Research Article

Effects of Nitrogen Rates and Time of Application on Yield of Maize: Rainfall Variability Influenced Time of N Application

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Despite the fact that maize productivity is relatively better than other major cereal crops, its current productivity is still far below its potential productivity. N rate and time of application are among the major abiotic factors limiting the productivity of the crop. Because of such gaps, the experiment was conducted at Bako Agricultural Research Center in 2013 and 2014 cropping seasons to determine optimum N rate and time of application. Four levels of N rates (46, 69, 92, and 115 N kg ha⁻¹) and four levels (T_1 , T_2 , T_3 , and T_4) of different time of N application were arranged in factorial combinations. Moreover, previously recommended N and the control were arranged in a randomized complete block design with three replications. In 2013, the highest significant biomass yield (21.2 tha⁻¹) was obtained at 115 N kg ha⁻¹ and T_4 followed by 69 N kg ha⁻¹ at T_1 and T_2 and 92 N kg ha⁻¹ at T_2 . In contrast, the highest grain yield in 2013 was obtained at 92 N kg ha⁻¹ at T_2 followed by 115 N kg ha⁻¹ at either T_2 or T_4 and 69 N kg ha⁻¹ at either T_1 or T_3 application time. Interestingly, a significant yield increase by 37% was obtained when 92 N kg ha⁻¹ at the time of T_2 was applied compared to previous recommended 110 N kg ha⁻¹ rate and time of application. In 2014, however, the highest yield was recorded when 92 N kg ha⁻¹ at T_1 was used. Application of 46 N kg ha⁻¹ at T_2 showed statistically similar yield performance when compared with previous N recommendation. The lowest yield was recorded from the control plot in both years. In 2013, the maximum net profit and acceptable marginal rate of return (MMR) were obtained when 92 N kg ha⁻¹ at T_2 was used for maize production during erratic and heavy rainfall distribution, particularly at a time of N application. However, the maximum net benefit (30743 ETB ha⁻¹) and acceptable MRR could be obtained when 92 N kg ha⁻¹ at T_1 was used if the rainfall amount and distribution are relatively uniform. In conclusion, application of 92 N kg ha⁻¹ at T_1 (10–15 DAP and 35–40 DAP) is the best N rate and time of application in good rainy seasons and hence recommended for the end users. However, in the case of erratic and heavy rainy seasons, application of 92 N kg ha⁻¹ at three times application regimes (1/3 N at 10–15 days after planting (DAP), 1/3 N at 35–40 DAP and 55–60 DAP) should be used to get maximum profit and acceptable MRR.

1. Introduction

Maize (*Zea mays*) is one of the main and popular cereal crops due to its high value as stable food as well as its stover demand for animal feed and fuel and even for construction purposes [1]. Maize is also the most important stable crop in terms of calorie intake in Ethiopian rural families. Approximately 88% of maize produced in Ethiopia is used as food, in both green cobs and grain [2]. Because of its multiple advantages, it ranks second in production area next to teff while it ranks first in its productivity among major cereal crops [3] and it is, therefore, one of the high priority crops to feed the ever-increasing Ethiopian population [2].

Despite the fact that its current productivity is higher than other major cereal crops, the yield productivity is below its potential. For instance, the potential yield of late maturing hybrid maize varieties can produce up to 9.5–12 tha⁻¹ at research field and 6–8.5 t ha⁻¹ at an on-farm field [4] whereas the national average productivity is 3.2 tha⁻¹ [5]. Even though many biotic and abiotic factors can contribute to these big yield gaps, soil fertility depletion and poor nutrient management are among the major factors contributing to low productivity [6].

Nitrogen (N) management in maize production system is one of the main concerns since it is the most important and primary nutrient for growth and development of the

crop [7]. Hence, application of fertilizer N resulting in higher biomass is commonly increased. Optimum rate and time of N application can enhance yield productivity and nutrient use efficiencies while reducing the environmental pollution [8, 9]. N application beyond the optimum requirement of maize could not increase yield and may lead to an elevated level of NO_3 in the soil and susceptibility to NO_3 loss by leaching [10]. Another report also indicated that abundant N supply favors NH_3 losses, especially if the supply is in excess of plant requirements [11]. However, the negative environmental impacts associated with maize production can be minimized through efficient N management, including appropriate rate and time of N recommendation [11].

Time of N application at appropriate crop growth stage is also another main focus to enhance N use efficiency and increase maize productivity. All applied N is not absorbed by the crop since leaching is one of the main challenges for N loss in high rainfall areas. Research reports had shown that about 50% and even more than this figure at higher doses of applied N remain unavailable to a crop due to N loss through leaching [12]. This leaching loss may be determined by a quantity of N applied, inappropriate time of application, soil permeability, and quantity of rainfall drops in the area [11]. However, an optimum and efficient time of N application can increase the recovery of applied N up to 58–70% and hence increase yield and grain quality of the crop [12, 13].

Previous N recommendation for maize production in Western Ethiopia was 92–110 kg/ha, half at the time of planting and half at 30–35 days after planting [2] while applying all at planting is the best alternative to large scale maize farming where mechanization is available [14]. However, many research findings verified that N application at the time of maize planting is not efficiently recovered since nodal root growth and development from emergence up to 1–2 leaves' development stage is a very young stage [9]. The same author showed that seed emergence usually occurs in 6–8 days after planting while 12–15 and 15–20 days after planting are needed to form one and two developed leaves for hybrid maize, respectively [9, 15]. At these stages, the seedlings depend on kernel food reserve since nodal root development is not yet started for nutrient absorption. If N application, however, at maize planting is done, its loss through leaching and runoff can be articulated since its absorption by the crop up to 10–15 days after planting is rare. Hence, application of N at the time of planting is easily lost through leaching or runoff in heavy rainfall areas and it not only is attributed to an environmental population but also results in nonprofit cost [11, 13, 16], and hence the disadvantages of N application at the time of planting may outweigh its advantages. Therefore, the objective of this study was to investigate optimum rate and time of N application to increase optimum and economically profitable maize yield.

2. Material and Methods

The experiment was conducted at Bako Agricultural Research Center for two consecutive years (2013 and 2014), and it is located in a subhumid area of Western Ethiopia which lies at a latitude of $9^{\circ}6'N$ and longitude of $37^{\circ}9'E$ and at an

altitude of 1650 m a.s.l. It has an annual mean minimum and maximum air temperatures of 13.5 and 29.7°C, respectively. The area received an annual rainfall of 1431 mm (2013) and 1067 mm (2014) with maximum precipitation being received in the months of May–August.

The soil of Bako area is reddish-brown, nitosol. It is an acidic soil with a pH range of 4.5–5.6. The surrounding area is a mixed farming zone and is one of the most important maize (*Zea mays* L.) growing belts in Ethiopia, and cultivations of teff (*Eragrostis tef*), finger millet (*Eleusine coronata*), common bean (*Phaseolus vulgaris* L.), sorghum (*Sorghum bicolor* L.), noug (*Guizotia abyssinica* L.f.), and soybean (*Glycine max* L.) are common. The area is predominantly maize based monocropping with low soil fertility problem that directly influences production and productivity of the cultivated crops.

The treatments consisted of two factors, namely, four levels of N rates (46, 69, 92, and 115 N kg ha⁻¹) and four different application times ($T_1 = 1/2$ N at 10–15 days after planting (DAP) and $1/2$ N at 35–40 DAP; $T_2 = 1/3$ N at 10–15 DAP, $1/3$ N at 35–40 DAP, and $1/3$ N at 55–60 DAP; $T_3 = 1/3$ N at 35–40 DAP, $1/3$ N at 55–60 DAP, and 75–80 DAP; and $T_4 = 1/4$ N at 10–15 DAP, $1/4$ N at 33–40 DAP, $1/4$ N at 55–60 DAP, and $1/4$ at 75–80 DAP) that were arranged in 4×4 factorial combinations. Moreover, previous rate and application time of N (referred as R) and the control plot receiving no N fertilizer were included for the comparisons purposes. A total of 16 treatment combinations plus previous recommended rate and time of N application and control plot without N were laid out using a randomized complete block design (RCBD) with three replications. Application time of N was done within the stated time ranges, but at the same date as per treatment arrangements.

The experimental plots were plowed three times at different time intervals starting from mid-May and leveled manually prior to field layout. Plant population for all experimental plots was 44444 plants ha⁻¹, 75 cm between rows and 30 cm between plants. Recommended phosphorus (20 kg P ha⁻¹) in the form of triple superphosphate (TSP) for all experimental plots including standard check and control plot was equally and uniformly applied at the time of maize planting. N was applied in the form of UREA as per treatment arrangements. One hybrid long maturing variety (BH661) of maize was used for the execution of the treatments. Its yield potential varies between 9.5 and 12 tha⁻¹ at research field and 6 and 8.5 tha⁻¹ at farmers' field under integrated agronomic managements. The variety was released by Bako National Maize Research Center in 2011 and it can be grown in a range of 1600–2200 m above sea level and it requires an annual rainfall of 1000–1500 with uniform distribution in its growing periods. The trial was planted on May 30th in the 2013 and June 1st in 2014. Other agronomic managements rather than treatment variations were uniformly applied to all experimental plots.

At the time of harvesting, the maize was harvested by excluding two border rows from each side. A net plot size for each plot was 2.25 m $\times$ 5.1 m (11.475 m²). Stand counts per net plot were counted at the time of harvesting. Finally,

TABLE 1: Analysis of variance for yield and yield components of maize as influenced by N rates, time of application, and the interaction effects in 2013 and 2014 at Bako, Western Ethiopia.

Sources of variations	D.f.	F probability ($P = 0.05$)			
		Biomass	Grain yield	HI	AE
Year (Yr)	1	<.001	<.001	<.001	<.001
Nitrogen (N)	3	<.001	<.001	0.012	<.001
Time of application (TA)	3	0.277	0.083	0.81	0.063
Yr $\times$ N	3	0.193	0.001	0.008	<.001
Yr $\times$ TA	3	0.093	0.054	0.126	0.106
N $\times$ TA	9	<.001	0.047	0.004	0.164
Yr $\times$ N $\times$ TA	9	<.001	0.024	0.062	0.159
Replication	2	0.155	0.116	0.271	0.121
Residual	62	—	—	—	—
Total	95				
SE		1.893	0.724	3.36	0.0113
CV (%)		8.6	7.6	7.6	8.6

HI: harvest index; AE: agronomic efficiency.

biomass yield, grain yield, harvest index, and other important agronomic traits were collected. Maize grain yield was adjusted to standard moisture contents to 10% as described as follows: adjusted yield = actual yield $\times$ 100 – $M/100 - D$, where M and D are measured and standard moisture contents, respectively. Agronomic efficiency was calculated as yield obtained per N applied. Costs that vary among treatments were also assessed. The cost of UREAa, the cost of labor required for the application, and cost for shelling were estimated by assessing the current local market prices. The price of UREA (1600 ETB 100 kg⁻¹) and daily labors (35 ETB per one person day based on government's current scale in the study area) and the cost of maize shelling (100 ETB t ha⁻¹) were considered to get the total cost that varied among the treatments. Time elapsed during UREA application for some plots of each treatment was recorded to calculate daily labor required for one hectare. One person per day was estimated based on eight working hours per day. However, other nonvaried costs were not included since all agronomic managements were equally and uniformly applied to each experimental plot. Before calculating gross revenue, maize yields obtained from each experimental plot were adjusted down by 10%. Finally, gross revenue was calculated as total yield obtained multiplied by field price (3800 ETB 1 tha⁻¹). The net benefit and the marginal rate of return (MRR) were also calculated as per standard manual [17]. Finally, combined analyses of variance (ANOVA) across seasons were carried out using Gen Stat 15th edition software, and the Duncan multiple range test at $P < 0.05$ was used for comparing treatment means. Sigma plot version 10 was used for graphing and error bar for each treatment mean was also plotted.

3. Results

The result of combined analysis revealed that seasonal variations highly ($P < 0.001$) affected biomass, grain yield, harvest index, and agronomic efficiency of the crop (Table 1). Even though main effects of time of N application did not

show significant variation to all parameters, there were highly significant effects due to the various applications of N rates. Moreover, the effect of N rate and time of application significantly affected biomass yield and harvest index while this interaction due to seasonal variations significantly affected both maize biomass and grain yield (Table 1). Therefore, separate analysis for each season was done since the seasonal rainfall variability considerably affected the response of treatments.

As depicted in Figure 2(a), application of N significantly affected the mean yield of maize. The highest significant mean yields (9.8 tha⁻¹) in 2013 were obtained when 92 N kg ha⁻¹ followed by 115 N kg ha⁻¹ was applied, but both are statistically at par. In addition, statistically comparable yield performance was obtained when 69 N kg ha⁻¹ was applied compared to 92 and 115 N kg ha⁻¹ applications. However, more than 23% and 45% significant yield increases were recorded when N at 92 kg ha⁻¹ was applied compared to 46 N kg ha⁻¹ and the control plot receiving no N application. In contrary, the lowest significant yield, except the control, was recorded when 110 N kg ha⁻¹ was applied as compared to other N rates. In 2013 season, the amount and the distribution of rainfall during the growing period of the crop were much higher than in 2014. The cumulative rainfall in the entire growing period, particularly from mid-June to August, was considerably higher in the 2013 (Figure 3(a)) than in 2014. Moreover, the daily rainfall distribution, particularly from early June to late August, was erratic and sometimes heavy rain, causing high runoff and even leading to leaching, occurred in 2013 (Figure 3(b)) compared to 2014.

In 2014, however, the response of maize yield to the main effect of N application rate did not show significant variations due to the application of 46, 69, 92 and 115 N kg ha⁻¹ though the highest grain yield was obtained when 69 N kg ha⁻¹ was applied (Figure 2(a)). The lowest yield was, however, recorded from the control plot without N. Even though the yield responses of maize to 110 N kg ha⁻¹ were significantly better

FIGURE 1: Mean monthly rainfall and minimum and maximum temperature of Bako research site, 2013-2014.

FIGURE 2: The effect of nitrogen rates (a) and application time (b) on the yield of maize in the 2013 and 2014 cropping seasons at Bako, Western Ethiopia.

in 2014 than in 2013, significantly lower yield except N control plot was recorded as compared to other N rates. This could be related to the annual or monthly amount (Figure 1) and cumulative and daily distribution of the rainfall in 2014. For instance, the monthly amount of rainfall from June to August in 2014 was significantly lower than during 2013 rainy season.

Application time of N was significantly varied across seasons (Figure 2(b)). The highest yield in 2013 was obtained at T_3 followed by T_2 and T_1 , but all are statistically at par. However, the lowest yield was attained at R (previous recommendation) followed by T_4 . The highest yield, however, was recorded at T_1 in 2014 though all treatment means were statistically similar. These response variations across the

seasons might also relate to rainfall amount and distributions (Figures 1 and 3).

Nitrogen rates by time of application also showed significant effects on both biomass and grain yield of maize in each season (Figure 4). In 2013, the highest significant biomass yield (21.2 t ha^{-1}) was obtained at 115 N kg ha^{-1} and T_4 (four times split application of equal doses) followed by 69 N kg ha^{-1} at T_1 and T_2 and 92 N kg ha^{-1} at T_2 , which are statistically at par. However, application of 69 kg ha^{-1} at T_4 and 46 kg ha^{-1} at T_2 or T_4 showed the lowest yield, except the control plot without N, compared to other treatment combinations and even with previous recommendation. The result revealed that more than 20% and 19% biomass yield advantages were obtained for 69 N kg ha^{-1} at T_3 and T_1 or

FIGURE 3: Daily rainfall distribution (a) and cumulative rainfall (b) received in growing periods of 2013 and 2014 rainy seasons at Bako, Western Ethiopia.

FIGURE 4: The effect of N rate and time of application on biomass yield of maize in the 2013 and 2014 rainy seasons.

92 N kg ha⁻¹ at T₃ compared to 110 N kg ha⁻¹, half of the total at planting and the remaining at knee height. This result may be related to rainfall amount and distribution that may lead to runoff and leaching due to mismatch N application and time of crop N demand. The lowest and significant biomass yield was recorded from control plot.

The overall means regardless of treatment variations revealed that significantly higher biomass yield (2.5 t ha⁻¹) was obtained in the 2014 than in 2013 (1.7 t ha⁻¹). This variation might be related to the effect of rainfall amount and distribution during the growing seasons (Figures 1 and 3).

In addition to higher monthly rainfall amount in pick rainy seasons, regarding rainfall distribution (Figures 1 and 3), the cumulative rainfall in different proposed application time was considerably higher in 2013 than 2014 (Figure 5), which may favor N losses through runoff and leaching. Similar to the result observed in 2013, the highest and significant biomass yield was obtained at a rate of 115 N kg ha⁻¹ and T₄ in the 2014, and more than 17% and 100% yield advantage were obtained when compared with previously recommended rate and time of N application and the control plot (Figure 5), respectively. Application of 69 N kg ha⁻¹ at T₁ or T₂ and 92 N kg ha⁻¹ at

FIGURE 5: Cumulative rainfall distribution in different proposed N application times in 2013 and 2014 rainy seasons.

T_2 statistically showed the next highest biomass even though these means are at parity with previous recommendation (110 N kg ha^{-1} at R). The lowest yield, except the control plot, was recorded when 115 N kg ha^{-1} at T_4 was practiced.

Maize yield response to N rates and time of application was also significantly varied across seasons (Figure 6). The highest grain yield in 2013 was obtained when 92 N kg ha^{-1} at T_2 followed by 115 N kg ha^{-1} at either T_2 or T_4 and 69 N kg ha^{-1} at either T_1 or T_3 applications time were practiced, but all means are statistically at par. The lowest yield, except the control plot, was recorded when 46 N kg ha^{-1} followed by 69 N kg ha^{-1} at T_4 was used. Interestingly, a significant yield increase by 29.7% and 24.4% was obtained when 69 N kg ha^{-1} at the time of T_1 and T_3 was applied compared to the application of 110 N kg ha^{-1} ; half at the time of planting and the remaining at the knee height were applied. The lowest, however, grain yield was recorded from control plot receiving no N fertilizer (Figure 6).

Similar to biomass yield, significantly higher grain yield was recorded in 2014 (9.9 t ha^{-1}) than in 2013 (8.7 t ha^{-1}). The

highest yields in 2014 were also recorded when 92 N kg ha^{-1} at T_1 followed by 115 N kg ha^{-1} at T_4 and 69 N kg ha^{-1} at T_1 was used although all of these means are statistically similar (Figure 6). The lower rate of N (46 kg ha^{-1}) at T_2 showed similar yield performance compared to the highest three treatment means. Interestingly, application of 46 N kg ha^{-1} at T_2 showed statistically similar yield performance, though with 10% yield advantage, when compared with the application of previously recommended 110 N kg ha^{-1} and when half of the total N at planting and the remaining half at the stage of knee height were applied (Figure 6). Moreover, more than 14% yield increase could be obtained when the application of either 69 N kg ha^{-1} or 92 N kg ha^{-1} at T_1 was practiced compared to previous N rate and time of application (Figure 6). The lowest yield was, however, recorded from control plot receiving no N.

Conversely, the highest and significant harvest index (HI) was recorded from the control plot without N (Figure 7) in each cropping season. Application of 46 N kg ha^{-1} at T_2 and 115 N kg ha^{-1} at T_4 showed the next significant HI in

FIGURE 6: The effect of N rate and time of application on grain yield of maize in the 2013 and 2014 cropping seasons at Bako, Western Ethiopia.

FIGURE 7: The effect of N rate and time of application on harvest index of maize in 2013 and 2014 cropping seasons.

2013 whereas 46 N kg ha⁻¹ at T₂ and 92 N kg ha⁻¹ at T₄ also showed the next significant HI in 2014 compared to other treatment means. However, previously recommended N and time of application showed significantly lower HI compared to different N rates and time of the applications (Figure 7).

Agronomic efficiency (AE) of the crop as affected by N rates indicated that the highest and significant AE was recorded at the lowest N rate and AE was linearly decreased as the function of N rate increased (Figure 8(a)). However,

the AE was not significantly varied due to the difference in time of application from T₁ to T₄ (Figure 8(b)). Significantly the lowest HI was, however, recorded from the previously recommended time of application (R).

Even though both biomass and grain yield of maize were minimum at lower N rate (46 N kg ha⁻¹), the highest and significant agronomic efficiency (AE) was recorded at a lower rate and there were decreased trends as the function of N rates increased from 46 to 115 N kg ha⁻¹ (Figure 8). However, time

FIGURE 8: The effect of N rate (a) and time of application (b) on combined means of agronomic efficiency of maize.

TABLE 2: Partial and marginal analysis as affected by N rates and time of application on maize in 2013 and 2014 cropping seasons.

Trt		TC	2013							2014					
N	TA		Yd	Ayd	GB	NB	DA	MRR	Yd	Ayd	GB	NB	DA	MRR	
Control		2503	6.7	6.0	22880	20377	—	—	7.9	7.1	27070	24568	—	—	
46	T ₁	4829	8.0	7.2	27360	22531	—	92.6	9.4	8.4	32031	27201	—	113	
46	T ₂	5318	8.2	7.4	27876	22558	—	5.53	10.3	9.3	35262	29944	—	561	
46	T ₃	5488	8.2	7.4	27930	22441	D	—	9.8	8.8	33486	27998	D	—	
69	T ₁	5695	9.3	8.4	31895	26200	—	967	9.3	8.4	31895	26200	D	—	
46	T ₄	5760	6.9	6.2	23683	17923	D	—	9.9	8.9	33775	28015	D	—	
69	T ₂	6076	8.4	7.6	28760	22684	D	—	8.4	7.6	28760	22684	D	—	
69	T ₃	6332	9.7	8.8	33276	26944	—	117	10.7	9.6	36581	30250	—	30.2	
92	T ₁	6448	9.1	8.2	31195	24747	D	—	10.9	9.8	37191	30743	—	423	
69	T ₄	6548	7.6	6.8	25903	19355	D	—	10.0	9.0	34276	27728	D	—	
110	R	6659	7.3	6.6	24898	18239	D	—	9.4	8.4	32060	25401	D	—	
92	T ₂	6904	10.3	9.2	35129	28225	—	224	9.9	8.9	33858	26954	D	—	
92	T ₃	7059	9.1	8.2	31155	24097	D	—	10.2	9.1	34714	27655	D	—	
115	T ₁	7193	9.4	8.5	32150	24957	D	—	10.1	9.2	34647	27454	D	—	
92	T ₄	7375	9.8	8.8	33477	26102	D	—	9.5	8.5	32309	24933	D	—	
115	T ₂	7630	9.5	8.5	32362	24732	D	—	9.9	8.9	33764	26134	D	—	
115	T ₃	7821	10.0	9.0	34079	26258	D	—	9.4	8.5	32099	24278	D	—	
115	T ₄	8143	8.6	7.8	29478	21335	D	—	10.8	9.8	37071	28928	D	—	

Trt = treatment combinations, N = nitrogen rate (kg/ha), TA = time of N application, TC = total cost that varied among treatments (ETB ha⁻¹), Yd = yield of maize (t/ha), Ayd = adjusted yield of maize (t/ha), GB = gross benefit (ETB ha⁻¹), NB = net benefit (ETB ha⁻¹), DA = dominance analysis, MRR = marginal rate of return (%), D = dominated, R = previously recommended time of N application, and 1 USD = 22.50 ETB.

of application except the recommended one (R) did not show any significant variation among the treatment means.

Partial and marginal analysis for means of treatment combinations against the previous recommendation and the control were carried out (Table 2). The result indicated that both partial and marginal analysis showed differences in each cropping season since the yield responses to the treatments were different across the seasons. In 2013 season, the highest net benefit (28225 ETB ha⁻¹) was obtained when 92 N kg ha⁻¹

at T₂ was carried out although the use of 69 N kg ha⁻¹ at T₃ followed by 69 N kg ha⁻¹ at T₁ gave the next maximum net benefit. However, the maximum net profit and acceptable marginal rate of return (MMR) were obtained when 92 N kg ha⁻¹ at T₂ was used for maize production during erratic and heavy rainfall distribution. In 2014 cropping season, however, the maximum net benefit was 30743 ETB ha⁻¹ followed by 30250 ETB ha⁻¹ and 29944 ETB ha⁻¹ which were achieved when 92 N kg ha⁻¹ at T₁, 69 N kg ha⁻¹ at T₃, and

46 N kg ha⁻¹ at T_2 were, respectively, applied. However, the analysis of MRR showed that application of 92 N kg ha⁻¹ at T_1 is the best practice that could give the maximum net benefit and the marginal rate of return in a less rainy season.

4. Discussion

Erratic rainfall distribution and the amount can considerably influence the response of maize to N application as it may cause runoff and leaching of applied N. Some research finding also confirmed that the yield of maize with high rainfall regimes is generally low due to poor nutrient use efficiency [18]. N use efficiency by the crop can be reduced under heavy rainfall, particularly at the time of application, since the nutrient can be lost through NO₃ losses and even through soil erosion [19]. If the rainfall amount and distribution are relatively adequate, like in 2014 cropping season, N uptake by the crop could be enhanced since runoff and even leaching effect can be reduced, and hence yield production and productivity are increased [11, 20]. However, the N use efficiency can be improved through the further split application of N at different growth stage absorbed by the crop since leaching is one of the main challenges for N loss in high rainfall areas [11, 20]. Jamal et al. [12] also indicated that about 50% at higher doses of applied N remains unavailable to a crop due to N loss through leaching in areas receiving heavy rainfall amount and uneven distribution.

In 2013, higher doses of N (115 kg ha⁻¹) could give similar yield performance as compared to the lower (69 N kg ha⁻¹). This might be due to low absorption of nitrogen by the crop since N losses through leaching and runoff may be high as compared to adequate and even distribution of the rainfall [21]. However, this result in line with other research reports revealed that grain yield of maize due to the application of N in a heavy and uneven distribution of rainfall areas significantly increased compared to the control plot [22, 23]. Application of recommended N half at the time of maize planting significantly reduced the yield of maize when compared with different N rates at a different time of application, but not at the time of planting. This result is directly related to N losses through leaching since the crop could not be utilized at the early emergence stage until its root development [15, 24]. Similar findings were also reported by other authors [11, 13, 16]

The response of maize at the higher rates of N was observed in 2014. This might be related to rainfall amount and distribution of rainfall, particularly at the time of N application that may reduce the loss [24–26]. Delayed time of application after root development significantly enhanced the yield of maize compared to before or at the time of planting [25]. This is in agreement with this result that application of N after 10–15 days after planting onwards significantly increased yield compared with farmers' practices. N use efficiency even under low rates of N at two to three times applications considerably enhances N absorption in good rainy seasons [6, 27]. Moreover, time of application significantly enhances N absorption, particularly at the time of critical N requirement for the crop [11, 13]. Other reports also confirmed that

split application of N after the good establishment of the crop markedly reduces N losses [16]. The lowest yield was, however, recorded from control plot receiving no N [6].

In line with the agreement of this result, both agronomic efficiency and HI were not significantly increased as the function of N rate increased and other reports were also similar [11, 13]. However, delayed application of N after crop establishment significantly increased HI compared to N application at the time of planting [24]. The highest AE and HI were recorded from the control plot [11, 28].

5. Conclusion

Despite the fact that maize productivity is relatively better than other major cereal crops, its current productivity is still far below its potential productivity. N rate and time of application are among the major abiotic factors limiting the production and productivity of the crop. Amount and distribution of rainfall across the seasons considerably influenced the responses of maize to rate and time of N application. In a heavy and uneven distribution of rainfall similar to 2013 cropping season, application of 92 N kg ha⁻¹ at T_2 (10–15 days after planting (DAP), 35–40 DAP, and 55–60 DAP) gave comparable optimum grain yield compared to other treatment means. Even though the application of 92 N kg ha⁻¹ gave optimum grain yield in 2014 season, two times application (10–15 DAP and 35–40 DAP) was an optimum time. In conclusion, application of 92 N kg ha⁻¹ at T_1 is the best N rate and time of application to get the maximum net benefit and acceptable MRR in good rainy seasons and hence is recommended for the end users. However, in case of erratic and heavy rainy seasons that may lead to N losses through runoff and leaching during time of N application, application of 92 N kg ha⁻¹ at three times application (1/3 N at 10–15 DAP, 1/3 N at 35–40 DAP, and 55–60 DAP) should be used to get maximum profit and acceptable MRR.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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