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The effects of nitrogen fertilization strategies on the productivity of maize (*Zea mays* L.) hybrids

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Abstract

Nitrogen (N) is one of the major limitations to crop productivity. Therefore, a field study was conducted to examine the impacts of N application strategies: N_1 – 20% of N at sowing through broadcast + 79% N at mid-season through fertigation + 1% of N at flowering through foliar application, N_2 – 40% of N at sowing through broadcast + 59% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_3 – 60% of N at sowing through broadcast + 39% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_4 – 80% of N at sowing through broadcast + 19% of N at mid-season through fertigation + and 1% of N at flowering through foliar and N_5 – 100% of N at sowing through broadcast, on the productivity of maize hybrids (H) single cross-6142 (H_1) and double cross-4444 (H_2) over a 2-year period, 2010–2011. During both years, N strategies and maize hybrids differed significantly for all the observed traits of yield and quality. The highest biological yield (16.99–17.62 t ha^{-1}) and grain yield (6.83–7.16 t ha^{-1}) were recorded by using the strategy N_3. Similar trends were also observed for other traits except the grain oil content which was the maximum (3.38–3.98%) at N_5. However, in both years, maximum biological yield (14.83–15.69 t ha^{-1}) and grain yield (5.01–6.02 t ha^{-1}) were evident in H_1. The interactive effect of $H_1 \times N_3$ gave maximum biological yield (17.55–20 t ha^{-1}) and grain yield (7.53–8.83 t ha^{-1}). In 2010 and 2011, the highest net income (1220–1272 USD ha^{-1}) and benefit cost ratio (2.52–2.56) was also attained at $H_1 \times N_3$. In conclusion, our results suggested that maize productivity (grain yield up to 5.01–6.02 t ha^{-1}) could be improved on economic basis (benefit cost ratio up to 2.52–2.56) by growing the single cross hybrid-6142 (H_1) with N application strategy N_3.

Key words: nitrogen application, quality components, yield, *Zea mays*.

Introduction

Maize (*Zea mays* L.) is an important cereal crop, consumed as food for a large proportion of the world (http://www.fao.org/docrep/t0395e/T0395E01.htm#Chapter 1 - Introduction). It is an important source of food, fodder and raw material for agro-based industries (Witt, Pasuquin, 2007). Its yield is affected by the use of poor quality seed, improper fertilizers, inadequate plant protection measures, low plant density, weed infestation and water shortage (Badu-Apraku et al., 2011). However, deficiency of nitrogen (N) is considered one of the major limiting factors of maize yield (Kamara et al., 2006; Badu-Apraku et al., 2011). Inadequate application of N causes the steady increase in maize yield (Gallais, Coque, 2005). It is a well documented fact that maize yield has been increased to ample amount by N nutrition (Kamara et al., 2006).

Maize hybrids are fast growing and high yielding (Russell, 1986), which therefore require more nutrients, N in particular. Selection of potentially high yielding hybrids which are well responsive to applied N is an important tool to improve grain yield (Kamara et al., 2006; De Carvalho et al., 2012). Different hybrids have different genetic ability for N intake, use and translocation (Paponov, Engels, 2003). Interaction between different genotypes and N fertilization shows the importance of selection of better performing hybrids to improve crop production (Gallais, Coque, 2005). Mostly, single cross hybrids produce higher grain yield and yield components in response to applied inputs (N in particular) than all the other hybrids (Griesh, Yakout, 2001; Badu-Apraku et al., 2011). However, it is difficult to conclude which hybrid/variety will perform better at certain N level. Only testing different hybrids with N nutrition variables would demonstrate the efficiency of a particular hybrid.

Fertilizer application methods and timing are one of the most important factors affecting the fertilizer use efficiency (Mohammad et al., 1999). Out of different fertilizer application methods, fertigation is regarded as the most reliable one (Hou et al., 2003). However, among side-dressing and broadcasting, side-dressing is considered the better one (Chaudhary, Prihar, 1974). Foliar application of N is also an effective and economic method for improvement of quality characteristics of plants (Chauhan et al., 2004). Likewise, splitting N at different growth stages could also be beneficial in increasing the grain yield of maize hybrids (Sangoi et al., 2007). Similarly, Mungai et al. (1999) found that N splitting into two fractions produced significantly higher yields than conventional maize cultivation in the tested area (no top-dressing). So far, little is known about the strategies of N application which check the combine effects of fertigation, foliar and broadcast (at different rates and times) on the maize hybrids.

In Pakistan, so far many filed studies have been conducted which investigated the role of N doses and maize hybrids in improving the yield and yield components (Iqbal et al., 2010; Khan et al., 2011), but not enough work has been yet conducted which simultaneously determine the impact of N splitting doses, times and methods of application on the maize hybrids. In the light of the information presented above, a field study was planned with the aim of evaluating the response of potentially high yielding maize hybrids to differing N application strategies and find the N splitting doses and times for improving the yield of maize hybrids on economic basis.

Materials and methods

This study was conducted at Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan during spring of two growing seasons, 2010 and 2011. The experimental soil was analyzed for the various physico-chemical properties (Table 1). Soil texture was classified as a *Cambisol* (*CM*); soil ECe was determined by the Conductivity bridge method; soil pH was measured potentiometrically with glass electrode in a mixture of soil: water at ratio of 1:2.5 w/v; organic matter was determined by the Modified Walkley-Black procedure; soil nitrogen (N) was determined by the Kjeldahl method; available phosphorus (P) was measured by Olsen method and available potassium (K) was measured by flame photometry.

Table 1. Physico-chemical analysis of experimental soils before sowing the crop in 2010 and 2011

Determination	Units	Value	
		2010	2011
Soil texture	–	sandy clay loam	sandy clay loam
Sand	%	65	68
Silt	%	16	12
Clay	%	19	20
ECe	dS m^{-1}	1.69	1.34
pH	–	8.1	7.7
Organic matter	%	0.65	0.54
N	%	0.026	0.031
Available P	ppm	5.65	4.55
Available K	ppm	224	201

The total rainfall, maximum, minimum and average temperatures and relative air humidity data for 2010 and 2011 during the spring maize growing period (February–June) are shown in Table 2. There was considerable variability in rainfall amounts and distribution from year to year. The amount of rainfall and average relative air humidity were more suitable for plant growth in 2011 than in 2010.

Table 2. Weather conditions during the two growing seasons (2010 and 2011) for maize in Faisalabad, Pakistan

	Total rainfall mm		Temperature °C max		Temperature °C min		Average temperature °C		Relative humidity %	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
February	11.9	20.6	22	20.2	9.5	8.7	15.7	14.4	62.7	73
March	8.8	6.8	30.4	26.4	16.5	13.1	23.5	19.8	57.5	59.8
April	1.3	20.9	34.4	32.0	21.4	17.2	29.9	24.8	36.8	47
May	11.2	14.6	40.7	40.6	25.4	24.9	31.1	32.8	31.7	43
June	1	78.3	40.1	38.6	27.7	26	33.9	32.3	40	55
Mean	6.84	28.24	33.52	31.56	20.1	17.98	26.82	24.82	45.74	55.56

The experiment was laid out in a split plot design with four replications. Nitrogen application strategies, i.e. N_1 – 20% of N at sowing through broadcast + 79% N at mid-season through fertigation + 1% of N at flowering through foliar application, N_2 – 40% of N at sowing through broadcast + 59% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_3 – 60% of N at sowing through broadcast + 39% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_4 – 80% of N at sowing through broadcast + 19% of N at mid-season through fertigation + and 1% of N at flowering through foliar and N_5 – 100% of N at sowing through broadcast were randomized in sub plots, and maize hybrids (H), namely single cross-6142 (H_1) and double cross-4444 (H_2) were randomized in main plots. Each calculated amounts of N in different percentages for respective treatments were broadcast manually, fertigated with irrigation water and sprayed by using a manual knapsack sprayer ("Jacto Knapsack Sprayer", Pakistan). Potentially high yielding maize hybrids (single cross-6142 and double cross-4444) were selected for this study which performed well in different studies (Khan et al., 2011). Each experimental plot was 6 × 3 m. Pre-sowing irrigation was applied at the depth of 10 cm. At field capacity seedbed was prepared by cultivating the soil three times with a tractor mounted cultivator each followed by planking. After that ridges were made with a tractor mounted ridger. Hybrid seeds were sown on

75 cm apart ridges by manual dibbling method (by placing two seeds manually per hill at 25 cm apart hills) using a seed rate of 30 kg ha^{-1}. The amount of P and K (each 125 kg ha^{-1}) remained constant in all treatments. The sources of NPK in all the treatments were urea, single super phosphate (SSP) and sulphate of potash (SOP). The whole amount of P and K was added in the soil at the time of sowing whilst N was applied according to each treatment. All other agronomic practices (irrigation, thinning, weed control, insect/pest control, etc.) were kept constant and uniform for all treatments. Crop was irrigated seven times at 7.5 cm depth. First irrigation was applied twenty five days after sowing while subsequent irrigations were applied with fifteen days intervals till flowering and from flowering to seed formation irrigations were applied with seven days intervals due to high water requirement of spring maize. Thinning was done at 3–4 leaf stage to maintain the single plant at each hill. Crop was kept free of weeds by hoeing twice to avoid weed-crop competition. Insecticide Furdan (active ingredient carbofuran 44 wt %) was applied 17.29 kg ha^{-1} to control the insect attacks (particularly maize stem borer (*Chilo partellus* Swin)) during whole maize growing season.

The data on agronomic and quality parameters were collected. Plant height at maturity was measured on ten randomly selected plants per plot using a measuring tape and the values were averaged. Number of grains per cob was determined by collecting ten cobs per plant and their grains were shelled, counted and then averaged. For 1000-grain weight, grains were counted per plot and weighed. Grain pith ratio was calculated using the formula: GPR = grain yield/pith yield. For cob sheath ratio, ten cobs were weighed with and without sheath and their ratio were determined. For biological yield, plants from each subplot were harvested manually, sun dried and weighed to determine the biological yield in kg per plot and then converted to t ha^{-1}. Similarly, for grain yield, cobs were separated from each harvested plot, sun dried, shelled and their grains were weighed and finally converted into t ha^{-1}.

For grain protein content, total N in grain was determined by Gunning and Hibbards method of sulphuric acid digestion and distillation by micro-Kjeldhal method. Nitrogen percentage was then multiplied by a constant factor 6.25 for calculating protein content in the grain. The oil content in grains was determined by means of Soxhlet fat extraction method. However, for grain starch content the sample was treated with 80% alcohol to remove sugars and then starch was extracted with perchloric acid. In hot acid medium, starch was hydrolyzed to glucose and dehydrated to hydromethyl furfural. This compound formed a green colour product with anthrone.

The data collected from the experiment on various parameters were statistically analyzed by using Fisher's analysis of variance technique and the difference among the treatments' means were compared using least significant difference (LSD) test at 5% probability level (Steel et al., 1997). On the other hand, economic analysis was also conducted for all the treatments in order to determine the net income and benefit cost ratio according to the method described in manual CIMMYT (1988). The purpose of this analysis was to estimate the economic returns of each productivity level.

Results and discussion

Plant height was significantly affected by year, hybrids (H), nitrogen (N) application strategies and H × N interactions (Table 3). The highest plant height was obtained in 2011. This result could be explained by differences in the weather conditions especially total rainfall amount and its distribution between years. Data further indicated that during both years maximum plant height was produced by H_1 compared to H_2. These results clearly suggested higher genetic potential of H_1. Similar findings have been reported by Griesh and Yakout (2001) and Khan et al. (2011). Among N application strategies, maximum plant height was obtained at N_3 during both years, whilst minimum plant height was obtained at N_5 during both years. Increasing trend of plant height under N nutrition was also observed by Iqbal et al. (2010). The maximum height of plants treated with N_3 might be due to better supply of N at different stages of crop development. Interactions between hybrids and N fertilization show that in both years maximum plant height was produced by the H_1 with N_3 during both experimental years (Table 6). However, in 2011 it was found statistically similar to $H_1 \times N_2$. Similar results of N and hybrid interaction on plant height were also noted by Kamara et al. (2006).

Number of grains per cob was significantly affected by year (Table 3). Higher number of grains per cob was recorded in 2011 than in 2010. This shows that differences in weather conditions over years might have affected the number of grains per cob. Results show that in both years H_1 produced higher number of grains per cob compared to H_2 (Table 3). Higher number of grains per cob indicated the better genetic potential of H_1. Similar results were obtained by Griesh and Yakout (2001) and Khan et al. (2011). As far as N application strategies were concerned, maximum number of grains per cob was produced in N_3 during both growing seasons (Table 3). However, in 2011 it was found at par with N_2 and N_1. In both years, minimum number of grains per cob was produced in N_5. Adequate N promotes the grain-filling as a result of stimulation of many physiological processes (Ning et al., 2010). So, the highest number of grains per cob in the case of N_3 might be due to optimum nutrition of N to the plants. Moreover, the least number of grains with N_5 was owing to the fact that, through broadcast, most of the nutrients become unavailable to the plants as a result of heavy losses. Interactions between hybrids and strategies of N fertilization exhibited no significant effect on the parameter under discussion during both years (Table 3). Contradictory results of interaction were obtained by Khan et al. (2011) for number of grains per cob.

There was a clear and significant difference among the years on the 1000-grain weight (Table 3). 1000-grain weight declines as a result of poor seed filling in years without enough rain and water in the soil. This was the case in the 2010 experiment. Similar results have been reported by Ozer (2003). Similarly, hybrids and N application strategies exhibited highly significant effect on 1000-grain weight in 2010 as well as in 2011 (Table 3). During both years, the maximum weight of 1000-grain was recorded in plants of H_1 with respect to the other hybrid. These results depicted the superiority of single cross hybrid over the double cross hybrid (Griesh, Yakout, 2001; Khan et al., 2011). In N fertilization strategies, during both years N_3 gave maximum 1000-grain weight, whilst minimum 1000-grain weight was produced by N_5 in both experimental years. Increased weight of 1000-grain suggested a substantial utilization of N by plants throughout their growing period. Similarly, Kamara et al. (2006) reported that adequate N fertilization increased the kernel weight. However, during both years interactions between hybrids and strategies of N application were not found significant (Table 3). These results disagree with the finding of Khan et al. (2011), who reported significant interaction of N and hybrids for 1000-grain weight.

Table 3. Effect of hybrids (H) and nitrogen (N) application strategies on plant height, number of grains per cob and 1000-grain weight of maize during 2010 and 2011

Treatments	Plant height cm		Number of grains per cob		1000-grain weight g	
	2010	2011	2010	2011	2010	2011
H_1	216.4 a	233.3 a	354.79 a	368.61 a	243.61 a	246.15 a
H_2	191.7 b	200.8 b	287.11 b	296.13 b	213.81 b	228.07 b
LSD	13.73	1.47	4.98	4.29	8.48	9.19
N_1	204.2 b	219.4 b	324.92 c	337.88 ab	231.77 c	242.95 c
N_2	227.1 a	229.3 b	340.80 b	345.27 a	239.78 b	252.52 b
N_3	233.2 a	241.8 a	352.86 a	360.48 a	257.27 a	265.67 a
N_4	182.8 c	189.7 c	294.55 d	315.23 bc	216.22 c	218.42 d
N_5	172.8 d	180.8 c	291.62 e	302.98 c	198.50 e	206 e
LSD	7.92	2.94	2.27	4.34	6.82	7.84
Year means	204.1 B	212.1 A	320.95 B	332.37 A	228.71 B	237.11 A
LSD	6.93		8.34		7.65	
H × N	*	*	NS	NS	NS	NS

Note. Means sharing similar letter(s) do not differ significantly at $p = 0.05$; * – significant, NS – non-significant; N_1 – 20% of N at sowing through broadcast + 79% N at mid-season through fertigation + 1% of N at flowering through foliar application, N_2 – 40% of N at sowing through broadcast + 59% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_3 – 60% of N at sowing through broadcast + 39% of N at mid-season through fertigation + 1% of N at flowering through foliar, N_4 – 80% of N at sowing through broadcast + 19% of N at mid-season through fertigation + and 1% of N at flowering through foliar and N_5 – 100% of N at sowing through broadcast; H_1 – single cross hybrid-6142, H_2 – double cross hybrid-4444.

Grain:pith ratio was significantly affected by year, hybrids, N application strategies and H × N interaction (Table 4). Higher increase in grain:pith ratio was observed in 2011 compared to 2010. In this research, during both years higher grain:pith ratio was produced by H_1 over the other. This was due to better genetic ability of single cross hybrid as compared to double cross (Griesh, Yakout, 2001). Among strategies of N application, N_3 gave the highest grain:pith ratio during both (2010 and 2011) growing seasons. The minimum grain:pith ratio was observed in plants treated with N_5. The high grain:pith ratio in the case of N_3 might be due to optimum supply of N at various growth stages. The low grain:pith ratio might be obtained due to higher losses of applied N through broadcast. However, interactive effect of H_1 and N_3 gave maximum grain pith ratio (Table 6). It was due to increased number of grains and 1000 grain weight by H_1 with N_3.

There was no effect of year on the cob:sheath ratio (Table 4). The outcomes of the present research depict that in both years the highest cob:sheath ratio was attained in H_1 than the H_2. Our results proved the superiority of single cross hybrid (Griesh, Yakout, 2001). In N application strategies, during both years highest cob:sheath ratio was observed with N_3 (Table 4). However, in 2011 it was found statistically at par with N_2. These results might be obtained due to better development of cob on account of optimum supply of N through

Table 4. Effect of hybrids (H) and nitrogen (N) application strategies on grain:pith ratio, cob:sheath ratio, biological yield and grain yield of maize during 2010 and 2011

Treatments	Grain:pith ratio		Cob:sheath ratio		Biological yield t ha^{-1}		Grain yield t ha^{-1}	
	2010	2011	2010	2011	2010	2011	2010	2011
H_1	2.70 a	3.13 a	15.71 a	16.04 a	14.83 a	15.69 a	5.01 a	6.02 a
H_2	2.09 b	2.14 b	10.98 b	13.18 b	11.13 b	11.97 b	4.02 b	4.08 b
LSD	0.06	0.60	0.56	1.79	0.04	0.59	0.03	0.34
N_1	2.25 c	2.47 c	13.21 c	15.66 b	12.22 c	13.91 c	4.34 c	5.3 c
N_2	2.83 b	3.01 b	15.73 b	16.7 ab	15.23 b	15.44 b	5.61 b	6.18 b
N_3	3.10 a	3.45 a	17.14 a	17.9 a	16.99 a	17.62 a	6.83 a	7.16 a
N_4	2.0 d	2.2 cd	11.26 d	12.2 c	11.15 d	11.4 d	3.04 d	3.45 d
N_5	1.82 e	2.03 d	9.38 e	10.58 c	9.33 e	10.77 d	2.76 e	3.16 d
LSD	0.04	0.27	0.21	2.20	0.01	1.45	0.02	0.40
Year means	2.40 B	2.64 A	13.35	14.10	12.98 B	13.83 A	4.51 B	5.05 A
LSD	0.22		NS		0.46		0.19	
H × N	*	*	NS	NS	*	*	*	*

Explanations under Table 3

different strategies. Nonetheless, cob:sheath ratio was not significantly affected by interactions between hybrids and N application strategies (Table 4), and it was found contradictory to Khaliq (2008) who reported that cultivars and N significantly affected the cob:sheath ratio.

Biological yield was significantly affected by the year (Table 4). Higher biological yield was recorded in 2011 than in 2010. These results might be obtained due to favourable environmental conditions in 2011. Maize hybrids, N application strategies and H × N had also significant effect on the biological yield during both years (Table 4). Higher biological yield was obtained in H_1 as compared to H_2. Similar results have been reported by Griesh and Yakout (2001). Findings further revealed that in 2010 and 2011 the highest biological yield was produced by the fertilization of N_3 compared to other strategies. The increase in biological yield was due to better growth and development of plants under balanced supply of N at all growth stages. These results are in line with the findings of Arif et al. (2010), who reported that an increase in biological yield was observed by application of N in splits at different growth stages. Among interactions, $H_1 \times N_3$ produced more biological yield in both seasons (Table 6). However, it was recorded at par with $H_1 \times N_2$ in 2011. Similar results were obtained by Khan et al. (2011).

Grain yield was also statistically significantly affected by the year (Table 4). The higher grain yield was obtained in 2011 than in 2010. In 2011, favourable climatic conditions might have resulted in more grain yield. However, hybrids, N application strategies and H × N had also highly significant effect on the grain yield (Table 4). Our results show that during both years H_1 yielded maximum compared to H_2 (Table 3). It might be due to the better yield potential of single cross hybrid (Griesh, Yakout, 2001). However, in both years highest grain yield was produced in N_3 over the others. Better yield of maize always demands optimum supply of N (Bertin, Gallais, 2000). Therefore, more grain yield by the application of N_3 might be due to balanced supply of N at different stages of crop development. Kamara et al. (2007), Iqbal et al. (2010) and Khan et al. (2011) also reported an increase in yield by N fertilization. These results are also in line with the finding of Tahir et al. (2008). Moreover, during both years interaction of $H_1 \times N_3$ was found superior in increasing the grain yield (Table 6). These facts have also been reported by Cui et al. (2009) and De Carvalho et al. (2012), who reported significant effects of interaction between hybrids and N nutrition for grain yield.

Table 5. Effect of hybridsn (H) and nitrogen (N) application strategies on quality components of maize during 2010 and 2011

Treatments	Grain protein content %		Grain oil content %		Grain starch content %	
	2010	2011	2010	2011	2010	2011
H_1	8.03 a	9.05 a	3.54 a	3.9 a	65.94 a	67.35 a
H_2	6.89 b	6.93 b	3.13 b	3.39 b	60.05 b	64.72 b
LSD	0.04	0.27	0.09	0.08	4.96	1.04
N_1	7.05 c	7.58 c	3.31 bc	3.72 c	62.96 c	66.64 c
N_2	8.07 b	8.11 b	3.27 c	3.3 d	67.20 b	68.04 b
N_3	9.43 a	9.84 a	2.70 d	2.89 e	69.17 a	69.63 a
N_4	6.84 d	7.41 c	3.38 b	3.98 b	59.87 d	63.63 d
N_5	5.91 e	7.02 d	4.01 a	4.33 a	56.77 e	62.26 e
LSD	0.05	0.49	0.08	0.14	3.87	0.49
Year means	7.46 B	7.99 A	3.33 B	3.65 A	62.99 B	66.04 A
LSD	0.30		0.07		0.56	
H × N	*	*	*	*	*	*

Explanations under Table 3

Table 6. Interactive effects of hybrids (H) and nitrogen (N) application strategies on plant height, grain:pith ratio, biological yield and grain yield of maize during 2010 and 2011

H × N	Plant height cm		Grain:pith ratio		Biological yield t ha^{-1}		Grain yield t ha^{-1}	
	2010	2011	2010	2011	2010	2011	2010	2011
$H_1 \times N_1$	192.5 d	237.1 bc	2.65 d	2.88 c	13.27 f	17.0 bc	4.92 e	6.53 c
$H_1 \times N_2$	238.1 b	247.7 ab	3.13 b	3.86 b	16.26 c	18.26 ab	6.21 b	7.85 b
$H_1 \times N_3$	254.4 a	258.4 a	3.27 a	4.46 a	17.55 a	20.0 a	7.53 a	8.83 a
$H_1 \times N_4$	219.4 c	190.8 ef	2.26 f	2.37 de	15.18 d	11.97 de	3.15 h	3.62 fg
$H_1 \times N_5$	177.6 e	182.6 f	2.21 f	2.06 de	11.90 g	11.21 de	3.25 g	3.29 g
$H_2 \times N_1$	215.9 c	201.6 de	1.85 g	2.06 de	11.18 h	10.83 de	3.75 f	4.06 ef
$H_2 \times N_2$	216.1 c	211.0 d	2.52 e	2.16 de	14.20 e	12.62 d	5.01 d	4.51 e
$H_2 \times N_3$	212.0 c	225.1 c	2.92 c	2.45 cd	16.43 b	15.25 c	6.12 c	5.5 d
$H_2 \times N_4$	146.3 f	188.6 ef	1.73 h	2.03 e	7.11 i	10.83 de	2.93 i	3.28 g
$H_2 \times N_5$	168.1 e	178.1 f	1.44 i	2.0 e	6.75 j	10.33 e	2.28 j	3.03 g
LSD	11.20	1.07	0.06	0.39	0.03	2.05	0.02	0.56

Explanations under Table 3

Grain protein content was significantly affected by the year, hybrids, N strategies and H × N interaction (Table 5). Mean comparison of the two year data revealed that higher protein content was recorded in 2011. These results could be obtained due to plant stress in March, 2011 when the rainfall was low (6.8 mm) (Table 2). Similarly, Fowler et al. (1990) also reported higher grain protein content due to limited water availability in soil. The results further revealed that during both years in H_1 compared to H_2 higher grain protein content was observed. Difference in grain protein was due to hybrid potential (Khan et al., 2011). In the case of N application strategies, during 2010 and 2011 maximum grain protein content was recorded by using the N_3. These results are related to the finding of Thomison et al. (2004) and Gallais et al. (2008), who reported that N application by different methods and at different timing had significant effect on grain protein content. However, reduced grain protein content was obtained in N_5. This might be due higher losses of N applied through broadcast.

Among the interactions, during both years interaction between H_1 and N_3 was more productive in enhancing the grain protein concentration (Table 7). Similar results were observed by Khan et al. (2011).

Year, hybrids, N application strategies and H × N had also significant effect on grain oil content (Table 5). In 2010 and 2011, the determined grain oil content was 3.33% and 3.65%, respectively. In 2010, the reduction in oil content was thought to be the result of unsuitable weather conditions. The increased temperature and water stress during grain filling was a major cause of reduced oil concentration. Similar results have been reported by Ozer (2003). Among hybrids, the highest grain oil content was observed in H_1 during 2010 as well as 2011. The difference in grain oil contents may be due to genetic makeup of cultivars (Griesh, Yakout, 2001; Khan et al., 2011). In the case of N application strategies, in 2010 and 2011 N_5 gave maximum grain oil content while minimum grain oil content was produced in N_3. These results might be obtained due to higher negative relation between N and oil content. Reduced concentration of grain oil in N_3 was due to higher supply of N. Likewise, Iqbal et al. (2010) and Khan et al. (2011) reported that N had little/no effect on grain oil content. Moreover, interactive effects of hybrids and N application strategies show that during both years maximum grain oil content was produced by $H_1 \times N_5$ (Table 7). Such results might be obtained due to inadequate supply of N by N_5, which produced high oil content in H_1.

The effect of year on the grain starch content was found significant (Table 5). Statistically, higher grain starch content was observed in 2nd (2011) year compared to 1st (2010) year. Among hybrids, during both years H_1 performed well in production of grain starch content than H_2. This was due to variation in the genetic makeup of hybrids (Griesh, Yakout, 2001; Khan et al., 2011). The effect of N application strategies on grain starch content was also found significant in both experimental years (Table 5). The maximum grain protein content was recorded in N_3, whilst the minimum grain starch content was recorded in N_5. These results are in line with the results of Singh et al. (2005), who reported that grain starch content was significantly affected by N application rate and method. The interactive effect of hybrids and N application strategies on the parameter under discussion was also proved significant during both years (Table 7). The maximum grain starch content was produced by $H_1 \times N_3$, while, the lowest grain starch content was recorded in H_1 with N_5. Increased grain starch concentration in H_1 with N_3 might be due to balanced supply of N. Similar results have been reported by Singh et al. (2005).

Table 7. Interactive effects of hybrids (H) and nitrogen (N) application strategies on quality components of maize during 2010 and 2011

H × N	Grain protein content %		Grain oil content %		Grain starch content %	
	2010	2011	2010	2011	2010	2011
$H_1 \times N_1$	7.05 e	8.25 c	3.38 cd	4.03 c	63.48 f	68.56 c
$H_1 \times N_2$	8.09 d	9.18 b	3.81 b	3.39 ef	68.60 b	69.63 b
$H_1 \times N_3$	9.81 a	11.83 a	3.12 e	3.09 g	69.77 a	71.76 a
$H_1 \times N_4$	8.63 c	8.12 c	3.45 c	4.29 b	65.51 e	63.93 ef
$H_1 \times N_5$	6.58 f	7.89 c	3.95 a	4.68 a	62.32 g	62.90 g
$H_2 \times N_1$	7.06 e	6.91 d	3.24 de	3.42 e	62.44 h	64.72 e
$H_2 \times N_2$	8.04 d	7.03 d	2.74 f	3.2 fg	65.81 d	66.45 d
$H_2 \times N_3$	9.04 b	7.85 c	2.27 g	2.7 h	68.56 c	67.5 c
$H_2 \times N_4$	5.05 h	6.7 d	3.32 cd	3.67 d	54.23 i	63.33 fg
$H_2 \times N_5$	5.24 g	6.16 e	4.07 a	3.98 c	51.22 j	61.63 h
LSD	0.06	0.49	0.06	0.20	5.47	0.69

Explanations under Table 3

Economic analysis was also performed which revealed that $H_1 \times N_3$ gave the highest net income during both experimental years as compared to other treatments (Table 8). However, the highest benefit cost ratio was also obtained with the treatment $H_1 \times N_3$.

Table 8. Effect of hybrids (H) and nitrogen (N) application strategies on the net income and benefit cost ratio during 2010 and 2011

Treatments	Total expenditure USD ha^{-1}		Gross income USD ha^{-1}		Net income USD ha^{-1}		Benefit cost ratio	
	2010	2011	2010	2011	2010	2011	2010	2011
$H_1 \times N_1$	745	757	1501	1542	755	784	2.01	2.04
$H_1 \times N_2$	774	786	1782	1837	1008	1051	2.30	2.34
$H_1 \times N_3$	803	816	2023	2088	1220	1272	2.52	2.56
$H_1 \times N_4$	716	726	1240	1273	523	546	1.73	1.75
$H_1 \times N_5$	723	735	1314	1342	591	607	1.82	1.83
$H_2 \times N_1$	730	743	1365	1408	635	665	1.87	1.89
$H_2 \times N_2$	752	765	1511	1566	759	801	2.01	2.05
$H_2 \times N_3$	759	772	1782	1828	1023	1056	2.35	2.37
$H_2 \times N_4$	701	706	1171	1192	469	486	1.67	1.69
$H_2 \times N_5$	694	706	1127	1165	433	458	1.62	1.65

Explanations under Table 3

Conclusion

Single cross hybrid-6142 (H_1) proved superior as compared to double cross hybrid-4444 (H_2). However, strategy N_3 (60% of N at sowing through broadcast + 39% of N at mid-season through fertigation + 1% of N at flowering through foliar) was most beneficial of all strategies tested. Hence, H_1 could be grown successfully on economic basis with N_3 for increasing grain yield and grain quality attributes.

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Tręšimo azotu įtaka paprastojo kukurūzo (*Zea mays* L.) hibridų produktyvumui

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Santrauka

Azotas (N) yra vienas pagrindinių veiksnių, turinčių įtakos augalų produktyvumui. Lauko eksperimentas buvo atliktas, siekiant ištirti šių tręšimo azotu strategijų: N_1 – 20 % N sėjos metu pakrikai + 79 % N viduryje sezono fertigacijos būdu + 1 % N žydėjimo metu per lapus, N_2 – 40 % N sėjos metu pakrikai + 59 % N viduryje sezono fertigacijos būdu + 1 % N žydėjimo metu per lapus, N_3 – 60 % N sėjos metu pakrikai + 39% N viduryje sezono fertigacijos būdu + 1 % N žydėjimo metu per lapus, N_4 – 80 % N sėjos metu pakrikai + 19 % N viduryje sezono fertigacijos būdu + ir 1 % žydėjimo metu per lapus ir N_5 – 100 % N sėjos metu pakrikai, įtaką kukurūzų hibridų – vieno kryžminimo hibrido 6142 (H_1) ir dvigubo kryžminimo hibrido 4444 (H_2) produktyvumui dvejų metų (2010–2011 m.) laikotarpiu. Taikant skirtingas tręšimo azotu strategijas, abiem metais kukurūzų hibridai reikšmingai skyrėsi visais tirtais derliaus ir jo kokybės požymiais. Didžiausi biologinis (16,99–17,62 t ha^{-1}) ir grūdų (6,83–7,16 t ha^{-1}) derliai buvo gauti taikant N_3 tręšimo strategiją. Panašios tendencijos buvo nustatytos ir kitų požymių, išskyrus aliejaus kiekį kukurūzų grūduose, kuris buvo didžiausias (3,38–3,98 %) taikant N_5 tręšimo strategiją. Tačiau abiem metais didžiausi biologinis (14,83–15,69 t ha^{-1}) ir grūdų (5,01–6,02 t ha^{-1}) derliai gauti H_1 augalų. Didžiausi biologinis (17,55–20 t ha^{-1}) ir grūdų (7,53–8,83 t ha^{-1}) derliai buvo gauti dėl derinio $H_1 \times N_3$ sąveikos. 2010 ir 2011 m. didžiausios grynosios pajamos (1220–1272 USD ha^{-1}) ir didžiausias naudos bei sąnaudų santykis (2,52–2,56) taip pat buvo gautas dėl derinio $H_1 \times N_3$ sąveikos. Tyrimo rezultatai parodė, kad ekonominiu atžvilgiu (naudos ir sąnaudų santykis 2,52–2,56) kukurūzų produktyvumas gali būti pagerintas (grūdų derlius iki 5,01–6,02 t ha^{-1}), auginant vieno kryžminimo hibridą 6142 (H_1) ir taikant N_3 tręšimo strategiją.

Reikšminiai žodžiai: derlius, kokybės komponentai, tręšimas azotu, *Zea mays*.