The Journal of Animal & Plant Sciences, 25(4): 2015, Page: 1022-1031
ISSN: 1018-7081

RESPONSE OF MAIZE YIELD, QUALITY AND NITROGEN USE EFFICIENCY INDICES TO DIFFERENT RATES AND APPLICATION TIMINGS

A. Niaz[*1, 2], M. Yaseen[2], M. Arshad[2] and R. Ahmad[3]

[1]Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute, Faisalabad, Pakistan
[2] Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad, Pakistan
[3] Department of Crop Physiology, University of Agriculture Faisalabad, Pakistan
[*]Corresponding Author's e-mail: abdullahniaz@ymail.com

ABSTRACT

Efficient use of nitrogen by maize warrants screening for an adequate amount to be applied at effective timing which could bring synchronization between N demand and its supply through fertilizer, increasing production and N use efficiency. A 4 × 5 factorial experiment was conducted to assess the effect of variable nitrogen rates and various application timing schemes on yield, quality, and nitrogen use efficiency indices of maize in randomized complete block design with three replications. Four N rates (N1 = 125, N2 = 150, N3 = 175 and N4 = 200 kg N ha^{-1}) were subjected to various timing schemes (S1 = 100% N before planting, S2 = 75% N before planting + 25% N at V9 (9 leaves stage), S3 = 50% N before planting + 50% N at V9, S4 = 25% N before planting + 75% N at V9 and S5 = 100% N top dressed at V9). Results indicated that delaying more than 25% of N rate late up to the V9 stage proved significantly better regarding all the studied parameters while S1 timing scheme was found to be least effective. The treatment combinations N4S3, N4S4 and N3S4 were significantly at par ($P>0.05$) giving 7.49, 7.34 and 7.12 t ha^{-1} grain yield, respectively. Treatment N3S4 provided significantly higher ($P<0.05$) N-partial factor productivity (40.68 kg kg^{-1}) and agronomic-N efficiency (28.22 kg kg^{-1}). Nitrogen rate N4 produced significantly higher ($P<0.05$)N concentration in stover (0.40%) and total N accumulation (173.86 kg ha^{-1}). Grain N concentration, grain protein concentration, grain oil concentration, N-uptake efficiency, N-physiological efficiency and N-internal utilization efficiency could not be significantly affected by N application rate of N4 above N3. Nitrogen rate N3 gave the highest degree of synchrony between N demand and supply. Nitrogen rates N1 and N2 gave significantly lower results than N3 and N4. It is concluded that split application of N3 through timing scheme S4 could be appropriate one giving higher production, grain quality and N use efficiency.

Key words: Nrate, application timing, N use efficiency, Synchrony between N demand and supply, maize.

INTRODUCTION

Fertilizers must be applied at levels required for best possible growth of crop in view of agro-climatic considerations and crop requirements. Higher fertilizer N rates could cause the lodging risk, encouraged diseases and commonly reduced the nitrogen use efficiency (Karim and Ramasamy, 2000; Halvorson *et al*., 2005). On the other hand, under application of fertilizers can obstruct crop growth bringing lower yields in the short term while in the long term it endangers sustainability in the course of erosion and soil mining. The low chemical fertilizer application rate together with decline in organic matter content of soil has a major role in curving the soil fertility (Kumwenda *et al*., 1996). Therefore, screening for the best appropriate N application rates is very much indispensable.

Nitrogen application timing is critical and is regarded the most important decision for high yielding hybrid maize production (Walsh, 2006). Synchronization between N supply and demand enhances N uptake rates and increase N use efficiency thereby reducing N losses (Rizwan *et al*., 2003). According to Binder *et al*. (2000) fast developmental phase of maize starts from V6 during which highest N uptake takes place, therefore, maize responds to the belated N application. According to Hassan *et al*. (2010), N application from V8 to V10 growth stages could be the appropriate time of N supply to convene its high demand. Nitrogen application during late vegetative growth was also supported by Schmidt *et al*. (2002) and Muthukumar *et al*. (2005) to be a means of increasing nitrogen use efficiency.

Partial factor productivity (PFP), agronomic efficiency (AE), uptake efficiency (RE), physiological efficiency (PE) and internal utilization efficiency (IE) constitute a set of simple indices and could be used in agronomic research to appraise the applied fertilizer efficiency particularly to assess the short-term response of crop to a nutrient (Cassman *et al*., 2002; Dobermann, 2007). Use of some other indices is also in practice but no additional advantages could have been reported for understanding fertilizer best management practices. More detailed insight into the fate of nutrients in agro-ecosystems could involve isotopes, which are principally helpful for understanding losses regarding immobilization, fixation and release mechanisms. But the 'difference method' (calculation of nutrient use efficiencies using differences in crop yield and/or nutrient uptake between fertilized plots and an unfertilized control) is cost-efficient and simple making it particularly suitable for on-farm research (Dobermann, 2007). To evaluate the effect of various rates of N fertilizer and N application timing schemes on harvest, grain quality, N accumulation and use efficiency of maize plants, four rates of nitrogen (125, 150, 175 and 200 kg N ha^{-1}) were subjected to various ratios between basal dose (broadcast-incorporated at the time of seed bed preparation) and top dressing at V9 growth stage (9 leaf stage) of maize.

MATERIALS AND METHODS

Site Description: Field experiment was conducted in 2010 at Research Farms (31°N: 73°E and 184.4 m above sea level), University of Agriculture Faisalabad, Pakistan. Soil was sandy clay loam with pH 7.7; Saturation 35%; EC_e 3.2 dS m^{-1}; CEC 6.1 $cmol_{(+)}$ kg^{-1}; Organic matter 0.61%; Total nitrogen 0.02%; Available P 6.9 mg kg^{-1} and Exchangeable K 129 mg kg^{-1}.

Experimentation: A 4 × 5 factorial experiment was conducted in randomized complete block (RCB) design using three replications. Seedbed was prepared by cultivating the soil for 2-3 times with tractor mounted cultivator followed by planking. Maize hybrid (Monsanto: DK-6525) was sown on February 18, 2010 using 75 cm apart ridges within an experimental plot of size 10 m^2. Sowing was done manually with the help of dibbler by maintaining plant to plant distance of 20 cm and 2-3 seeds were placed per hole. Thinning was done after germination to keep one plant and maintain plant to plant distance, giving the recommended plant density of 66666 maize plants ha^{-1}. To all the experimental plots, whole of the P_2O_5 (@ 150 kg ha^{-1}) and K_2O (@ 100 kg ha^{-1}) was applied through Single Super Phosphate (SSP) and Sulphate of Potash (SOP), respectively, at sowing time; however, nitrogen was applied between two stages; seed bed preparation and V9 (9 leaves stage) according to the theme of each treatment. Four N rates; N1 (125 kg N ha^{-1}), N2 (150 kg N ha^{-1}), N3 (175 kg N ha^{-1}) and N4 (200 kg N ha^{-1}) were tested in this experiment, while various N application timing schemes included; S1 (100% N broadcast-incorporated before planting at seed bed preparation), S2 (75% N broadcast-incorporated before planting at seed bed preparation + 25% N top dressed at V9), S3 (50% N broadcast-incorporated before planting at seed bed preparation + 50% N top dressed at V9), S4 (25% N broadcast-incorporated before planting at seed bed preparation + 75% N top dressed at V9) and S5 (100% N top dressed at V9). Two controls; C1 (nothing applied) and C2 (only P_2O_5 and K_2O) were also kept in the study. Meteorological data was taken from nearly situated agricultural meteorology cell. Throughout the experiment (from sowing toharvesting on May 28, 2010), average temperature, average relative humidity, total rainfall, average sun shine, average evapotranspiration and average wind speed were recorded to be 27.4 ºC, 44.2%, 21.3 mm, 8.7 hours, 4.7 mm and 4.8 km h^{-1}, respectively. A total of 6 irrigations were applied using canal water up to physiological maturity of the crop. Weeds were controlled manually. Granular insecticide Furadon (3% G) (FMC, Pakistan) was applied twice @ 20 kg ha^{-1} to control stem borer. Grain yield was recorded on subplot basis and then converted into tons per hectare (t ha^{-1}). Biological yield comprises grain, stover and pith yield. Crop from each subplot was harvested manually, sun dried and weighed to determine the biological yield in kg per plot and then converted to t ha^{-1}. Nitrogen content of maize grain and stover samples collected from each subplot was determined by using the micro-Kjeldhal method. After oven drying and recording the weights plant samples were milled to a fine powder with a particle size <0.2 mm to determine the total nitrogen content and calculate total N accumulation in above ground parts in kg ha^{-1}. Grain Protein Concentration (%) was determined using the formula;

Grain Protein Concentration (%) = Grain N (%) x 6.25 (Amanullah, 2004)

Oil content (%) of the representative seed sample was determined by Soxhlet method described by Low (1990). While, agronomic indices used to measure nitrogen use efficiency included;

N-Partial Factor Productivity

$$PFP_N = \text{kg harvested product per kg nitrogen applied}$$

$$= \frac{\text{Yield (kg ha}^{-1}\text{)}}{\text{N applied (kg ha}^{-1}\text{)}}$$

N-Agronomic Efficiency

AE_N = kg yield increase per kg nitrogen applied

$$= \frac{\text{Grain yield from plots with N (kg ha}^{-1}\text{) - Grain yield from plots without N (kg ha}^{-1}\text{)}}{\text{N applied (kg ha}^{-1}\text{)}}$$

N Uptake/Recovery Efficiency

RE_N = kg increase in N accumulation per kg N applied

$$= \frac{\text{N accumulation from plots with N (kg ha}^{-1}\text{) – N accumulationfrom plots without N (kg ha}^{-1}\text{)}}{\text{N applied (kg ha}^{-1}\text{)}}$$

N-Physiological Efficiency

$$PE_N = \text{kg yield increase per kg increase in N accumulation from fertilizer}$$

$$= \frac{\text{Grain yield from plots with N (kg ha}^{-1}\text{) - Grain yield from plots without N (kg ha}^{-1}\text{)}}{\text{N accumulation from plots with N (kg ha}^{-1}\text{) – N accumulation from plots without N (kg ha}^{-1}\text{)}}$$

N-Internal Utilization Efficiency

$$IE_N = \text{kg yield per kg nutrient accumulation}$$

$$= \frac{\text{Grain Yield (kg ha}^{-1}\text{)}}{\text{N accumulation (kg ha}^{-1}\text{)}}$$

Degree of Synchrony between N Demand and Supply

Expression that represents the degree of synchrony between N supplyand demand:

$$F_N/(1-I_N/U_N)$$

Where;

- U_N: Crop N accumulation in aboveground biomass at physiological maturity in N-fertilized plots (kg N ha^{-1})
- I_N: Crop N accumulation in control plots without applied N (kg N ha^{-1})
- F_N: The amount of applied N fertilizer (kg N ha^{-1}).

More the value of this expression, lesser will be the synchrony between N supply and demand and vice versa.

Statistical Analysis: Data were subjected to analysis of variance (ANOVA) and for significant differences between treatment means; least significant difference test (LSD) at P ≤ 0.05 (Steel *et al*., 1997) was used. Summary of ANOVA is given in Table I.

RESULTS

Grain and biological yields: The maximum grain yield (7.49 t ha^{-1}) was recorded with higher N rate (N4) when subjected to timing scheme S3. Nevertheless, other combinations, N4S4 (7.34 t ha^{-1}) and N3S4 (7.12 t ha^{-1}) were also at par to N4S3 for higher grain yields (Figure 1). Similarly, the interaction N4S3 provided highest biological yield (18.82 t ha^{-1}), while the combination N4S4 was also at par giving 18.71 t ha^{-1} biological yield (Figure 2). The minimum grain (3.22 t ha^{-1}) and biological yields (11.66 t ha^{-1}) were recorded with treatment combination of N1S1.

N accumulation parameters: The N application rate of 175 kg ha^{-1} (N3) showed plants with maximum grain nitrogen concentration (1.31%) but the upper application of 200 kg ha^{-1} (N4) was also at par to N3 with 1.30% nitrogen in grains. Stover nitrogen concentration and total above ground crop N accumulation consistently increased with increase in nitrogen rates, being maximum (0.40% and 173.68 kg ha^{-1}, respectively) using N application rate N4 (Table II).

Regarding N application timings, timing scheme S4 provided the maximum grain (1.27%) and stover nitrogen (0.38%) concentrations. Total above ground crop N accumulation was maximum (160.36 kg ha^{-1}) with S4 treatment and it was at par with S3 (153.77 kg ha^{-1}) while significantly higher from all other S treatments. The decreasing order of S treatments for total above ground crop N accumulation was found as S4 > S3 > S5 > S2 > S1 (Table II). Therefore, it is obvious that decrease in basal N dose and increasing the quantity of N in second split to be applied at V9 significantly enhanced nitrogen accumulation but complete elimination of basal N reversed this increasing trend (Table II).

Grain quality parameters: The grain crude protein and the grain oil concentration increased with increase in nitrogen but up to N3 (175 kg ha^{-1}). Further increase to N4 (200 kg ha^{-1}) could not affect significantly rather curved the measurements from 8.18 to 8.14% and 4.21 to 4.19% compared to N3, respectively (Table II).

Application of more nitrogen in second split at V9 significantly increased the grain protein and oil concentration but up to S4 and when the entire nitrogen was applied at V9 (S5) the grain protein and oil decreased again; the maximum being observed as 7.93% and 4.08%, respectively with S4 treatment and it was statistically significant (P<0.05) from other S treatments (Table II).

N use efficiency parameters: N-partial factor productivity and the N-agronomic efficiency were recorded to be maximum (40.68 kg kg^{-1} and 28.22 kg kg^{-1}, respectively) with the interaction of N3S4 and at par to this were the combinations of N3S3 (39.46 kg kg^{-1}) for N-partial factor productivity (Figure 3); while N3S3 (27.00 kg kg^{-1}) and N4S3 (26.53 kg kg^{-1}) for N-agronomic efficiency (Figure 4). The minimum N-Partial factor productivity (25.77 kg kg^{-1}) and N-agronomic efficiency (8.32 kg kg^{-1}) were recorded with treatment combination of N1S1. Therefore, it seemed that 125 kg N ha^{-1} could not be an adequate application level regarding nourishing of this hybrid maize. Moreover, application of entire N at planting did not appear as a wise choice.

It was further observed from the results that the treatment N3 (175 kg N ha^{-1}) showed the highest N-uptake efficiency (0.58 kg kg^{-1}). Nevertheless, N4 (200 kg ha^{-1}) was at par (P>0.05) to N3 with reduced value of 0.55 kg kg^{-1}. The remaining two efficiency parameters; N-physiological efficiency and N-internal utilization efficiency increased consistently with increasing N rates; N4 provided the maximum values (42.86 kg kg^{-1} and 39.60 kg kg^{-1}, respectively) but for these two types of N use efficiency, N3 and N2 (150 kg N ha^{-1}) were also at par with N4 giving physiological efficiency as 41.76 kg kg^{-1} and 40.95 kg kg^{-1}, respectively; while internal utilization efficiency of 38.95 kg kg^{-1} and 37.75 kg kg^{-1}, respectively (Table III).

Table I: Summary of analysis of variance (ANOVA).

Sr. No.	Parameters	N Rates (N)	Timing Schemes (S)	N Rates x Timing Schemes (N x S)
1	Grain yield	*	*	*
2	Biological yield	*	*	*
3	Grain N concentration	*	*	NS
4	Stover N concentration	*	*	NS
5	Above ground crop N accumulation	*	*	NS
6	Grain protein concentration	*	*	NS
7	Grain oil concentration	*	*	NS
8	N-partial factor productivity	*	*	*
9	N-agronomic efficiency	*	*	*
10	N-uptake efficiency	*	*	NS
11	N-physiological efficiency	*	*	NS
12	N-internal utilization efficiency	*	*	NS
13	Synchrony b/t N demand and supply	*	*	NS

NS = non-significant ($P>0.05$); * = significant ($P<0.05$)

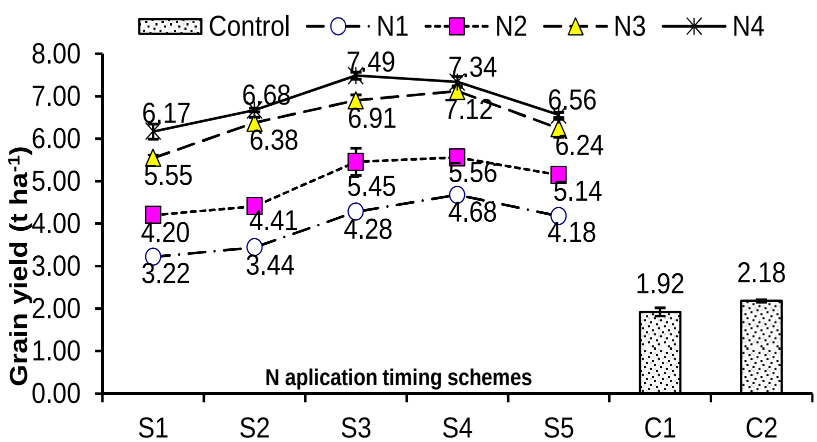

Figure 1: Grain yield of hybrid maize at different N application rates subjected to various application timing schemes

C1 = no addition, C2= 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

With respect to application timing schemes, N-uptake efficiency was found maximum (0.59 kg kg^{-1}) with S4 timing scheme, however, S3 was also at par with S4 giving measurement of 0.54 kg kg^{-1}. The maximum N-physiological efficiency was observed as 42.95 kg kg^{-1} with S5 treatment but it was statistically at par with S3 (42.72 kg kg^{-1}) and S4 (41.44 kg kg^{-1}). The N-internal utilization efficiency was maximum (39.15 kg kg^{-1}) with S3 treatment but with S5 (38.98 kg kg^{-1}), S4 (38.52 kg kg^{-1}) and S2 (37.03 kg kg^{-1}) it was statistically at par (Table III).

Synchrony between N demand and supply: The maximum value (317.77) for the expression $\{F_N/(1-I_N/U_N)\}$ was recorded with N4, thus the higher N rate gave the significantly lowest degree of synchrony between N demand and supply. The lowest value (285.24) of $\{F_N/(1-I_N/U_N)\}$ i.e. the highest synchrony between N demand and supply was recorded with N3 (Table III). Regarding timing schemes, maximum value (323.71) of the expression $\{F_N/(1-I_N/U_N)\}$, i.e. the lowest degree of synchrony between N demand and supply was noted with S1 timing scheme. The lowest value (273.08) of $\{F_N/(1-I_N/U_N)\}$, therefore, the maximum degree of synchrony between N demand and supply was observed with S4 treatment but S3 (283.83) was also statistically at par (Table III).

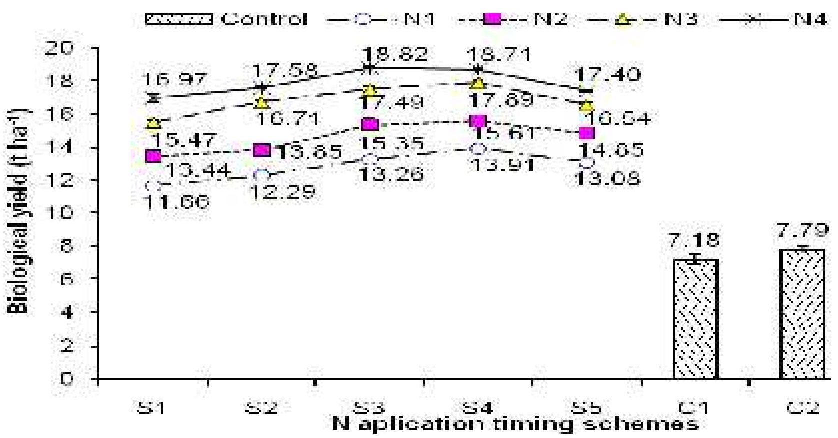

Figure 2:Biological yield of hybrid maize at different N application rates subjected to various application timing schemes

C1 = no addition, C2= 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

Table II: Grain nitrogen concentration, stover nitrogen concentration, above ground crop N accumulation, grain protein concentration and grain oil concentration as influenced by nitrogen rates and application timing schemes.

	Grain N concentration	Stover N concentration	Above ground crop N accumulation	Grain protein concentration	Grain oil concentration
	%	%	kg ha^{-1}	%	%
C1	0.74 ± 0.015a	0.20 ± 0.004a	54.99 ± 2.32a	4.64 ± 0.10a	2.33 ± 0.05a
C2	0.81 ± 0.025a	0.22 ± 0.007a	63.30 ± 3.92a	5.05 ± 0.15a	2.54 ± 0.08a
N Rates					
N1	1.02 ± 0.016c	0.30 ± 0.004d	112.48 ± 2.44d	6.40 ± 0.10c	3.25 ± 0.05c
N2	1.11 ± 0.019b	0.32 ± 0.004c	131.41 ± 3.06c	6.92 ± 0.12b	3.55 ± 0.06b
N3	1.31 ± 0.018a	0.39 ± 0.007b	165.20 ± 3.28b	8.18 ± 0.11a	4.21 ± 0.06a
N4	1.30 ± 0.019a	0.40 ± 0.008a	173.86 ± 4.69a	8.14 ± 0.12a	4.19 ± 0.06a
LSD ($P \leq 0.05$)	**0.03**	**0.01**	**7.16**	**0.21**	**0.10**
N Application Timing Schemes					
S1	1.12 ± 0.038d	0.33 ± 0.011c	133.28 ± 7.70c	6.98 ± 0.24d	3.57 ± 0.12d
S2	1.14 ± 0.035cd	0.34 ± 0.013b	139.30 ± 7.26bc	7.13 ± 0.22cd	3.66 ± 0.12cd
S3	1.22 ± 0.043b	0.37 ± 0.015a	153.77 ± 8.80a	7.64 ± 0.27b	3.93 ± 0.14b
S4	1.27 ± 0.043a	0.38 ± 0.016a	160.36 ± 8.61a	7.93 ± 0.27a	4.08 ± 0.14a
S5	1.18 ± 0.037c	0.34 ± 0.012bc	141.97 ± 7.10b	7.36 ± 0.23c	3.75 ± 0.13c
LSD ($P \leq 0.05$)	**0.04**	**0.01**	**8.01**	**0.23**	**0.12**

Means (n = 3) sharing similar letters in a cell are statistically non-significant (P>0.05)

C1 = no addition, C2= 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

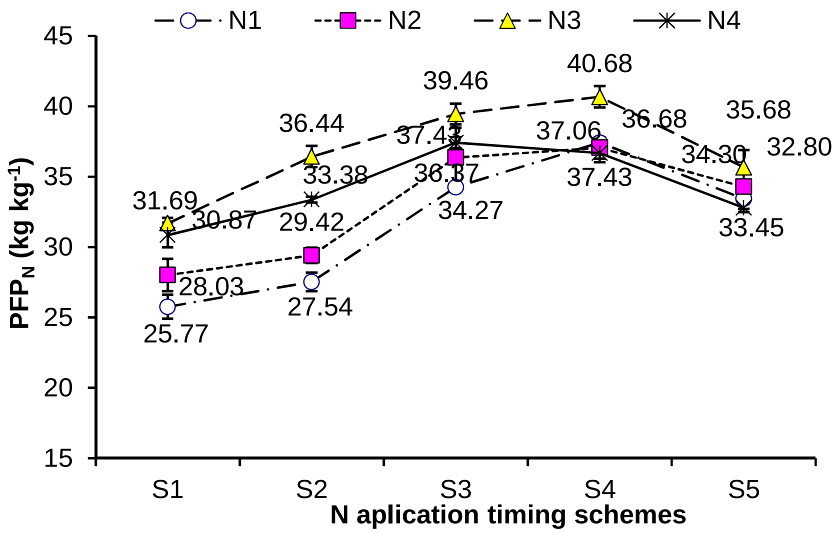

Figure 3: N-partial factor productivity of hybrid maize at different N application rates subjected to various application timing schemes.

N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

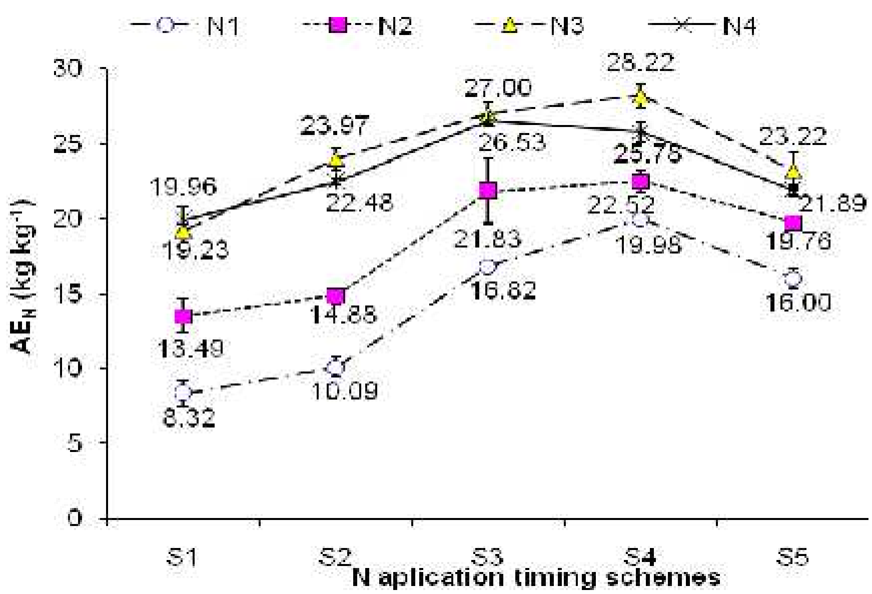

Figure 4: N-agronomic efficiency of hybrid maize at different N application rates subjected to various application timing schemes

N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

Table III: Nitrogen use efficiency indices and the synchrony between nitrogen demand and supply as influenced by variable nitrogen rates and application timing schemes.

Treatments	N-Uptake Efficiency (RE_N)	N-Physiological Efficiency (PE_N)	N-Internal Utilization Efficiency (IE_N)	Expression for synchrony between N demand and supply $\{F_N/(1-I_N/U_N)\}$
	kg kg^{-1}			
N Rates				
N1	0.39 ± 0.020c	35.71 ± 1.94b	35.13 ± 0.84b	292.29 ± 9.45b
N2	0.45 ± 0.020b	40.95 ± 1.90a	37.75 ± 0.97a	293.41 ± 6.45b
N3	0.58 ± 0.019a	41.76 ± 0.79a	38.95 ± 0.48a	285.24 ± 3.41c
N4	0.55 ± 0.023a	42.86 ± 1.52a	39.60 ± 0.85a	317.77 ± 5.58a
LSD (P ≤ 0.05)	**0.04**	**4.05**	**2.12**	**14.20**
N Application Timing Schemes				
S1	0.42 ± 0.029c	36.04 ± 2.09b	35.61 ± 1.01b	323.71 ± 8.32a
S2	0.46 ± 0.025bc	38.46 ± 2.54ab	37.03 ± 1.37ab	305.63 ± 6.13b
S3	0.54 ± 0.031a	42.72 ± 1.54a	39.15 ± 0.89a	283.83 ± 5.28cd
S4	0.59 ± 0.026a	41.44 ± 1.03a	38.52 ± 0.61a	273.08 ± 5.12d
S5	0.48 ± 0.024b	42.95 ± 1.50a	38.98 ± 0.78a	299.65 ± 6.65bc
LSD (P ≤ 0.05)	**0.05**	**4.52**	**2.37**	**15.87**

Means (n=3) sharing similar letters in a cell are statistically non-significant (P>0.05)
N1 = 125 kg N ha^{-1}, N2 = 150 kg N ha^{-1}, N3 = 175 kg N ha^{-1}, N4 = 200 kg N ha^{-1}, S1 = 100% N broadcast-incorporated at seed bed preparation + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S2 = 75% N broadcast-incorporated at seed bed preparation + 25% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S3 = 50% N broadcast-incorporated at seed bed preparation + 50% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S4 = 25% N broadcast-incorporated at seed bed preparation + 75% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}, S5 = 100% N top dressed at V9 + 150 kg P_2O_5 ha^{-1} + 100 kg K_2O ha^{-1}

DISCUSSION

Nitrogen fertilization is unanimously accepted as a key factor for elevated yield and optimal economic returns (Amanullah and Almas, 2009) and N deficiency could be one of the key yield limiting causes for cereal production (Shah *et al*., 2003). Increase in yield with increasing N might be attributed to enhanced N uptake by maize followed by partitioning of more assimilates to cobs. Results are in conformity with the findings of Oscar and Tollenaar (2006), Amanullah and Almas (2009) and Delibaltova *et al*. (2010) who described the invigorating effect of N for maize grain yield. Significant effect of N rates on biological yield could be ascribed to higher grain yield, dry matter accumulation and the N uptake. Results are in line with the findings of Bakht *et al*. (2006) and Alizade *et al*. (2007).

The significant increase in nitrogen accumulation in response to increasing N rates could be credited; to additional nutrients availability and to elevated N concentration in particular, to speedy growth and development of roots and shoots, to improved microbial activity and thus to increasing soil N mineralization making available more soil N to plants. A sturdy correlation between soil inorganic N and maize N accumulation has already been reported by Delgado (2002), Quaye *et al*. (2009), Hassan *et al*. (2010) and Saeed (2010).

Increase in grain crude protein concentration with increase in N could be attributed to the fact that N be a component of protein as it was reported by Haque *et al*. (2001) that inadequate supply of N could cause retarded growth owing to be a constituent of protein and nucleic acids. Similarly, according to Ayub *et al*. (2002a) N application could increase the nutritive value of grain due to increase in grain crude protein concentration. Maize oil is a good energy source and our results are in line with those of Rasheed *et al*. (2004) who reported that increasing N application could increase the maize grain oil concentration. Results are also similar to Saeed (2010) who attributed the increase in maize grain oil percentage with increment in N application rate to the fact that a sufficient N supply is necessary for oil biosynthesis in maize through size optimization of required enzymatic machinery. Conversely, results are not in line with those of Ayub *et al*. (2000), Hati *et al*. (2001), Nadeem *et al*. (2009) and Rehman *et al*. (2011) who recorded decreased seed oil content with increasing N rates. Rafiq (2010) reported that though oil contents decreased with increasing nitrogen levels but the decrease was non-significant. This discrepancy could be attributed to the interaction of nitrogen and phosphorus as was reported by Blumenthal *et al*. (2008) that studies with disagreement regarding grain oil concentration in response to N rates could differ in their phosphorus application rates. Together with N, higher application rate of phosphorus and/or potash might be the source of increasing grain oil concentration of maize. Maize hybrids are widely cultivated for their grain oil contents, so, their response could vary throwing in bulk of photosynthates for oil synthesis.

The use efficiency of fertilizer N depends on its application rates. Our results are in line with those of Zada *et al*. (2000) and Rehman *et al*. (2011) who reported that nutrient use efficiency increased but up to a certain level of fertilizer application and then it curved with further increase in fertilizer application probably due to the fact that higher rates of fertilizer could lead to relatively more losses of nutrient. Results are contrary to Pikul *et al*. (2005), who observed that increase in N application rates brought a continuous decrease in nitrogen use efficiency. Increased application quantity followed by higher uptake and utilization efficiency of the nutrient in grain production could be the cause of higher partial factor productivity (Cassman *et al*., 1996). Lower N-partial factor productivity and N-agronomic efficiency at the higher N application rate might be ascribed to nutrient imbalance and the declined soil indigenous N supply.

N uptake efficiency increased with increased N rates but then decreased, thus being maximum near the middle of the range of N application rates. Results support the findings of Rehman *et al*. (2011) that the highest N uptake efficiency was recorded with medium N fertilizer rate. In case of N utilization efficiency, results showed that it first increased with increase in N application rate then decreased followed by an increase again. Rehman *et al*. (2011) also observed the lowest N utilization efficiency with the medium N fertilizer rate. The inverse relation between N uptake efficiency and N utilization efficiency might be explained in that N uptake efficiency has direct relation with total N accumulation by plant while N utilization efficiency possesses an indirect one. Presterl *et al*. (2002) also recorded a negative relationship between these two components of N use efficiency.

N-physiological efficiency increased with increasing N rates owing to increase in grain yield. Together with other efficiency components, the N-physiological efficiency must also be considered while managing for improved N use efficiency of cereal production systems to help measure economic impact on grain yield concerning inputs and accumulation of N (Cassman *et al*., 2002).

Synchronization of N demand and its supply through split application at various growth stages is essential for increased yield and N use efficiency (Amanullah and Almas, 2009). Little but incessant N supply according to plant need could bring better utilization of applied N and hence causing less significant losses (Torbert *et al*., 2001). To avoid N losses and to augment the economic returns for farmers, it is required to sustain a high crop yield which is not possible without efficient N use and split N application might be the best technique an agriculturist could use at the farm (Amanullah and Almas, 2009). Similarly, according to Binder *et al*. (2000) delayed application of N fertilizers to maize has numerous advantages but effectiveness depends upon the degree of N deficiency; completely N deficient maize crop when received N fertilization late in the vegetative phase yielded comparatively higher than no N fertilization but could not attained the maximum yield. This finding of Binder and his coworkers supported our finding that application of the entire N late at V9 growth stage though appeared relatively promising than entire usage before planting at seedbed preparation but was less effective than split plans which involved some N application at earlier than V9.

Our results showed that applying the entire N rate at seedbed preparation was least effective way of N management with respect to yield and N use efficiency of maize crop while delay in N application proved to be a better tactics. Gradually increasing the N amount in second split to be applied at V9 increased the yield, quality and nitrogen use efficiency parameters and synchrony between N demand and supply. Application of the entire N late in the vegetative phase at V9 growth stage brought relatively higher yield of maize than entire or 75% N application before planting. Nevertheless, omitting basal N dose completely could not bring as promising results as splitting plans of supplying 25 or 50% N rate at seedbed preparation. Results are in line with those of Walsh (2006) who recorded the highest fertilizer N use efficiency with split N application plan (at seedbed preparation + side dressed at V10). The lowest N use efficiency was recorded when no N was applied at seedbed preparation and the entire N application was delayed up to VT (tasseling) growth stage and this was ascribed to the fact that since want for N fertilizer throughout the crop establishment followed by rapid developmental phase could not be satisfied in the beginning of growing season, even the huge amounts of N application later on did not allow the crop to recover fully achieving the maximum yields.

Conclusion: Nitrogen fertilizer rates and its application timing schemes significantly affected maize production, grain quality and nitrogen use efficiency indices. Where application of the entire N at seed bed preparation seems better to avoid, delaying all N application to about mid of the vegetative phase (V9 growth stage) seems not appropriate too. Split use of 175 kg N ha^{-1} (broadcast-incorporating only 25% of N at seed bed preparation while the rest to be applied at V9 stagethrough top dressing) is recommended.Mostly, top dressing is preferred by the local farmers owing to be a relatively easy method to apply second split of N fertilizers during growth phase of maize. Nevertheless, side dressing of second split of N should also be tested bringing comparative effect on yield and N use efficiency of maize.

REFERENCES

Alizade, O., I. Majidi, H.A. Nadian and G.H.N. Mohamadi (2007). Effect of drought stress and nitrogen rates on yield and yield components of corn. I. A. U J. Agric. Sci. 13(2): 427-437.

Amanullah, (2004). Physiology, Partitioning of assimilates and yields of maize as affected by plant density, rate and time of nitrogen application. Ph.D. dissertation, Dept. Agron., NWFP Agric. Uni., Peshawar, Pakistan.

Amanullah and L.K. Almas (2009). Partial factor productivity, agronomic efficiency, and economic analyses of maize in wheat-maize cropping system in Pakistan. Southern Agricultural Economics Association Annual Meetings, January 31- February 3, Atlanta, Georgia.

Ayub, M., A. Tanveer, R. Ahmad and M. Tariq (2000). Fodder yield and quality of two maize (*Zea mays* L.) varieties at different nitrogen levels. Andhra Agric. J. 4: 7-11.

Ayub, M., M.A. Nadeem, A. Tanveer and A. Husnain (2002a). Effect of different levels of nitrogen and harvesting times on growth, yield and quality of sorghum fodder. Asian J. Plant Sci. 4: 304-307.

Bakht, J., S. Ahmad, M. Tariq, H. Akber and M. Shafi (2006). Response of maize to planting methods and fertilizer N. J. Agri. Biol. Sci. 1(3): 8-14.

Binder, D. L., D. H. Sander and D.T. Walters (2000). Maize response to time of nitrogen application as affected by level of nitrogen deficiency. Agron. J. 92: 1228-1236.

Blumenthal, J., D. Baltensperger, K.G. Cassman, S. Mason and A. Pavlista (2008). Importance and Effect of Nitrogen on Crop Quality and Health. Agronomy Faculty Publications. Paper 200. Uni. Nebraska – Lincoln. http://digitalcommons.unl.edu/agronomyfacpub/200

Cassman, K.G., A. Dobermann and D.T. Walters (2002). Agroecosystems, nitrogen-use efficiency and nitrogen management. Ambio. 31(2): 132-140.

Cassman, K.G., G.C. Gines, M.A. Dizon, M.I. Samson and J.M. Alcantar (1996). Nitrogen use efficiency in tropical lowland rice systems: contribution from indigenous and applied nitrogen. Field Crop Res. 47: 1-12.

Delgado, R (2002). Evaluation of maize growth and N uptake at various levels of N availability in a mollisol of Venezuela. Agron- tropic-Maracay 52(1): 5-22.

Delibaltova, V., H. Kirchev, A. Sevov, A. Matev and N. Yordanova (2010). Genotypic response of maize hybrids to different nitrogen applications under climatic conditions of Plovdiv region. BALWOIS – 25-29 May 2010, Ohrid, Republic of Macedonia.

Dobermann, A. (2007). Nutrient use efficiency – measurement and management. In: A. Krauss, K. Isherwood and P. Heffer (eds.), Fertilizer Best Management Practices-General Principles, Strategy for their Adoption and Voluntary Initiatives vs. Regulations. First edition, IFA, Paris, France.

Halvorson, A.D., F.C. Schweissing, M.E. Bartolo and C.A. Reule (2005). Corn response to nitrogen fertilization in a soil with high residual nitrogen. Agron. J. 97: 1222-1229.

Haque, M.M., A. Hamid and N.I. Bhuiyan (2001). Nutrient uptake and productivity as affected by nitrogen and potassium application levels in maize/sweet potato intercropping system. Korean J. Crop Sci. 46(1): 1-5.

Hassan, S.W., F.C. Oad, S. Tunio, A.W. Gandahi, M.H. Siddiqui, S.M. Oad and A.W. Jagirani (2010). Effect of N application and N splitting strategy on maize N uptake, biomass production and physio-agronomic characteristics.Sarhad J. Agric. 26(4): 551-558.

Hati, K.M., K.G. Mandal, A.K. Misra, P.K. Ghosh and C.L. Acharya (2001). Effect of irrigation regimes and nutrient management on soil water dynamics, evapotranspiration and yield of wheat in Vertisol. Indian J. Agric. Sci. 71: 581-587.

Karim, A.A. and C. Ramasamy (2000). Expanding frontiers of agriculture: contemporary issues. Kalyani Publishers, Ludhiana, India.

Kumwenda, J.D. T., S.R. Waddington, S.S. Snapp, R.B. Jones and M.J. Blackie (1996). Soil fertility management research for the maize cropping systems of smallholders in southern Africa: A review. Natural Resources Group Paper 96-02. Mexico City: International Maize and Wheat Improvement Center (CIMMYT).

Low, N.H (1990). Food Analysis, 417/717. Laboratory Mannual, Deptt. Appl. Microbiol. Food Sci., Univ. Saskatchewan, Canada. PP: 37-38.

Muthukumar, V.B., K. Velayudham and N. Thavaprakaash (2005). Growth and yield of baby corn (*Zea mays* L.) as influenced by plant growth regulators and different time of nitrogen application. Res. J. Agric. Biol. Sci. 1(4): 303-307.

Nadeem, M. A., Z. Iqbal, M. Ayub, K. Mubeen and M. Ibrahim (2009). Effect of nitrogen application on forage yield and quality of maize sown alone and in mixture with legumes. Pakistan J. Life Soc. Sci. 7(2): 161-167.

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

Pikul, J.L., L. Hammack and W.E. Riedell (2005). Corn yield, nitrogen use and corn rootworm infestation of rotations in the northern corn belt. Agron. J. 97: 854-863.

Presterl, T., S. Groh, M. Landbeck, G. Seitz, W. Schmidt and H.H. Geiger (2002). Nitrogen uptake and utilization efficiency of European maize hybrids developed under conditions of low and high nitrogen input. Plant Breeding. 121: 480-486.

Quaye, A.K., K.B. Laryea and S. Abeney-Mickson (2009). Soil water and nitrogen interaction effects on maize (*Zea mays* L.) grown on a vertisol. J. Forestry Hort. Soil Sci. 3(1): 1-11.

Rafiq, M.A (2010). Production potential of maize as affected by intercropping, planting geometry, population dynamics and fertilizer management. PhD. Thesis, Dept. Agron., Uni. Agri. Faisalabad, Pakistan.

Rasheed, M., H. Ali and T. Mahmood (2004). Impact of nitrogen and sulfur application on growth and yield of maize (*Zea mays* L.) crop. J. Res. Sci. 15(2): 153-157.

Rehman A., M.F. Saleem, M.E. Safdar, S. Hussain and N. Akhtar (2011). Grain quality, nutrient use efficiency, and bioeconomics of maize under different sowing methods and NPK levels. Chilean J. Agri. Res. 71(4): 586-593.

Rizwan, M., M. Maqsood, M. Rafiq, M. Saeed and Z. Ali (2003). Maize (Zea mays L.) response to split application of nitrogen. Int. J. Agri. Biol. 5(1): 19-21.

Saeed, M. (2010). Studies into enhancing productivity of hybrid maize (*Zea mays* L.) under various agro-management practices. Ph.D. Thesis, Dept. Agron., Uni. Agri. Faisalabad, Pakistan.

Schmidt, J.P., A.J. Dwjoia, R.B. Ferguson, R.K. Taylor, R.K. Young and J.L. Halvin (2002). Corn yield response to nitrogen at multiple locations in field. Agron. J. 94: 798-806.

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 Res. 83: 1-11.

Steel, R.G.D., J.H. Torrie and D.A. Dicky (1997). Principles and Procedures of Statistics- A Biometrical Approach 3rd Ed. McGraw Hill Book International Co. Singapore. pp. 204-227.

Torbert, H.A., K.N. Potter and J.E. Morrison (2001). Tillage system, fertilizer nitrogen rate and timing effect on corn yields in the Texas Blackland Prairie. Agron. J. 93: 1119-1124.

Walsh, O.S. (2006). Effect of delayed nitrogen fertilization on corn grain yields. M. Sc. Thesis. Graduate College. Oklahoma State Uni., Oklahoma.

Zada, K., P. Shah and M. Arif (2000). Management of organic farming: effectiveness of farm yard manure (FYM) and nitrogen for maize productivity. Sarhad J. Agric. 16: 461-465.