Pak. J. Bot., 41(2): 761-768, 2009.

NITROGEN LEVELS AND ITS TIME OF APPLICATION INFLUENCE LEAF AREA, HEIGHT AND BIOMASS OF MAIZE PLANTED AT LOW AND HIGH DENSITY

AMANULLAH[1*], KHAN BAHADAR MARWAT[2], PAIGHAM SHAH[1], NOOR MAULA[3] AND SHAHNAZ ARIFULLAH[4]

[*1]*Department of Agronomy, NWFP Agricultural University, Peshawar, Pakistan*
[2]*Department of Weed Science, NWFP Agricultural University, Peshawar, Pakistan*
[3]*Department of Extension Education, NWFP Agricultural University of Peshawar, Pakistan*
[4]*IDS, NWFP Agricultural University of Peshawar, Pakistan.*

Abstract

Field experiments were conducted at the New Developmental Research Farm of NWFP Agricultural University, Peshawar during 2002-03 and 2003-04 to investigate the impacts of nitrogen (N) rate and its time of application on leaf area, plant height and biomass yield of maize (*Zea mays* L., cv. Azam) planted at low and high density. Factorial experimental treatments comprising two plant densities (P1 = 60,000 and P2 = 100,000 plants ha^{-1}) and three nitrogen rates (N1 = 60, N2 = 120 and N3 = 180 kg N ha^{-1}) were kept in main plots, while six split application for N in different proportions were kept in subplots at different growth stages of maize in two equal (S1), three equal (S2), three unequal (S3), four equal (S4), five equal (S5) and five unequal splits (S6) at sowing and with 1st, 2nd, 3rd and 4th irrigation at two weeks intervals. Mean single leaf area (MSLA), and plant height was significantly higher in 2002-03 than in the 2003-04. Maize produced significantly taller plant and ear heights as well as biomass yield at high than at low density. MSLA and leaf area per plant (LAPP), plant and ear heights as well as biomass yield showed a remarkable increase with increasing N rate and number of N split applications. It is concluded that growing maize at high density with application of 50% higher N rate (180 kg ha^{-1}) than the recommended rate of N (120 kg ha^{-1}) in four to five splits can increase leaf area and plant height that could result in maximum biomass yield of maize and hence increase productivity of maize crop.

Introduction

Maize (*Zea mays* L.) is the second most important crop after wheat in the North West Frontier Province (NWFP) of Pakistan but its yield per unit area is very low. Average maize yield of Punjab province was 63% higher than NWFP during 2005-06 growing season (Anon., 2007). Overall nutrient consumption in Punjab province increased by 3.9% while, in NWFP consumption of nutrient decreased by 3.3% in 2005-06 as compared to 2004-05 (Anon., 2006). Nitrogen fertilizer is universally accepted as a key component to high yield and optimum economic return as it plays a very important role in crop productivity (Ahmad, 2000) and its deficiency constitutes one of the major yield limiting factors for cereal production (Shah *et al.,* 2003). Over N fertilization is a common problem for the wheat-maize rotation system (Zhao *et al.,* 2006), while its deficiency from seedling to V8 stage cause 30% reduction in yield, withholding N supply from V8 to maturity reduce yield by 22%, however, there is no yield reduction when N is deficient from silking or 3 wk after silking to physiological maturity (Subedi & Ma, 2005). Increasing plant density for short season maize increases cumulative intercepted photo synthetically active radiation, which compensates for a short growing season to achieve high yield with substantially less irrigation (Edwards *et al.,* 2005). The difference in the dry matter accumulation in maize is attributed to post-silking N uptake and it improves with increase in N rate (Rajcan & Tollenaar (1999). Differences in biomass yield and N uptake varied partly due to decreased soil N mineralization and partly due to the drier weather conditions of different years, and N uptake rate has been found to assist the improvement of DM yield in maize (Greef *et al.,* (1999). Maize biomass yield increases with increase in plant density and N rate (Gaurkar & Bharad, 1998). Hamid & Nasab (2001) reported that both grain and biomass yields in maize are correlated with vegetative and reproductive phase duration.

Leaf area influence interception and utilization of solar radiation of maize crop canopies and consequently maize dry matter accumulation and grain yield. Leaf area and number are important factors in the estimation of canopy photosynthesis in crop growth simulation models that compute dry matter accumulation from temporal integration of canopies photosynthesis (Boote *et al.,* 1996). Oscar & Tollenaar (2006) reported that breadth of the area per leaf profile decreases under high soil nitrogen level and high plant density. They reported that leaf area and yield increased with higher rate of N. According to Pandey *et al.,* (2000), maize genotypes differs in its ability to maintain leaf area, LAI, crop growth rate (CGR) and above ground dry matter production at different levels of water deficit and N supply.

Plant height, inter-node length and ear height is greater under high density and leaf area decreases with increase in plant density in maize (Modarres *et al*., 1998; Hassan, 2000). Plant height and biomass yield in maize increases up to a plant density of 71900 plants ha^{-1} and 280 kg N ha^{-1}, but further increase in both plant density and N rate has no significant effect on plant height and biomass yield (Turgut, 2000). Toler *et al.,* (1999) reported 15% higher light interception and biomass yield at higher than at lower plant density of maize. Plant density in maize affects plant architecture, alters growth and developmental patterns and influences carbohydrate production and partition (Casal, 1985). Studies on proper combination of N and plant density in the maize growing agro-ecological zones of NWFP are lacking. This experiment was, therefore, designed with an objective to investigate impacts of differential N rates and its time of application on leaf area, height and biomass at various growth stages of maize planted at low and high densities at Peshawar.

Materials and Methods

Site description: Experiments were conducted at the Agriculture Research Farm of the NWFP Agricultural University, Peshawar during 2002-03 and 2003-04. 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. Soil physio-chemical properties such as soil texture (Gee & Bauder, 1986), organic matter (Nelson & Sommers, 1982), AB-DTPA extractable phosphorus and exchangeable potassium (Soltanpour, 1985) were determined. Rainfall during the experimental period varied from 1.0 to 73.2 mm (July), 116.6 to 51.6 mm (August) and 14.9 to 45.2 mm (September) in 2002-03 and 2003-04, respectively.

Experimentation: A 2 x 3 x 6 factorial experiment was conducted in a randomized complete block (RCB) design with split-plot arrangement using four replications. Factorial experimental treatments were two plant densities [P1= 60,000 (Low) and P2= 100,000 plants ha^{-1}(High)] and three N rates [N1 = 60, N2 = 120 and N3 = 180 kg N ha^{-1}] applied to main plots, while six split application for N in different proportions were applied to subplots at sowing time and then at 2 wk interval in two equal splits [S1 = 50% at sowing and 50% at 14 DAE (days after emergence)], three unequal splits [S2 = 50% at sowing, 25% at 14 DAE and 25% at 28 DAE), three equal splits [S3 = 33.3% each at sowing, 14 DAE and at 28 DAE), four equal splits [S4 = 25% each at sowing, 14, 28, and 42 DAE), five equal splits [S5 = 20% each at sowing, 14, 28, 42 and 56 DAE)] and five unequal splits [S6 = 8.3, 16.6, 25, 33.3 and 16.6% at sowing, 14, 28, 42, and 56 DAE, respectively].

Maize variety, Azam was used in the experiment. A sub-plot size of 4.2 m x 6 m, having 6 rows, 6 m long and 70 cm apart, was used. Fertilizer N (urea) was applied at the time of sowing and with 1^{st}, 2^{nd}, 3^{rd} and 4^{th} irrigation at two wk intervals i.e., 14, 28, 42, and 56 DAE. A uniform basal dose of 60 kg P_2O_5 (single super phosphate) ha^{-1} and 50 kg K_2O (sulphate of potash) ha^{-1} was applied and mixed with soil during seedbed preparation. The plots were planted thicker and the two desired plant densities of 60,000 and 100,000 plants ha^{-1} were obtained in the different experimental units by thinning one week after emergence.

Data were collected on mean single and leaf area $plant^{-1}$, plant and ear heights, and biomass yield at various growth stages. Leaf area, length and width of 100 leaves were measured using leaf area machine in the Agronomy laboratory and the factor (0.75) was calculated. Length and width of the five middle leaves of 10 plants in each sub plot were measured using measuring tape. Mean leaf area and leaf area per plant was obtained using the following formulae.

Mean Leaf area = Leaf length x Leaf width x 0.75
Leaf area per plant = Mean leaf area x Number of leaves per plant

Plant height was obtained by measuring the height of 10 plants from ground level to the tips of the tassels at physiological maturity and then average plant height was determined. Similarly, ear height was recorded by measuring the height of 10 plants from ground level to the top ear at physiological maturity and then average ear height was determined. Ten plants in the four middle rows in each experimental unit were harvested at silking and physiological maturity. The plants were dried, weighed and then converted to biomass yield ha^{-1}.

Statistical analysis: Data was statistically analyzed according to Steel & Torrie (1980) and means were compared between treatments by least significant difference (LSD) at $p \leq 0.05$.

Results and Discussion

Leaf area: Combined statistical analysis of the two years data showed that year had significant effects on mean single leaf area (MSLA) as shown in Table 1. Maize produced significantly larger MSLA in the year 2002-03 than in the year 2003-04. The decrease in the MSLA in the year 2003-04 compared to 2002-03 might be attributed to the fluctuation in the amount and distribution of rainfall in two years. In 2002-03, higher rainfall during vegetative growth period in the month of August (116.6 mm) might have increased N uptake by plants and partitioned more assimilates to leaves and thus resulting in higher MSLA in 2002-03, compared with lower MSLA in 2003-04 due to 50 % less amount of rainfall in the month of August (51.6 mm). Harold *et al.,* (2006) reported that maize N availability varied greatly from year to year due to weather fluctuation. Wang *et* *al.*, (2007) 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.

Table 1. Impact of year on leaf area, plant and ear height, biomass yield at silking and physiological maturity of maize during 2002-03 and 2003-04.

Year (Y)	Single leaf area (cm^2)	Leaf area $plant^{-1}$ (cm^2)	Plant height (cm)	Ear height (cm)	Biomass at silking (kg ha^{-1})	Biomass at maturity (kg ha^{-1})
Y1	502.66a	5305.0	192.5a	90.6	6984	14696
Y2	447.19b	4721.0	177.0b	85.8	7032	16328
LSD (p≤0.05)	**35.36**	**ns**	**11.09**	**ns**	**ns**	**ns**

Where Y1 = 2002-03 and Y2 = 2003-04. Mean values of the same category followed by different letters are significant at p≤0.05 using LSD.

Table 2. Impact of planting density on leaf area, plant and ear height, biomass yield at silking and physiological maturity of maize during 2002-03 and 2003-04.

Planting density (D)	Single leaf area (cm^2)	Leaf area $plant^{-1}$ (cm^2)	Plant height (cm)	Ear height (cm)	Biomass at silking (kg ha^{-1})	Biomass at maturity (kg ha^{-1})
P1	481.31	5043.08	179.6b	83.5b	5310b	11862b
P2	468.53	4983.55	189.7a	91.8a	8710a	19550a
LSD (p≤0.05)	**ns**	**ns**	**3.79**	**2.51**	**977**	**2757**

Where P1 = 60,000 plants ha^{-1} and P2 = 100,000 plants ha-1. Mean values of the same category followed by different letters are significant at p≤0.05 using LSD.

Table 3. Impact of N rates on leaf area, plant and ear height, biomass yield at silking and physiological maturity of maize during 2002-03 and 2003-04.

N rates (N)	Single leaf area (cm^2)	Leaf area $plant^{-1}$ (cm^2)	Plant height (cm)	Ear height (cm)	Biomasss at silking (kg ha^{-1})	Biomass at maturity (kg ha^{-1})
N1	438.97c	4534.64c	179.6b	84.6b	6504c	14664b
N2	477.58b	4983.67b	185.7a	87.5b	7016b	15528b
N3	508.22a	5521.55a	188.7a	90.9a	7512a	17000a
LSD (p≤0.05)	17.18	225.22	4.64	3.08	331	934

Where N1 = 60 kg N ha^{-1}, N2 = 120 kg N ha^{-1} and N3 = 180 kg N ha^{-1}. Mean values of the same category followed by different letters are significant at p≤0.05 using LSD.

Table 4. Impact of timing of N application on leaf area, plant and ear height, biomass yield at silking and physiological maturity of maize during 2002-03 and 2003-04.

N timings/ splits (S)	Single leaf area (cm^2)	Leaf area $plant^{-1}$ (cm^2)	Plant height (cm)	Ear height (cm)	Biomass at silking (kg ha^{-1})	Biomass at maturity (kg ha^{-1})
S1	454.06c	4595.08d	181.0c	85.4c	6632e	13984e
S2	452.85c	4607.25d	181.0c	85.5c	6936d	14560d
S3	459.29c	4754.69cd	181.7bc	85.3c	6984cd	15664c
S4	470.08c	4952.92c	184.0b	88.0b	7080bc	16448b
S5	497.77b	5457.15b	189.6a	91.1a	7096b	16592ab
S6	515.48a	5712.63a	190.7a	90.9a	7304a	17128a
LSD (p≤0.05)	**17.43**	**223.04**	**2.51**	**2.12**	**109**	**558**

Where S1 = Two equal splits (50-50%), S2 = Three un-equal splits (50-25-25%), S3 = Three equal splits (33-33-33%), S4 = Four equal splits (25-25-25-25%), S5 = Five equal splits (20-20-20-20-20%) and S6 = Five un-equal splits (8-17-25-33-17%). Mean values of the same category followed by different letters are significant at p≤0.05 using LSD.

Increase in N rate showed positive relationship with increase in MSLA and leaf area per plant (LAPP) (Table 3). The highest MSLA and LAPP were recorded in plots receiving N at the higher rate (N3). Similarly, increase in number of N splits showed positive relationship with increase in MSLA and LAPP (Table 4). The highest MSLA and LAPP were recorded in plots which received N in five unequal splits (S6). The increase in MSLA and LAPP at higher N rate and number of N splits might have increased leaf area expansion rate as a result of faster cell division and greater cell expansion and concomitantly increased photosynthate formation that resulted in higher MSLA and LAPP of maize. Oscar & Tollenaar (2006) reported that LAI increased with the application of higher rate of N while, Pandey *et al.,* (2000) reported that a maize crop differs in its ability to maintain LAI and above ground dry matter production at different levels of N supply. Maximum number of split applications of N (S5 and S6) delayed vegetative and reproductive growth period of maize that resulted in significant increase in number of leaves per plant (Amanullah *et al.,* 2009) that might have increased MSLA and LAPP.

Plant and ear height: Maize grew taller in the first than in the second year (Table 1). The decrease in the maize plant height in the year 2003-04 as compared to 2002-03 might be attributed to the fluctuation in the amount and distribution of rainfall in two years. In 2002-03, higher rainfall during vegetative growth period in the month of August (116.6 mm) might have increased N uptake by plants and partitioned more assimilates to maize stem and thus maize produced taller plants in 2002-03 as compared with plants in 2003-04 because of less amount of rainfall in the month of August (51.6 mm).

At high density maize produced about 10 cm taller plants and higher ear heights than at low plant density (Table 2). At high density interplant competition for light among maize plants increased which might have increased inter node length and thus increased plant and ear heights. Increase in plant and ear height in maize was earlier reported by Modarres *et al.,* (1998) and Ogunlela *et al.,* (2005) at high than at low density. However, Sadeghi & Bahrani (2002) observed that plant density had no significant effects on the maize heights. The discrepancy in the results of Sadeghi & Bahrani (2002) and the results of this experiment might be due to the variation in the climates and native soil fertility status of the experimental sites, and the difference in the species used in both experiments.

Increase in N rate increased plant and ear heights with the highest rate of 180 kg N ha^{-1} produced the taller plants and higher ears heights; while the shorter plants and ears heights were recorded in the plots which received the lowest rate of 60 kg N ha^{-1} (Table 3). Tallest plant and ears heights were observed in the plots to which N was applied in unequal splits at five stages (S6) by applying 33% of N at 45 days after emergence (Table 4). Increase in N rates and number of splits extended vegetative growth period of maize (Amanullah *et al.,* 2009) that might have increased photosynthate formation and partitioning to stems that might have favorable impacts on plant and ear heights of maize. These results are in close conformity with the results obtained by Akbar *et al,* (1999) who found that plant height in maize increases with increase in N rate. However, Sadeghi & Bahrani (2002) reported that increase in N rates had no significant effects on plant height. The discrepancy in the results obtained in this study and that of Sadeghi & Bahrani (2002) might be due to the difference in the range of population stand, native fertility status and the species used.

Biomass yield: Year had no significant effects on biomass yield at silking and physiological maturity (Table 1). However, in contrast to the higher MSLA and plant height in the first than in the second year, biomass yields at silking and physiological maturity were comparatively higher in the second year as compared to the first year. The decrease in maize biomass in the first year than second year might be attributed to the fluctuation in the amount and distribution of rainfall in two years. In the second year, higher rainfall during the reproductive growth period of maize in the month of September (45.2 mm) might have increased N uptake by plants and partitioned more assimilates to ears that increased number of seeds per ear, ear weight and number of ears per 100 plants (un-published data) that might be the possible cause of higher biomass yields in the second year (2003-04) as compared to the lower biomass yields in the first year because of less amount of rainfall (14.9 mm) during reproductive stage of maize. Kahabka *et al.,* (2004) reported that site-specific N application to maize is a way of maximizing yield potential while minimizing fertilizer cost.

Biomass yields at various growth stages of maize showed positive relationship with increase in plant density (Table 2). At high density vegetative growth of maize was extended, more number of leaves per plant were produced that increased light interception at the high density (Amanullah *et al.,* 2009), as a result more assimilates were produced by maize crop that increased plant heights as well as light interception (Amanullah *et al.,* 2008) which ultimately lead to higher biomass yields at high than at low plant density. Toler *et al.,* (1999) reported 15% higher light interception and higher biomass yield at high than at low plant density of maize. Edwards *et al.,* (2005) suggested that increasing plant density for short season maize increased cumulative intercepted photo synthetically active radiation, which compensated for a short growing season to achieve high yield.

Biomass yield at various growth stages increased significantly with increase in N rate (Table 3). The increase in biomass yield at higher N than lower N rate might be due to the increase in MSLA, LAPP and plant heights at higher than at lower N rate. Hamid & Nasab (2001) and Greef *et al.,* (1999) reported positive correlation between N rates and dry matter yield in maize. Biomass yield at various growth stages increased significantly with increase in number of N splits (Table 4). Application of N at later vegetative stages of maize extended growth phase (Amanullah *et al.,* 2009) and produced relatively more assimilates by maize crop in response to the longer growth period as a result plant height, MSLA and LAPP was significantly increased that might be the possible cause of greater biomass yield of maize while increasing number of N split applications. Rajcan & Tollenaar (1999) reported that the difference in the dry matter accumulation in maize is attributed to post-silking N uptake and it significantly increases with increase in N rate. Mariga *et al.,* (2000) reported that biomass yield in maize considerably increased when N was applied up to tassel initiation stage. Scharf *et al.,* (2002) observed significant increase in maize yield when N was applied in splits.

Conclusions

Improper plant density and N management particularly with continued soil nutrient mining and fluctuations in rainfall are major factors contributing to reduced leaf area, plant height and biomass yields of maize in the north-western Pakistan. Application of higher rate of 180 kg N ha^{-1} i.e., about 50% more than recommended N rate with four or five splits resulted in maximum MSLA, LAPP, plant height and biomass yields. Our findings suggest that farmers who traditionally grow maize at high plant density to get higher fodder yield (biomass) but apply very low N rate, only at sowing time (one split) or sometimes two splits which is lost very quickly because of high soil pH, high temperature and shortage of water. Farmers are therefore requiring demonstration of the benefits of the higher N rate with increase in number of split applications. Further research work for understanding the impacts of different planting densities, higher rate of N and time of its application for high sustainable biomass production in different agro-ecological conditions is also suggested.

Acknowledgements

Financial support from the Department of Agronomy, Faculty of Crop Production Sciences, NWFP Agricultural University, Peshawar is gratefully acknowledged.

References

Ahmad, N. 2000. Fertilizer Scenario in Pakistan Policies and Development. In: *Proceedings of the conference: Agriculture and Fertilizer Use*. Planning and Development Division, Government of Pakistan, February 15-16, 1999, NFDC, Islamabad, Pakistan.

Akbar, F., A.Wahid, S. Akhtar, A.N. Ahmad, and F.M. Chaudhary. 1999. Optimization of method and time of nitrogen application for increased nitrogen use efficiency and yield in maize. *Pakistan Journal of Botany,* 31: 337-341.

Amanullah, H. Rahman and Z. Shah. 2008. Effects of plant density and N on growth dynamics and light interception in maize. *Archives of Agronomy and Soil Science,* 54: 401-411.

Amanullah, R., A. Khattak and S.K. Khalil. 2009. Effects of plant density and N on phenology and yield of maize. *Journal of Plant Nutrition*, 32: 246-260.

Anonymous. 2006. *Fertilizer review 2005-06.* Govt. of Pakistan, Planning and Development Division, National Fertilizer Development Centre, Islamabad, Pakistan.

Anonymous. 2007. *Pakistan Statistical Year Book* 2007. Statistics Division, Ministry of Economic Affairs and Statistics, Govt. Of Pakistan, Islamabad (www.statpak.gov.pk/depts/fbs/pub)

Boote, K.B., J.W. Jones and N.B. Pickering. 1996. Potential uses and limitations of crop models. *Agronomy Journal* 88: 704-716.

Casal, J.J., V.A. Deregibus and R.A. Sanchez. 1985. Variations in tiller dynamics and morphology in *Lolium multiflorum* Lam., vegetative and reproductive plants as affected by differences in red/far-red irradiation. *Annals of Botany,* 56: 533-559.

Edwards, J.T., L.C. Purcell and E.D. Vories. 2005. Light interception and yield potential of short season maize hybrids in the Midsouth. *Agronomy Journal,* 97: 225-234.

Gaurkar, S.G. and G.M. Bharad. 1998. Effect of plant population, detopping and nitrogen levels on growth and yield of maize. *PKV Research Journal,* 22: 136-137.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. p. 383-411. In: *Methods of soil analysis* (Ed.): A. Klute, Part I. 2nd Edition, American Society of Agronomy, Madison, W.I., USA.

Greef, J.M., H. Ott, R. Wulfes and F. Taube. 1999. Growth analysis of dry matter accumulation and N uptake of forage maize cultivars affected by N supply. *Journal of Agriculture Science,* 132: 31-43.

Hamid, A. and A.D.M. Nasab. 2001. The effect of various plant densities and N levels on phenology of two medium maturity corn hybrids. *Iranian Journal of Agriculture Science,* 32: 857-874.

Harold, M.V.E., B.K.J. Sogbedji, J. Melkonian, R.S. Dharmakeerthi, H. Dadfar and I. Tan. 2006. *Nitrogen Management under Maize in Humid Regions*: The 18th World Congress of Soil (Science held on July 9-15, 2006) at Philadelphia, Pennsylvania, USA.

Hassan, A.A. 2000. Effect of plant population on yield and yield components of eight Egyptian maize hybrids. *Bulletin of Faculty of Agric. Univ. of Cairo,* 51: 1-16. *Abstracted in Field Crops Abstracts,* 54: 249312; 2001.

Kahabka, J.E., H.M. Van, E.J. McClenahan and W.J. Cox. 2004. Spatial analysis of maize response to nitrogen fertilizer in central New York. *Precision Agriculture,* 5: 463-476.

Mariga I.K., M. Jonga and O.A. Chivinge. 2000. The effect of timing of application of basal and topdressing fertilizers on maize yield at two rates of basal fertilizer. *Crop Research Hissar,* 20: 372-380.

Modarres, A.M., R.I. Hamilton, M. Dijak, L.M. Dwyer, D.W. Stewart, D.E. Mather and D.L. Smith. 1998. Plant population density effects on maize inbred lines grown in short-season environments. *Crop Science*, 38: 104-108.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. p. 574-577. In: *Methods soil analysis,* (Eds.): A.L. Page, R.H. Miller and D.R. Kenney. Part II, 2^{nd} edition. American Society of Agronomy, Madison, W.I., USA.

Ogunlela, V.B., G.M. Amoruwa and O.O. Olongunde. 2005. Growth, yield components and micronutrient nutrition of field maize grown as affected by nitrogen fertilization and plant density. *Nutrient Cycling in Agro ecosystems,* 17: 385-1314.

Oscar, R.V. and M. Tollennar. 2006. Effect of genotype, nitrogen, plant density and row spacing on the area-per-leaf profile in maize. *Agronomy Journal*, 98: 94-99.

Pandey, R.K., J.W. Maranville and M.M. Chetima. 2000. Deficit irrigation and nitrogen effects on maize in a Sahelian environment. II. Shoot growth, nitrogen uptake and water extraction. *Agriculture and Water Management,* 46: 15-27.

Rajcan, I. and M. Tollenaar. 1999. Source: sink ratio and leaf senescence in maize: I. Dry matter accumulation and partitioning during grain filling. *Field Crops Research,* 60: 245-253.

Sadeghi, H. and M.J. Bahrani. 2002. Effects of plant density and N rates on morphological characteristics and protein contents of corn. *Iranian Journal of Agriculture Science,* 33: 403-412.

Scharf, P.C., W.J. Wiebold and J.A. Lory. 2002. Yield response to nitrogen fertilizer timing and deficiency level. *Agronomy Journal,* 94: 435-441.

Shah, Z., S.H. Shah, M.B. Peoples, G.D. Schwenke, and D.F. Herriedge. 2003. Crop residue and fertilizer N effects on nitrogen fixation and yields of legume-cereal rotations and soil organic fertility. *Field Crops Research,* 83: 1-11.

Soltanpour, P.N. 1985. Use of AB-DTPA to evaluate elements availability and toxicity. *Communication in Soil Science and Plant Analysis,* 16: 323-338.

Steel, R.G.D. and J.H. Torrie. 1980. *Principles and procedures of Statistics.* 2^{nd} edition. McGraw-Hill, USA.

Subedi, K.D. and B.L. Ma. 2005. Nitrogen uptake and partitioning in stay green and leafy maize hybrids. *Crop Science,* 45: 740-747.

Toler, J.E., E.C. Murdock, G.S. Stapleton and S.U. Wallace. 1999. Corn leaf orientation effects on light interception, intra-specific competition and grain yields. *Journal of Production Agriculture,* 12: 396-399.

Turgut, I. 2000. Effects of plant populations and nitrogen doses on fresh ear yield and yield components of sweet corn grown under Bursa conditions. *Turkish Journal of Agriculture and Forestry,* 24: 341-347.

Wang, X., W.B. Hoogmoed, D. Cai, U.D. Perdok and O. Oenema. 2007. Crop residue, manure and fertilizer in dryland maize under reduced tillage in northern China: II nutrient balances and soil fertility. *Nutrient Cycling in Agro ecosystems,* 79: 17-34.

Zhao, R.F., X.P. Chen, F.S. Zhang, H. Zhang, J. Schroder and V. Romheld. 2006. Fertilization and N balance in a wheat-maize rotation system in North China. *Agronomy Journal,* 98: 938-945.

(Received for publication 15 July 2008)