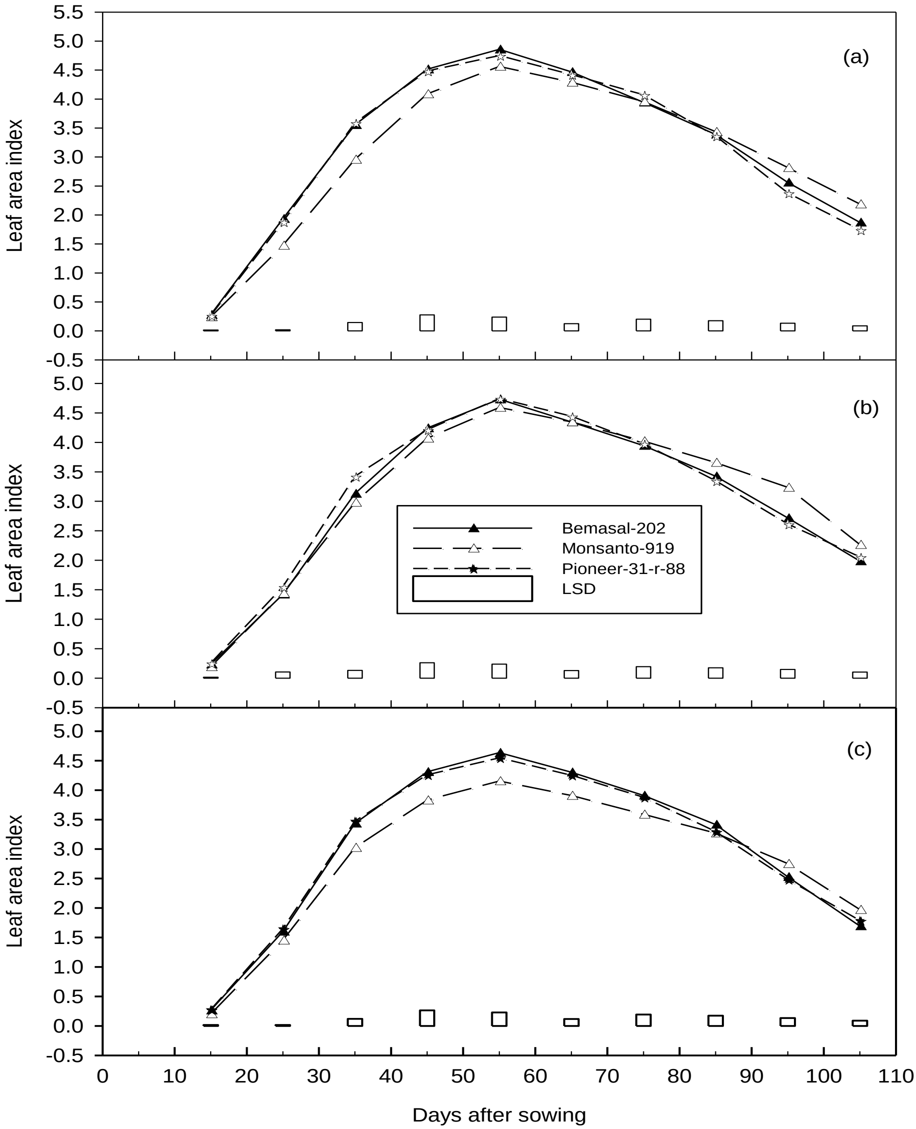

Fig. 2. Change in two years pooled leaf area index of different hybrids with time at (a) Faisalabad (b) Sargodha and (c) Sahiwal Bars represent LSD at 5%.

Overall, mean values of final TDM were 1761, 1797 and 1681 g m^{-2} at Faisalabad, Sargodha and Sahiwal, respectively. High values of TDM at Faisalabad and Sargodha were due to optimum climatic conditions i.e. lower mean temperature and more rainfall as compared to Sahiwal during vegetative growth period. Sahiwal faced high temperature during this period which was the reason of higher evapotranspiration losses and ultimately poor growth. Moreover, soil salinity (Table 1) stunted the crop growth at Sahiwal.

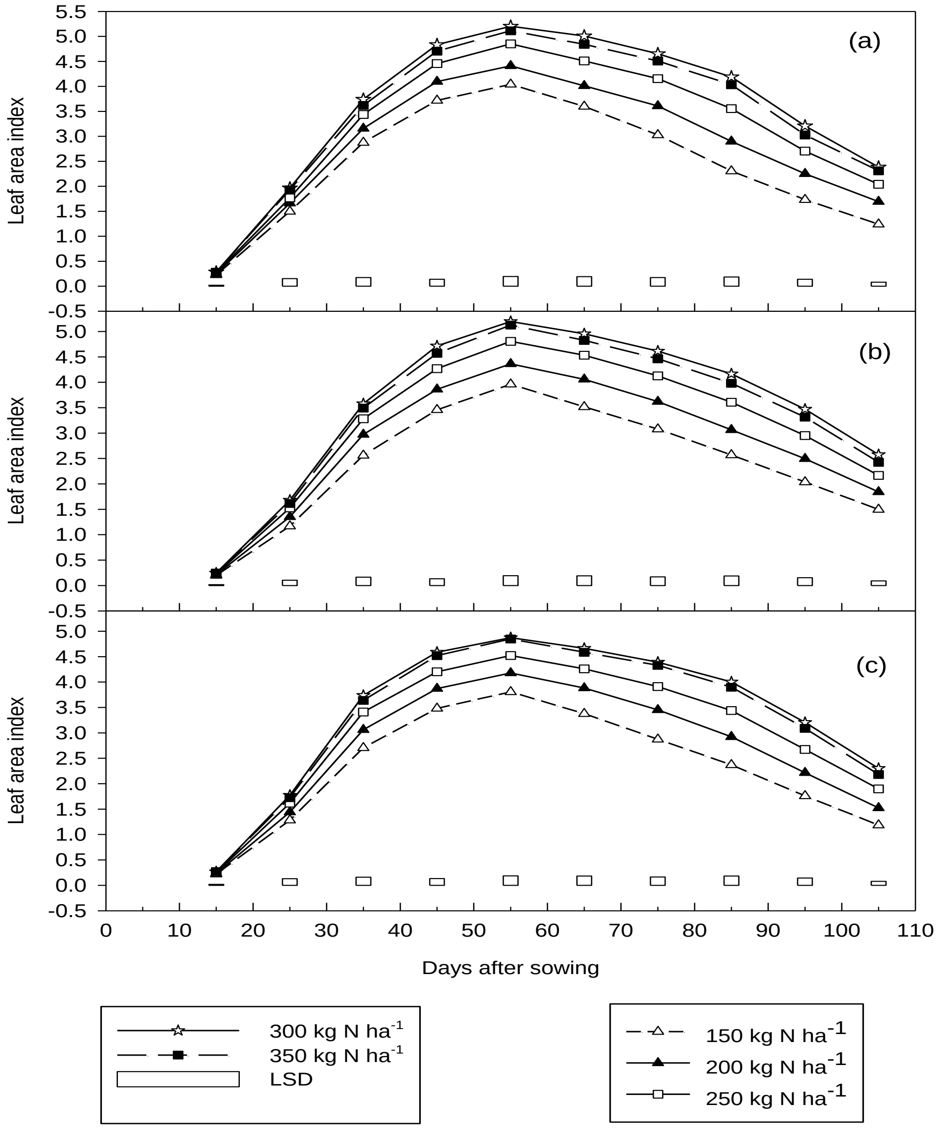

Fig. 3. Change in two years pooled leaf area index in response of N rates with time at (a) Faisalabad (b) Sargodha and (c) Sahiwal Bars represent LSD at 5%.

Components of yield

Plant population m^{-2} at harvest: Seasonal effect on plant population m^{-2} at harvest was non significant at all locations and it was 6.93 and 6.90 plants m^{-2} during 2004 and 2005, respectively (Table 3). Hybrid differences in plant population m^{-2} were non-significant. Averaged from the three locations, mean plant population m^{-2} was 6.92 in all hybrids.

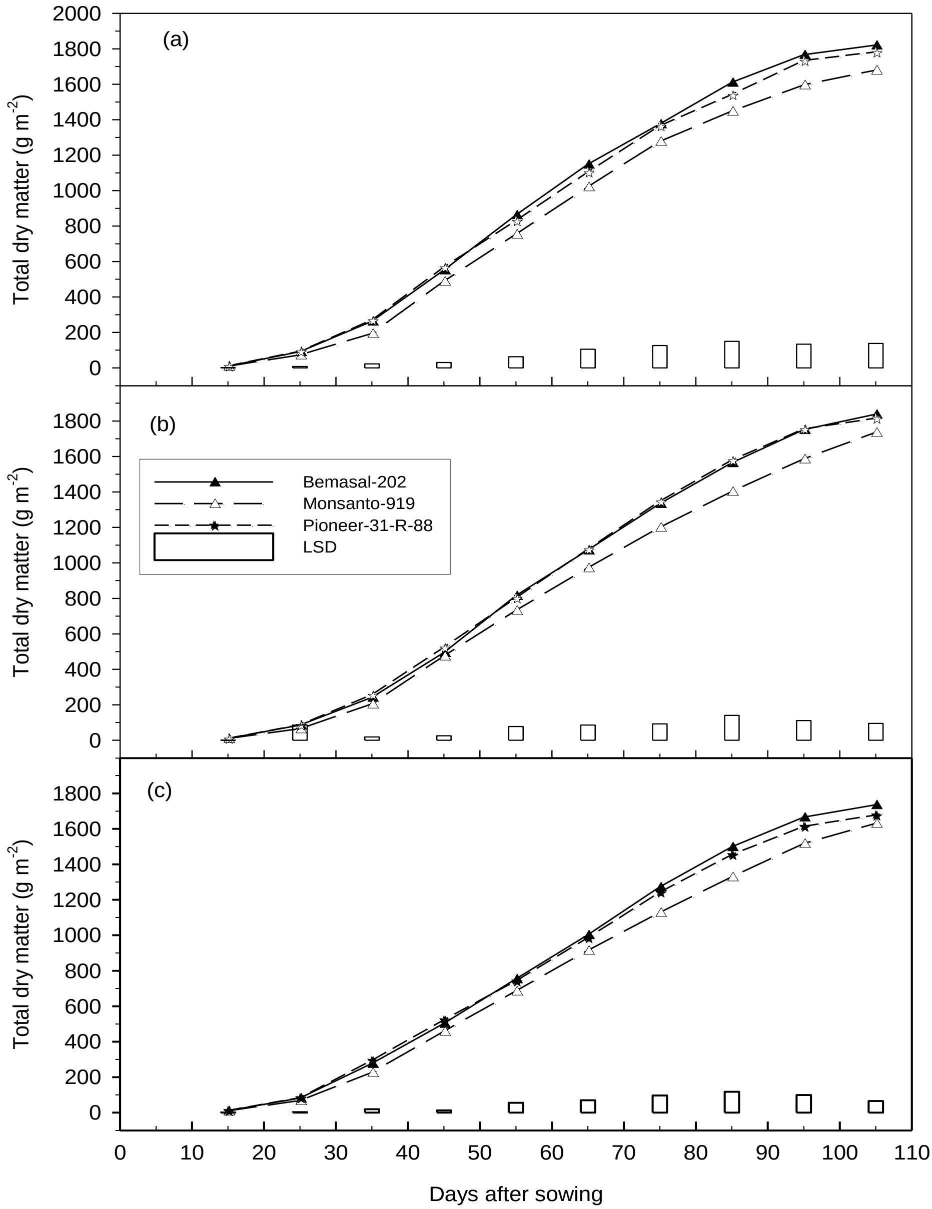

Fig. 4. Change in two years pooled TDM accumulation of different hybrids with time at (a) Faisalabad (b) Sargodha and (c) Sahiwal Bars represent LSD at 5%.

Increasing levels of nitrogen also did not affect significantly plant population m^{-2} at the final harvest. Averaged over sites, mean values ranged from 6.91 to 6.92 plants m^{-2} in all treatments with grand mean value of 6.90 m^{-2} at Sargodha and 6.93 m^{-2} at Faisalabad and Sahiwal. Similar plant densities among treatments were possibly because of gap filling after germination and less mortality rate.

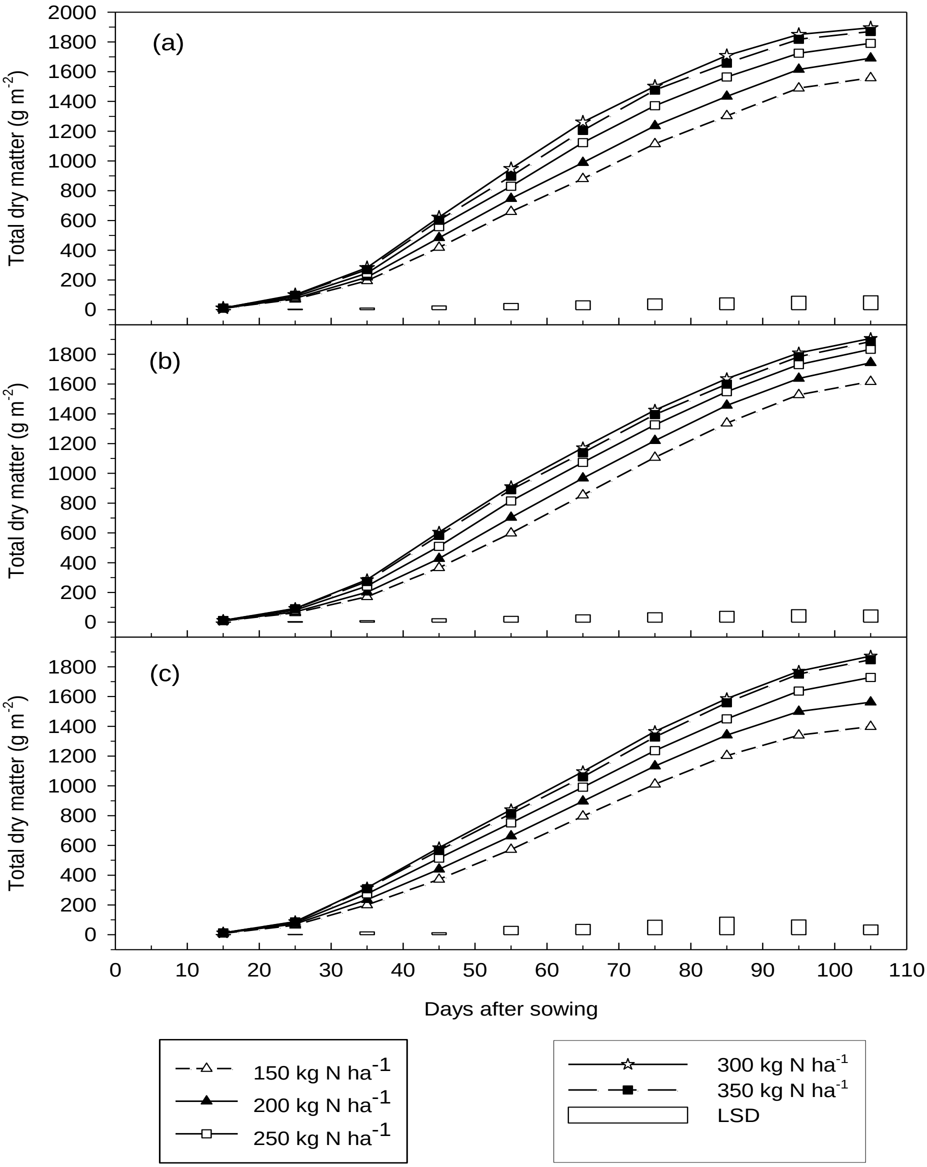

Fig. 5. Change in two years pooled TDM accumulation in response of N rates with time at (a) Faisalabad (b) Sargodha and (c) Sahiwal Bars represent LSD at 5%.

Number of grains m^{-2}: Grain numbers per unit area is usually the most critical determinant of maize grain yield (Ritchie *et al.,* 1998). Number of grains cob^{-1} is the main contributing parameter for grain yield. It is evident from Table 3 that year effect on number of grains m^{-2} was highly significant at all locations, with a similar trend. The mean number of grains m^{-2} was 16% higher (3225.46 vs 2779.26) in 2005 as compared to 2004 at different locations. Lesser number of grains could be due to larger grains during 2004.

Differences of hybrids for number of grains m^{-2} were significant at Faisalabad and Sahiwal while found non significant at Sargodha. The average higher number of grains m^{-2} was produced by hybrid Pioneer-31-R-88 (3051) followed by Bemasal-202 that produced 3037 grains m^{-2}. Minimum number of grains m^{-2} (2920) was recorded in case of Monsanto-919.

Fertilizer levels response was highly significant at all locations and was quadratic at Faisalabad and Sahiwal while it was linear at Sargodha (Table 3). Averaged over locations the maximum number of grains m^{-2} (3239) was produced in N_4 treatment (300 kg N ha^{-1}) which was at par with N_5 (350 kg N ha^{-1}) treatment that produced 3183 grains m^{-2}. N_3 (250 kg N ha^{-1}) treatment produced 3066 grains m^{-2} that was statistically significant than standard treatment N_2 (200 kg N ha^{-1}) that produced 2868 grains m^{-2}. Statistically minimum number of grains m^{-2} (2658) was produced in plots that were fertilized with 150 kg N ha^{-1} (N_1). These results substantiate the findings of Rasheed *et al.,* (2004) who concluded that increasing level of nitrogen enhanced the number of grains per unit area. Interactive effects of cultivar and fertilizer levels were found non significant at all locations.

Overall, mean values of number of grains m^{-2} were 3269, 3016 and 2722 at Faisalabad, Sargodha and Sahiwal, respectively (Table 3).

1000 grain weight: Mean grain weight is an important yield contributing factor, which plays a decisive role in presenting the potential of a variety. Significant differences were observed between two years at all three sites (Table 3). Over all at three sites, crop produced 18 % heavier grains (319.2 vs 271.0 g) during 2004 as compared to 2005. More number of grains during 2005 might be the reason of lesser grain weight.

Data regarding thousand grain weights revealed that it was significantly affected by different cultivars at all locations with similar trend. Overall heavier grains were recorded from hybrid Bemasal-202 (313.99 g) followed by Pioneer 31-R-88 that produced 307.9 g, while lighter grains were noted in case of Monsanto-919 (263.5 g). It might be due to genetic potential of hybrids as Sangoi *et al.,* (2001) reported that modern day hybrids like Ag- 9012 is more productive than the older hybrids. These results were also in agreement with Younas *et al.,* (2002) who also reported that 395.2 g per 1000 grain weight was recorded from Ghauri followed by hybrid 3043 having 1000 grain weight 349.3g.

Fertilizer levels response was linear at Faisalabad and Sahiwal while cubic at Sargodha. Averaged over locations, the maximum 1000 grain weight (319.3 g) was produced in N_4 treatment (300 kg N ha^{-1}) which was at par with treatments N_5 (350 kg N ha^{-1}) that produced 1000 grain weight (313.5 g). N_3 (250 kg N ha^{-1}) treatment produced 300.7 g that was significantly higher than standard rate N_2 (200 kg N ha^{-1}) which produced 279.0 g. The minimum 1000 grain weight (263.2) was registered in plots that were fertilized with 150 kg N ha^{-1} (N_1). The results suggested that adequate N supply had enhanced the source efficiency (more dry matter accumulation per unit area/ time) as well as sink capacity (kernel weight). The interactive effect between cultivars and nitrogen levels was found to be non significant.

Overall, mean grain weight was lower (286 g) at Faisalabad than at Sargodha (308 g) and Sahiwal (291 g). Grain weights of different treatments were linearly related to grain yield at all location and the regression accounted for 94, 98, 96 and 87 % at Faisalabad, Sargodha, Sahiwal and pooled for all locations, respectively (Fig. 6).

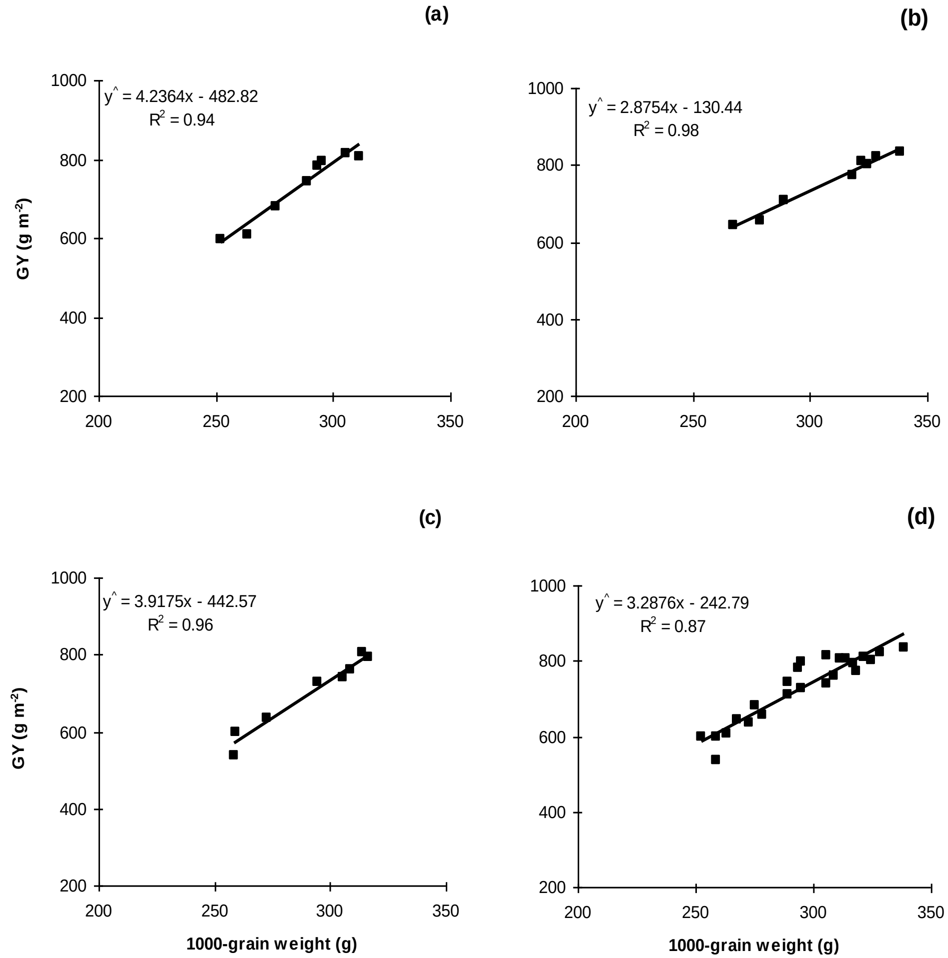

Fig. 6. Relationship between two years pooled grain yield and 1000- grain weight at (a) Faisalabad (b) Sargodha (c) Sahiwal and (d) pooled for all locations.

Grain yield: Year effects on grain yield of maize were highly significant at Sargodha and Sahiwal sites while it was non significant at Faisalabad site (Table 4). Grain yield was recorded 10 % (7.20 vs 7.92 t ha^{-1}) and 14 % (6.52 vs 7.45 t ha^{-1}) more at Sargodha and Sahiwal sites, respectively in 2005 as compared to 2004. It was mainly attributed to more number of grains during 2005 at these experimental sites. Differences in yield between years might be ascribed to different daily variations in maximum and minimum temperatures resulting in different daily leaf temperature across the year, more total rainfall during 2005 than 2004, different patterns of rainfall and relative humidity over the two years and other temporal variations in the environment. Such environmental variations across the year also resulted in better growth and development of maize in 2005 than 2004 which is evident from the results discussed earlier. D'Andrea *et al.*, (2008) also reported year difference (8.97 vs 7.11 t ha^{-1}) in maize yield in 2000 and 2001.

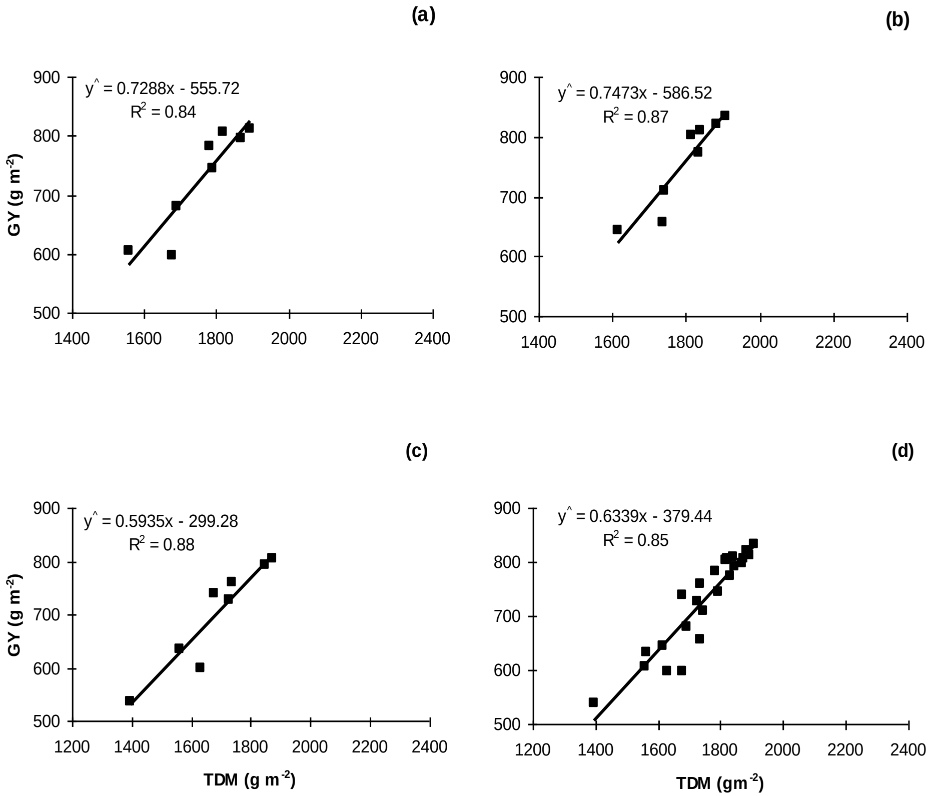

Fig. 7. Relationship between two years pooled grain yield and TDM at (a) Faisalabad (b) Sargodha (c) Sahiwal (d) pooled for all locations.

Hybrid differences in grain yield were significant at all locations with similar trend. Average maximum grain yield (7.91 t ha^{-1}) was recorded in case of Bemasal-202 followed by Pioneer-31-R-88 producing (7.75 t ha^{-1}) that were statistically at par with each other. The minimum grain yield (6.98 t ha^{-1}) was produced by Monsanto-919. These findings are in line with the work of Younas *et al.*, (2002) who compared maize hybrids and concluded that C-919 out yielded all other hybrids by producing 9.92 t ha^{-1} as against the lowest yield 6.85 t ha^{-1} produced by the hybrid 3043.

Data in Table 4 showed that different nitrogen levels markedly increased grain yield over standard (200 kg N ha^{-1}) treatment. At all locations response of nitrogen was quadratic in nature. The plots fertilized with 150 kg N ha^{-1} (below standard treatment) produced significantly less mean grain yield (5.96 t ha^{-1}) than plots fertilized at higher levels. The maximum grain yield (8.17 t ha^{-1}) was recorded in plot fertilized with 300 kg N ha^{-1}which was statistically at par with yield (8.03 t ha^{-1}) at N_5 (350 kg N ha^{-1}) treatment. N_3 (250 kg N ha^{-1}) treatment gave grain yield 6.74 t ha^{-1} while standard treatment N_2 (200 kg N ha^{-1}) produced considerably lower yield (5.96 t ha^{-1}) than higher levels of nitrogen. Nitrogen stress in plots fertilized at lesser levels of nitrogen could be the cause of lesser LAI or LAD integral of LAI, which leads to lower radiation interception, growth rate, RUE and therefore kernel number and grain yield (Girardin *et al.,* 1987; Muchow, 1988; Sinclair & Horie, 1989; Uhart & Andrade, 1995; Maqsood & Azam-Ali, 2007; Ahmad *et al.,* 2007). These results substantiate the findings of other workers who also noted similar effects of nitrogen levels on yield in maize (Luschinger *et al.,* 1999; Kogbe & Adediran, 2003). O, Neil *et al.,* (2004) also reported a greater yield response for corn with increasing N application under adequate soil water conditions. Combined effect of hybrid and nitrogen level was non-significant in both years.

Overall, mean grain yield was lower (7.27 t ha^{-1}) at Faisalabad than at Sargodha (8.23 t ha^{-1}) and Sahiwal (8.49 t ha^{-1}). These differences in grain yield were mainly due to differences in interception of photosynthetically active radiation (PAR) especially during grain filling stage (Maqsood & Azam-Ali, 2007). Grain yield of different treatments was linearly related to TDM at all location and the regression accounted for 84, 87, 88 and 85% at Faisalabad, Sargodha, Sahiwal and pooled for all locations, respectively (Fig. 7).

Total dry matter: Data (Table 4) showed that seasonal effect on total dry matter (TDM) was significant at Sargodha and Sahiwal, while at Faisalabad differences in TDM were non significant. Averaged over locations, crop produced 7% more TDM (18.02 vs 16.91 t ha^{-1}) during 2005 as compared to 2004.

Total dry matter production, at final harvest, was significantly affected by hybrids at all locations in similar trend. Averaged over locations maximum TDM was accumulated by Bemasal-202 (17.98 t ha^{-1}) that was statistically at par with Pioneer-31-R-88 that produced total dry matter17.58 t ha^{-1}. Minimum TDM accumulation was recorded in hybrid Monsanto-919 (Table 4).

The response of TDM production to increasing levels of nitrogen was highly significant at all locations. Quadratic response of nitrogen to TDM was observed at all three locations. Averaged over locations the maximum TDM (18.91 t ha^{-1}) was produced by N_4 (300 kg N ha^{-1}) treatment which was statistically at par with N_5 (350 kg N ha^{-1}) treatment, which gave TDM of 18.68 t ha^{-1} followed by treatment N_3 (250 kg N ha^{-1}) producing 17.84 t ha^{-1}. Standard nitrogen level N_2 (200 kg N ha^{-1}) produced lesser yield of TDM (16.65 t ha^{-1}) than high levels N_3, N_4 and N_5, respectively while minimum TDM was recorded in treatment N_1 (100 kg N ha^{-1}) that was 15.24 t ha^{-1}. The increase in TDM with higher level of nitrogen was due to better crop growth, which gave maximum plant height, LAI and ultimately produced more biological yield. Similar results were found by Ahmad *et al.,* (2007) who reported that nitrogen fertilizer application increased yield and yield components, both for maize and wheat crops. Corn biomass increased with applied N in a quadratic manner was also reported by Shapiro *et al.,* (2006). Total dry matter production in maize was also directly proportional to radiation interception as reported by Kiniry *et al.,* (1989). The interactive effect between cultivars and nitrogen levels were found to be statistically non significant. These observations are fully supported by Khan *et al.,* (1999) and Sharar *et al.,* (2003). Overall, mean TDM accumulation at harvest was lower (17 t ha^{-1}) at Sahiwal than Faisalabad and Sargodha (18 t ha^{-1}).

Harvest index: Harvest index shows the physiological efficiency of plants to convert the fraction of photoassimilates to grain yield. Table 4 showed that year effect on harvest index (HI) of maize was non significant at all locations. However crop had an average HI 41.20, 41.76 % in 2004 and 2005, respectively.

Table 5. Correlation between grain yield and yield components of maize.

Character	Correlation co-efficient (r)			
	Faisalabad	**Sargodha**	**Sahiwal**	**Pooled (n=24)**
Number of grains m^{-2}	0.71^{*}	0.80^{**}	0.93^{**}	0.63^{**}
1000 grain weight	0.97^{**}	0.99^{**}	0.98^{**}	0.93^{**}
Total dry matter	0.92^{**}	0.93^{**}	0.94^{**}	0.92^{**}
Harvest index	0.94^{**}	0.92^{**}	0.70^{*}	0.89^{**}

Hybrid differences in harvest index (HI) were significant at all locations (Table 4). Averaged over locations the hybrid Pioneer-31-R-88 had higher harvest index (43.94 %), which was statistically at par with Bemasal-202 giving HI (43.94 %). Monsanto-919 gave statistically less harvest index 39.37%. Substantially high HI for Pioneer-31-R-88 and Bemasal-202 might be attributed to its genotypic superiority to utilize more photoassimilates for grain yield formation.

Application of nitrogen fertilizer at different levels showed highly significant effect on harvest index at all locations. These effects were linear at Faisalabad and Sargodha while quadratic in nature at Sahiwal. Averaged over locations N_4 treatment (300 kg N ha^{-1}) gave maximum HI (43.17%) which is at par with treatment N_5 (350 kg N ha^{-1}) giving 42.71% and N_3 (250 kg N ha^{-1}) that gave 41.66%. Standard treatment N_2 (200 kg N ha^{-1}) gave 40.44% that is significantly lower than N_3, N_4 and N_5. Statistically less harvest index was recorded in treatment N_1 (150 kg N ha^{-1}) that was 39.12%. Results suggested that an optimum supply of nitrogen is essential for optimizing partitioning of dry matter between grain and other parts of maize plant. Higher the efficiency of converting dry matter into economic yield, higher will be the value of harvest index (%). Many workers (Bangarwa *et al.*, 1988; Sabir *et al.*, 2000) also reported similar results. Overall, mean HI was 41.19%, 41.89% and 41.36% at Faisalabad, Sargodha and Sahiwal, respectively.

Correlation between grain yield and components of yield: Simple linear correlation analysis between grain yield and different components of yield is presented in Table 5. The data showed a highly positive correlation between grain yield and different components of yield such as number of grains m^{-2} and 1000-grain weight. A highly significant association of grain yield with TDM and HI was also shown.

Conclusion

Growth and yield responses of different maize hybrids were evaluated at multiple locations representing the range of different environments and soil characteristics. The results presented here exposed that there was, in general significant variability in response of maize crop to increasing nitrogen rates among locations. However yield increase up to 300 kg N ha^{-1} following that differences were non significant. Optimum temperature and rainfall were helpful in increasing growth rate, uptake of nitrogen and ultimate increase in grain yield.

Selection of suitable hybrid for each location is also helpful in sustaining crop yield. The results of this study confirmed that hybrid Bemasal-202 outperformed under semiarid conditions of Punjab. Yield differences among treatments were attributed to the number of grains m^{-2} and grain weight. It was further observed that year with high temperature (>30°C) and lesser rainfall had significantly lowered the growth and yield of maize under semiarid irrigated condition. This type of research can be used to modify existing fertilizer recommendations methods by including fertility status of soil, proper irrigation scheduling and mid season adjustments based on current climatic conditions to increase the nitrogen use efficiency, minimize costs and sustain yields.

References

Ahmad, R., S.M. Shahzad, A. Khalid, M. Arshad and M.H. Mahmood. 2007. Growth and yield response of wheat (*Triticum aestivum* L.) and maize (*Zea mayzs* L.) to nitrogen and L-Tryptophan enriched compost. *Pak. J. Bot*., 39(2): 541-549.

Anonymous. 2008. *Economic Survey of Pakistan*. 2007-2008, Finance Division, Economic Advisory Wing, Islamabad, Pakistan.

Bangarwa, A.S., M.S. Kairon and K.P. Singh. 1988. Effect of plant density and level and proportion of nitrogen fertilization on growth, yield and yield component of winter maize. *Ind. J. Agric. Sci*., 58(11): 854-856.

Bundy, L.G. and T.W. Andraski. 1995. Soil yield potential effects on performance of soil nitrate tests. *J. Prod. Agric*., 8: 561-568.

Cerrato, M.E. and A.M. Blackmer. 1991. Relationships between leaf nitrogen concentrations and the nitrogen status of corn. *J. Prod. Agric*., 4: 525-531.

D'Andrea, K.E., M.E. Otegui and A.G. Cirilo. 2008. Kernel number determination differs among maize hybrids in response to nitrogen. *Field Crops Research.,* 105: 228-239.

D'Andrea, K.E., M.E. Otegui, A.G. Cirilo and G.H. Eyherabide. 2006. Genotypic variability in morphological physiological traits among maize inbred lines. I. Response to nitrogen availability. *Crop Sci.*, 46: 1266-1276.

Derby, N.E., D.D. Steele, J. Terpstra, R.E. Knighton and F.X.M. Casey. 2005. Interactions of nitrogen, weather, soil, and irrigation on corn yield. *Agron. J*., 97: 1342-1351.

Eghball, B. and G.E. Varvel. 1997. Fractal analysis of temporal yield variability of crop sequences: Implications for site-specific management. *Agron. J*., 89: 851-855.

Girardin, P., M. Tollenaar, A. Deltour and J. Muldoon. 1987. Temporary N starvation in maize (*Zea mays* L.): Effects on development, dry matter accumulation and grain yield. *Agronomie (Paris).*, 7: 289-296.

Gomes, K.A. and A.A. Gomes. 1984. *Statistical Procedures for Agricultural Research*. Wiley-Interscience, John Wiley and Sons, New York.

Kay, B.D., A. A. Mahboubi, E.G. Beauchamp and R.S. Dharmakeerthi. 2006. Integrating soil and weather data to describe variability in plant available nitrogen. *Soil Sci. Soc. Am. J.*, 70: 1210-1221.

Khan, M., S. Akbar, K. Ahmad and M.S. Baloch. 1999. Evaluation of corn hybrids for grain yield in D. I. Khan. *Pak. J. Biol. Sci.*, 2(2): 413-414.

Kiniry, J.R., C.A. Jones, J.C.O. Toole, R. Blanchet, M. Cabelguenne and D.A. Spanel. 1989. Radiation use efficiency in biomass accumulation prior to grain filling for five grain crop species. *Field Crops Res*., 20: 51-64.

Kogbe, J.O.S. and J.A. Adediran. 2003. Influence of N and P application on yield of maize in Savanna zone of Nigeria. *Afri.J. of Biotec*., 2(10): 345-349.

Luchsinger, L.A., A.J.D. Opazo and V.O. Neira. 1999. Response of sweet corn to nitrogen fertilization. *Investigation Agricola*, 19(1/2): 9-18(Field Crop Absts., 53(7): 4524:2000).

Maqsood, M. and S.N. Azam-Ali. 2007. Effects of environmental stress on growth, radiation use efficiency and yield of finger millet (*Eleucine coracana*). *Pak. J. Bot.*, 39(2): 463-474.

McCullough, D.E., P. Giradin, M. Mihajlovic, A.A. Guilera and M. Tollenaar. 1994. Influence of N supply on development and dry matter accumulation of an old and new maize hybrid. *Can. J. Plant Sci.,* 74: 471-477.

Muchow, R.C. 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in semiarid tropical environment I. Leaf growth and leaf nitrogen. *Field Crops Res*., 18: 1-16.

O'Neill, P.M., J.F. Shanahan, J.S. Schepers and B. Caldwell. 2004. Agronomic responses of corn hybrids from different areas to deficit and adequate level of water and nitrogen. *Agron. J.,* 96: 1660-1667.

Rasheed, M., W.M. Bhutta, M. Anwar-ul-Haq and A. Ghaffar. 2004. Genotypic response of maize hybrids to NP applications. *Int. J. Agri. Biol.,* 4: 721-722.

Raun, W.R. and G.V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. *Agron. J.,* 91: 357-363.

Ritchie, J.T., U. Singh, D.C. Godwin and W.T. Bowen. 1998. Cereal growth, development and yield. In: *Understanding Options for Agricultural Production:* (Eds.): Tsuji, G. Y., G. Hoogenboom, and P. K. Thornton. 79-98. Dordrecht: Kluwer Academic Publishers.

Sabir, M.R., I. Ahmad and M.A. Shahzad. 2000. Effect of nitrogen and phosphorus on yield and quality of two hybrids of maize (*Zea mays* L.). *J. Agric. Res.,* 38(4): 339-346.

Sangoi, L., M. Ender, A.F. Guidolin, M.L. Almeida and V.A. Konflanz. 2001. Nitrogen fertilization impact on agronomic traits of maize hybrids released at different decades. *Pesq. Agropec. Bars. Brasilia*., 36(5): 757-764.

Schmitt, M.A. and G.W. Randall. 1994. Developing a soil nitrogen test for improved recommendations for corn. *J. Prod. Agric.,* 7: 328-334.

Shapiro, C.A. and C.S. Wortmann. 2006. Corn response to nitrogen rate, row spacing and plant density in eastern Nebraska. *Agron. J.,* 98: 529-535.

Sharar, M., S.M. Ayub, M. Nadeem and N. Ahmad. 2003. Effect of different rates of nitrogen and phosphorus on growth and grain yield of maize (*Zea mays* L.). *Asian J. Plant Sci.,* 2(3): 347-349.

Sinclair, T.R. and T. Horie. 1989. Leaf nitrogen, photosynthesis and crop radiation use efficiency: A review. *Crop Sci*., 29: 90-98.

Sogbedji, J.M., H.M. Van Es, S.D. Klausner, D.R. Bouldin and W.J. Cox. 2001. Spatial and temporal processes affecting nitrogen availability at the landscape scale. *Soil Tillage Res*., 58: 233-244.

Uhart, S.A. and F.H. Andrade. 1995. Nitrogen deficiency in maize. I. Effect on crop growth, development, dry matter partitioning and kernel set. *Crop Sci*., 35: 1376-1383.

Waraich, E.A., R. Ahmad, A. Ali and Saifullah. 2007. Irrigation and nitrogen effects on development and yield in wheat (*Triticum aestivum* L.). *Pak. J. Bot*., 39(5): 1663-1672.

Wienhold, B.J., T.P. Trooien and G.A. Reichman. 1995. Yield and nitrogen use efficiency of irrigated corn in the northern Great Plains. *Agron. J*., 87(5): 842-846.

Wright, D. 1982. Crop Physiology. In: *Agricultural Note Book*; (Ed.): R.J. Halley. Butter Worth Scientific, London.

Younas, M., H. Rehman and G. Hayder. 2002. Magnitude of variability for yield and yield associated traits in maize hybrids. *Asian J. Plant Sci.,* 1(6): 694-696.

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