Source and rate of nitrogen application influence agronomic N-use efficiency and harvest index in maize (*Zea mays* L) genotypes

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Abstract

The objective of this research work was to compare the agronomic N use efficiency (NUE_A) and harvest index response of different maize (*Zea mays* L) genotypes to different N-fertilizer sources [urea, calcium ammonium nitrate (CAN) and ammonium sulphate (AS)] at various levels (0, 50, 100, 150, and 200 kg ha^{-1}). Field experiments were conducted at the Agriculture Research Farm of The University of Agriculture, Peshawar, Pakistan during summer 2008 (year one) and 2010 (year two). The two years data indicated that NUE_A had negative relationship with increase in N rate (50 > 100 > 150 > 200 kg ha^{-1}) while harvest index had positive relationship with increase in N rate up to 150 kg ha^{-1} (200 < 150 > 100 > 50 kg ha^{-1}). Both NUE_A and harvest index ranked first with application of AS (AS > CAN > urea). The maize hybrid produced higher NUE_A and harvest index than local cultivars (Pioneer-3025 > Jalal > Azam). Although AS had the highest NUE_A and harvest was still considered the less profitable N-fertilizer source because of its highest N cost kg^{-1} [AS (143 and 191 PKR kg N^{-1}) > CAN (77 and 97 PKR kg N^{-1}) > urea (44 and 56 PKR kg N^{-1})] in 2008 and 2010, respectively. The decline in AS price could make it more profitable and most beneficial N-fertilizer source in the calcareous soils of the country because of its free available sulfur (24%) lacking in urea and CAN.

Keywords: *Zea mays* L, genotypes, N levels, N source, agronomic N use efficiency, harvest index

Introduction

Developing nitrogen (N) efficient cultivars is a major challenge of modern plant breeding, and improvement in N-use efficiency (NUE) would therefore significantly contribute to securing world food and feed production and raise agricultural incomes (Geiger, 2009).The current agricultural and economic environment means that farmers must optimize the application of N fertilizers to avoid pollution by nitrates and to preserve their economic margin. Therefore, it has become of major importance to select for cereal cultivars that absorb and metabolize N in the most efficient way for grain or silage production (Hirel, 2001). There is a chance to find efficient genotypes in maize because of its variability (Paponov et al, 2005; Presterl et al, 2002), where some productive genotype can be find that they are efficient, in conditions of N stress (Cüi et al, 2009). Efficient use of N for maize production is important for increasing grain yield, maximizing economic return and minimizing NO_3 leaching to ground water (Gehl et al, 2005). Efficient fertilizer use can be defined as maximum returns per unit of fertilizer applied (Mortvedt et al, 2001). Weather and soil can contribute in the efficiency of N use in corn genotypes (Muchow 1998; Presterl et al, 2002). While there is a large body of published research on technologies for increasing NUE, relatively few have been adopted by farmers because they are not cost-effective or practical (Cassman et al, 2002). Smil (1999) estimated that the total N input to the world's cropland at 169 Tg N yr^{-1}. Inorganic N fertilizer, biological N fixation from legumes and other N-fixing organisms, atmospheric deposition, animal manures, and crop residues account for 46%, 20%, 12%, 11%, and 7%, respectively, of this total (Cassman et al, 2002). Hence, 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) are the three main N fertilizer sources for crop production in Pakistan, but there is lack of research to indicate that which N fertilizer source is more efficient in terms of agronomic N use efficiency (NUE_A). Significant responses of maize to different N–sources have been demonstrated by many studies (Risse, 2004; Powel, 2005; Kantey, 2007; Mehra, 2007; Osundare, 2009). In all these studies, significant differences in growth and yield of maize among various N sources were reported. 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). Farmers are always concerned about getting the biggest bang for their dollar when it comes to fertilizer, especially today as fertilizer N prices hove near $0.40 per pound. Nitrogen use efficiency (NUE) for wheat and corn production today seldom exceeds 40%, and the worldwide average is right at 33%. This means that for every one pound of N applied, 67% of that pound is lost via denitrification, volatiliza-

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

Weather Data	Growing Season 2008				Growing season 2010			
	July	August	Sept	Oct	July	August	Sept	Oct
Mean Temperature (°C)	31	30	28	25	31	29	24	24
Max Temperature (°C)	36	35	34	32	34	33	34	32
Min Temperature (°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
Wind Speed (km h^{-1})	19	14	11	6	15	13	11	5

tion, plant N loss, and/or leaching. A 20% increase in NUE worldwide for cereal production would be worth more than 10 billion dollars (Raun and Zhang, 2006).

Though the existing maize genotypes have a high yield potential, soil and climatic conditions of Pakistan are very ideal for its production, yet grain yield and NUE_A is very low as compared with other countries. The causes of lower yield and NUE_A include injudicious use of N fertilizer and selection 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 genotypes and low cost N fertilizers at appropriate level needs to be find out and managed to increase maize productivity and NUE_A. Management practices that minimize N losses and maximize the quantity of N recovered by the crop will increase production efficiency and reduce potential impacts on N use on the environment (Havlin et al, 2009). Amanullah et al (2012) reported that the higher average yield in the Punjab Province than Khyber Pakhtunkhwa Province in Pakistan was due to the use of hybrid maize and efficient fertilizer use by the farmers in Punjab than Khyber Pakhtunkhwa. Application of N at a higher rate and more splits is a key factor in the wheat-maize cropping system to the N deficient soils in Northwestern Pakistan for sustainable maize productivity and higher net returns (Amanullah et al, 2010). The three major chemical fertilizer sources of nitrogen in Pakistan are urea, calcium ammonium nitrate (CAN) and ammonium sulphate (AS). However, there is lack of research to investigate the agronomic N use efficiency (NUE_A) and harvest index while using these three N fertilizer sources. This experiment was therefore designed with an objective to investigate impact of different sources of N fertilizers applied at various levels on the NUE_A and harvest index of maize hybrid (Pioneer-3025) in comparison to the two local cultivars (Jalal and Azam) as checks.

Materials and Methods

Site Description

Field experiments were 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°N latitude, 71.35°E longitude at an altitude of 350 m above sea level in Peshawar valley. Peshawar is located about 1,600 km north of the Indian Ocean and has continental type of climate. The research farm is irrigated by Warsak canal from Kabul River. 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, 2009). Weather data for the maize growing periods in 2008 and 2010 are given in Table 1.

Experimentation

A 4 x 3 x 3 factorial experiment was conducted in randomized complete block (RCB) design with split-plot arrangement using three replications. Factorial experimental treatments were four N (nitrogen) levels [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 2^{nd} irrigation (30 days after emergence). The crop was irrigated seven times in each year. The stem borers were controlled with application of Furadan at knee height. After maturity, the four central rows were harvested, the material was sun dried up to constant weight, the dried material was weighed by spring balance and converted into biological yield (kg ha^{-1}). The ears were then separated, threshed, weighed and converted into grain yield (kg ha^{-1}). The agronomic nitrogen use efficiency (NUE_A) and harvest index (HI) were calculated using the formulae:

NUE_A = (Grain yield with N – Grain yield without N) ÷ N rate

HI = (Grain yield ÷ Biological yield) * 100

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel et al (1996), and means between treatments was com-

Table 2 - Analysis of variance for Agronomic-NUE and harvest index of maize genotypes as affected by levels and source of N application in the two years.

Source of variance	DF	Probability for NUE_A		Probability for harvest index	
		Year one	Year two	Year one	Year two
Replications	2				
Treatments	12	0.000	0.000	0.000	0.478
N sources	2	0.000	0.050	0.025	0.288
N levels	3	0.000	0.000	0.001	0.222
NL x NS	6	0.000	0.003	0.038	0.689
Control vs. rest	1	0.000	0.000	0.000	0.391
Error I	24	--	--	--	--
Genotypes	2	0.000	0.011	0.000	0.004
NS x G	4	0.895	0.193	0.402	0.292
NL x G	6	0.250	0.621	0.000	0.204
NS x NL x G	12	0.825	0.848	0.084	0.741
Error II	52	--	--	--	--
Total	116				

pared by least significant difference ($P \leq 0.05$). Analysis of variance of the data for the two years is given in Table 2.

Results

The rest (all the experimental plots applied with N) had the agronomic nitrogen use efficiency (NUE_A) of 14.3 in year one (Table 3) and 11.2 kg grains kg^{-1} in year two (Table 4). Among the N levels, NUE_A decreased from a maximum (19.5 and 14.1 kg grains kg^{-1}) at the lowest N rate (50 kg N ha^{-1}) to a minimum (9.5 and 7.5 kg grains kg^{-1}) at the highest N rate (200 kg N ha^{-1}) in year one and year two (Table 3 and 4, respectively) indicating negative relationship of NUE_A with increase in N rate. Among the N fertilizers sources, application of AS produced the highest NUE_A of 16.1 kg grains kg^{-1} in year one (Table 3), and 12.7 kg grains kg^{-1} in year two (Table 4). Urea with the lowest NUE_A of 10.9 kg grains kg^{-1} in year one and 10.0 kg grains kg^{-1} in year two ranked in the bottom in terms of NUE_A. Among the maize genotypes, the hybrid (Pioneer-3025) had the highest NUE_A of 18.9 and 13.7 kg grains kg^{-1} in year one (Table 3) and year two

Table 3 - Effect of N-fertilizer source and levels on nitrogen use efficiency (kg grains kg^{-1} N) of maize genotypes in year one.

N source	N Levels (kg ha^{-1})			
	50	100	150	200
Urea	10.42	11.47	12.17	9.36
CAN	21.71	18.43	13.15	10.00
AS	26.46	16.31	12.53	9.05
Maize genotypes				
Azam	15.18	13.67	9.89	7.32
Jalal	16.72	13.79	11.77	7.28
Pioneer-3025	26.69	18.74	16.19	13.82
Mean	19.53	15.40	12.61	9.47
	N source			
	Urea	CAN	AS	Mean
Azam	8.76	12.68	13.11	11.51
Jalal	8.87	14.40	13.90	12.39
Pioneer-3025	14.94	20.38	21.25	18.86
Mean	10.85	15.82	16.08	
	Preplanned comparison			
	Control	Rest		
	0.00	14.25		
Source of variance	$LSD_{0.05}$			
Treatments	2.36			
N sources (NS)	1.18			
N levels (NL)	1.36			
NL x NS	2.36			
Genotypes (G)	1.87			
NS x G	ns			
NL x G	ns			
NS x NL x G	ns			

Table 4 - Effect of N-fertilizer source and levels on nitrogen use efficiency (kg grains kg^{-1} N) of maize genotypes in year two.

N source	N Levels (kg ha^{-1})			
	50	100	150	200
Urea	9.28	14.15	8.98	7.57
CAN	11.96	12.92	10.96	7.71
AS	22.10	12.40	10.27	7.34
Maize genotypes				
Azam	9.71	12.96	9.28	6.73
Jalal	14.85	11.68	8.81	5.69
Pioneer-3025	18.78	14.83	12.11	10.20
Mean	14.45	13.16	10.07	7.54
	N source			
	Urea	CAN	AS	Mean
Azam	7.51	11.41	10.10	9.67
Jalal	9.29	10.49	10.99	10.26
Pioneer-3025	13.18	10.77	17.99	13.98
Mean	10.00	10.89	13.03	
	Preplanned comparison			
	Control	Rest		
	0.00	11.30		
Source of variance	$LSD_{0.05}$			
Treatments	4.46			
N sources (NS)	2.23			
N levels (NL)	2.58			
NL x NS	4.46			
Genotypes (G)	2.83			
NS x G	ns			
NL x G	ns			
NS x NL x G	ns			

(Table 4), respectively. The local cultivar (Jalal) stood second; while another local cultivar (Azam) with the lowest NUE_A of 11.5 and 9.7 kg grains kg^{-1} in year one and two, respectively, ranked in the bottom in terms of NUE_A (Table 3 and 4). Interaction of N sources into N level (rates) (NS x NL) indicated that at the lowest rate of N (50 kg N ha^{-1}), AS had the highest NUE_A, followed by CAN and urea had the lowest NUE_A (Table 3). When N was applied at the rate of 100 kg N ha-1, then CAN had the highest NUE_A, followed by AS and the urea again had the lowest NUE_A. At the two highest N rates (150 and 200 kg N ha^{-1}), there was no significant differences in the NUE_A while using different N fertilizers in year one (Table 3). In year two, interaction of N sources into N level (rates) (NS x NL) indicated that at the lowest rate of N (50 kg N ha^{-1}), AS had the highest NUE_A once again, followed by CAN and urea had the lowest NUE_A (Table 4). When N was applied at the rate of 100 kg N ha^{-1}, then urea this time had the highest NUE_A than AS and CAN. At the two highest N rates (150 and 200 kg N ha^{-1}), there was no significant differences in the NUE_A while using different N fertilizers in year one, although, AS was better than the other two sources of N (Table 4).

The harvest index was higher for the rest plots (38.14%) than control (34.95%) in year one (Table 5), but the differences in harvest index in control vs. rest were significantly not different from each other in year two (Table 6). In year one, the harvest index was significantly higher (39.12%) when maize was applied at the rate of 150 kg N ha^{-1}, followed by 38.18% at 100 kg N ha^{-1} while the lowest harvest index of 37.45% was obtained at the lowest rate of N (Table 5). Nitrogen rates had no significant effects on the harvest index of maize in year two (Table 6). Application of AS gave the highest harvest index (38.6%), while urea had the lowest harvest index (37.6%) in year one (Table 5). Nitrogen sources had no significant effects on the harvest index of maize in year two (Table 6). The maize genotype, Pioneer-3025, produced the highest harvest index of 42.3% in year one (Table 5) and 42.0% in year two (Table 6). Azam had relatively higher harvest index than Jalal in both years. In year one, interaction of N sources into N level (rates) (NS x NL) indicated that at the lowest rate of N, AS had the highest harvest index than the two other two sources of N (Table 5). Application of CAN at the rate of 100 kg N ha^{-1} had better performance than AS and CAN. At 150 kg N ha^{-1}, AS stood first > CAN > urea in terms of harvest index, while no significant differences in harvest index was observed in different N sources when applied at 200 kg N ha^{-1} (Table 5). In year one, interaction of N levels into genotypes (NL x G) indicated that at all three sources of N, the hybrid had significantly higher harvest index than the two local cultivars, and the differences in harvest index of the two local cultivars were statistically the same (Table 5).

Table 5 - Effect of N-fertilizer source and levels on harvest index (%) of maize genotypes in year one.

N source	N Levels (kg ha^{-1})			
	50	100	150	200
Urea	37.30	37.09	38.12	38.09
CAN	37.13	39.02	38.75	37.71
AS	37.92	38.44	40.50	37.65
Maize genotypes				
Azam	36.62	36.66	37.32	35.80
Jalal	35.77	35.60	36.60	34.19
Pioneer-3025	39.96	42.28	43.44	43.47
Mean	37.45	38.18	39.12	37.82
	N source			
	Urea	CAN	AS	Mean
Azam	36.30	36.56	36.94	36.60
Jalal	35.25	35.65	35.72	35.54
Pioneer-3025	41.40	42.24	43.22	42.29
Mean	37.65	38.15	38.63	
	Preplanned comparison			
	Control	Rest		
	34.95	38.14		
Source of variance	$LSD_{0.05}$			
Treatments	1.366			
N sources (NS)	0.683			
N levels (NL)	0.789			
NL x NS	1.366			
Genotypes (G)	0.581			
NS x G	ns			
NL x G	1.210			
NS x NL x G	ns			

Discussion

The differences in the agronomic nitrogen use efficiency (NUE_A) and harvest index in the two years (2008 and 2010) could be due the fluctuation in the rainfall data (Table 1). Earlier, Amanullah and Almas (2009) reported higher NUE_A of 22.49 kg grains kg^{-1} in 2003 than in 2002 (21.61 kg grains kg^{-1}), and variation in NUE_A of both years was attributed to the variation in rainfall of two years. The average rainfall during the second year was greater than in the first year and as a result the crop produced maximum yields and that resulted in maximum NUE_A in the second year as compared with that of the first year (Amanullah and Almas, 2009). These results agrees with Muchow (1998) that N efficiency changes with the weather and soil conditions. 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. Seasonal variation in the amount and distribution of rain was partly responsible for year differences in NUE in sorghum cultivars, N fertilizer had a significant influence on NUE in both years which ranged from76.3 to l29.2 g DM g-1 N in 1993 and 87.7 to 117.8 g DM g^{-1} N in 1994 (Buah et al. 1998).

Among the N levels, NUE_A decreased from a maximum (19.5 and 14. kg grains kg^{-1}) at the lowest N rate (50 kg N ha-1) to a minimum (9.5 and 7.0 kg grains kg^{-1}) at the highest N rate (200 kg N ha^{-1}) in year one and two, respectively (Table 3 and 4) indicating negative relationship of NUE_A with increase in N rate. These results are in comparison with those of Pablo et al (2008) who reported that increase in N rate decrease NUE in maize, and Amanullah and Almas (2009) found that NUE_A had negative relationship with increase in N rate. Amanullah and Almas (2009) reported maximum NUE_A (27.73 kg grains kg^{-1} N) when maize was applied with the lowest N rate (60 kg ha^{-1}) and the minimum NUE_A (19.31 kg grains kg^{-1} N) with the highest N rate (180 kg ha^{-1}). Karim and Ramasamy (2000) suggested that higher fertilizer use efficiency which was always associated with low fertilizer rate, cultural practices meant for promoting integrated nutrient management could helped to effect saving in the amount of fertilizer applied to the crops and there to improve fertilizer use efficiency. In year one, the higher harvest index with 150 kg N ha^{-1} was attributed to the higher yield of maize produced and further increase in N up to 200 kg N ha^{-1} increased biological yield at a higher rate than grain yield resulting in lower

Table 6 - Effect of N-fertilizer source and levels on harvest index (%) of maize genotypes in year two.

N source	N Levels (kg ha^{-1})			
	50	100	150	200
Urea	38.6	39.5	40.1	39.5
CAN	36.4	42.7	37.5	36.0
AS	39.4	41.6	40.5	39.9
Maize genotypes				
Azam	33.7	41.7	38.9	40.6
Jalal	38.3	38.3	36.8	35.3
Pioneer-3025	42.4	43.8	42.4	39.6
Mean	38.1	41.3	39.3	38.5
		N source		
	Urea	CAN	AS	Mean
Azam	38.6	39.2	38.5	38.7
Jalal	36.4	36.9	38.3	37.2
Pioneer-3025	43.4	38.4	44.3	42.0
Mean	39.4	38.1	40.4	
	Preplanned comparison			
	Control	Rest		
	37.5	39.3		
Source of variance	$LSD_{0.05}$			
Treatments	ns			
N sources (NS)	ns			
N levels (NL)	ns			
NL x NS	ns			
Genotypes (G)	2.7			
NS x G	ns			
NL x G	ns			
NS x NL x G	ns			

harvest index (Table 5). Indicating that harvest index had positive relationship with grain yield and negative relationship with biological yield. Amanullah and Shah (2010) found that harvest index showed positive relationship with increase in N rates. The highest HI (39%) was noted in plots to which the highest rate of 180 kg N ha^{-1} was applied, while the minimum HI (30%) was recorded in plots to which the lowest rate of 60 kg N ha^{-1} was applied. The higher rate of N application increased leaf area per plant (Amanullah et al, 2009a), crop growth rate (Amanullah et al, 2008), number of kernels per ear and ears per 100 plants, and grain yield (Amanullah et al, 2009b) that increased HI in maize. But some researchers found that increase in N rate had no effect on HI in maize (Shapiro and Wortmann, 2006).

The higher NUE_A (Table 3 and 4) and higher harvest index (Table 5 and 6) with AS was attributed to the increase in grain yield with application of AS. Since AS contains S (24%) which might have decreased the soil pH in the calcareous and high pH soils in the study area (Amanullah et al, 2009), and thus might have increased the availability of micronutrients (Kacar and Katkat, 2007) that could be the possible reason of higher grain yield and higher NUE_A as well as harvest index in this experiment. Rahman and Koentjoro (2011), and Amanullah and Almas (2009) found positive correlation between NUE_A and grain yield in maize. Amanullah and Shah (2010) found positive correlation between harvest index and grain yield. Chien et al (2011) declared that 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 Khyber Pakhtunkhwa (Northwest Pakistan) where most of the soils are calcareous soils, AS because of its free sulfur content, could be the most beneficial N-fertilizer in terms of crop growth and yield. However, because of the highest N cost of AS (143 and 191 PKR kg N^{-1}; one USD = 95 PKR) > CAN (77 and 97 PKR kg N^{-1}) > urea (44 and 56 PKR kg N^{-1}) in Y_1 and Y_2, respectively, the poor growers can't to afford to buy AS. Moreover, the transportation charges of AS is more because of its low N content (21%) than urea (46% N) and CAN (26% N). Lloyd et al (1997) reported that urea (£100 per ton) is a less expensive form of N fertilizer than ammonium nitrate (£130 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). Nitrogen loss from urea can be reduced if urea is coated or if a urease inhibitor is properly used (Raun and Zhang, 2006). Research at the Lahoma, OK experiment station conducted from 1971 to 2004 has shown little differences in long-term wheat grain yields between anhydrous ammonia, urea, ammonium nitrate, and sulfur coated urea. A trend for lower yields with anhydrous ammonia and sulfur coated urea at the high N rates has been observed but differences have generally been small (Raun and Zhang, 2006). Ammonium sulphate, because of its residual acidity, has been discontinued, and therefore not recommended (Kurtz, 2004). 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). The superiority emanates from the ability of CAN to supply N in the forms of $NH4^+$ and $NO3^-$, compared to urea and AS that can only supply N in form of $NH4^+$. Thus, the presence of $NH4^+$ and $NO3^-$ in CAN accounts for the better performance of maize with CAN than urea (Powell, 2005; Mehra, 2007; Osundare, 2009). The calcium element (an exchangeable base) helps in the neutralization of soil acidity, thereby enhancing the availability of certain nutrients in the soil (Risse, 2004; Kantey, 2007; Mehra, 2007). However, CAN eliminates potential combustion hazards as compared to ammonium nitrate (NH_4NO_3) and CAN is most popular in Europe and South Africa (Halvin et al, 2009). In Northwestern Pakistan the soils don't have the acidy problem because these soils are calcareous in nature with high pH (Amanullah et al, 2009) and so these soils would be more productive and have higher NUE_A with application of AS. Because the S content (24%) in AS would decrease the soil pH and could increase availability of micronutrients, improve crop growth and yield (Amanullah et al, 2011). 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). However, the favorable manufacturing, handling, storage, low transportation charges, marketing and easy availability make urea the most competitive N fertilizer source in Northwest Pakistan than AS and CAN.

The higher NUE_A (Table 3 and 4) and higher harvest index (Table 5 and 6) of hybrid than local cultivars was attributed to the higher grain yield of the hybrid than local cultivars. Differences in grain yield of maize genotypes were earlier reported by Ferreira et al (2001) and de Carvalho et al (2012). In Ardabil, Iran, the three different maize cultivars Korduna, Kenez 410 and Konsur had NUE of 25.34, 11.97, and 5.24 kg kg^{-1} N, respectively (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. GEN03, GEN10, and GEN16 were considered the most efficient genotypes in terms of agronomic N use efficiency. According to Rahman and Koentjoro (2011), root architecture (root length, root number, root dry weight) correlated significantly to N uptake efficiency in maize genotypes. As morphological parameter, root architecture or root system often used to study N uptake because root is the main organ of nutrient and water transportation in plant that absorb and re-translocate N associated with root architecture (Gallais, 2008). Buah et al (1998) found that hybrid NUE was more than the lines and its yields were nearly doubled that of the lines in 1993 and 48% greater in 1994. In sorghum crop, Gardner et al (1994) found that cultivars with greater NUE had reduced grain yield.

The interaction (NS x NL) indicated that at the lowest rate of N, AS had the highest NUE_A, followed by CAN and urea had the lowest NUE_A (Table 3 and 4). When N was applied at the rate of 100 kg N ha^{-1}, then CAN had the highest NUE_A, followed by AS and the urea again had the lowest NUE_A. At the two highest N rates (150 and 200 kg N ha^{-1}), there was no significant differences in the NUE_A while using different N fertilizers. 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. Anderson et al (1985) observed that the ability of a maize genotype to increase grain yield with high N rates was not necessarily associated with greater NUE values. Fageria et al (2011) found that the higher and lower N rate of AS produced higher grain yield 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. In year one, interaction of N sources into N level (rates) (NS x NL) indicated that at the lowest rate of N, AS had the highest harvest index than the two other two sources of N (Table 5). Application of CAN at the rate of 100 kg N ha^{-1} had better performance than AS and CAN. At 150 kg N ha^{-1}, AS stood first > CAN > urea in terms of harvest index, while no significant differences in harvest index was observed in different N sources when applied at 200 kg N ha^{-1} (Table 5). In year one, interaction of N levels into genotypes (NL x G) indicated that at all three sources of N, the hybrid had significantly higher harvest index than the two local cultivars, and the differences in harvest index of the two local cultivars were statistically the same (Table 5). 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. Thus, genotypes with differences in grain yield potential may have differences in N accumulation and NUE (Sinclair and de Wit, 1975). The interactive effects of genotypes x nitrogen on grain yield and NUE has been reported by Cüi et al (2009), while Prestel et al (2002) reported that grain yield and NUE in maize genotypes changes with environments x nitrogen levels interaction. 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 fertilizer inputs, 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 genotypes within species, and their interactions with the environment. The low NUE_A by the two local cultivars was attributed to their low yield, yield components and harvest index. Differences in N use efficiency, harvest index, economic yield and net returns in different maize genotypes was earlier reported by Mkhabela et al (2001).

Conclusions

The recent higher N-fertilizers price combined with very low income of the growers had negative impacts on crop productivity, profitability and agronomic N use efficiency (NUE_A) in Northwestern Pakistan. The results of this study confirmed that maize harvest index and NUE_A changed while using different genotypes, source and rate of N fertilizers, as well as change in weather condition in two years. Harvest index increased with increase in N rate up to 150 kg ha^{-1} (200 < 150 > 100 > 50 kg ha^{-1}) and NUE_A increased with decrease in N rate (50 > 100 > 150 > 200 kg ha^{-1}). The relationship of grain yield with NUE_A and harvest index was positive. The NUE_A and harvest index varied in the same order with N source (ammonium sulphate > calcium ammonium nitrate > urea) and genotype (Pioneer-3025 > Jalal > Azam). Because the price kg^{-1} N from different N-fertilizers was more for AS (143 and 191 PKR kg N^{-1}; one USD = 95 PKR) > CAN (77 and 97 PKR kg N^{-1}) > urea (44 and 56 PKR kg N^{-1}). It is therefore recommend that the price of N-fertilizers should be fixed on the basis of N quantity present in a bag rather than the whole bag. It is injustice with the farmers to buy a bag of AS (21% N) and CAN (26% N) at a higher price than urea (46% N). The decline in price of AS could make it more profitable and beneficial N-fertilizer source on calcareous and high pH soils because of its free available sulfur (24% S) important for improving soil condition, crop growth, increase yield and NUE_A than urea and CAN. The decline in CAN price could also make it more beneficial N fertilizer source in other soils having Ca deficiency or soils acidic in nature. 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 of highest net returns. The higher NUE_A and harvest index of maize hybrid in this study was attributed to its higher grain. The increase in NUE_A could reduce the negative impacts of N on the environment reported by many researchers. The variation in NUE_A and harvest index in the two years of study was due to the fluctuation in the price of N-fertilizers and fluctuation in weather condition. This problem poses a challenge for the development of technical recommendations targeted for diverse environments.

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