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Research Article

INFLUENCE OF NITROGEN FERTILIZER RATE AND ITS TIME OF APPLICATION ON PRODUCTIVITY OF MAIZE *(ZEA MAYS L.)* IN SOUTHERN ETHIOPIA

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ABSTRACT. The study was conducted in Hadero Tunto Zuria District, Kambata Tambaro Zone, Southern Ethiopia during the main cropping season of 2019 to investigate optimum nitrogen fertilizer rate and its time of application to increase the productivity of maize crops. Soil fertility depletion and poor nutrient management are the major factors contributing to the low productivity of the crop. The treatments consisted of two factors, namely, four levels of nitrogen rates and five different application times. The experiment was laid in a randomized complete block design (RCBD) in factorial arrangements with three replications. The analysis of variance showed that the maximum grain yield (6.417 t ha^{-1}) was obtained with the highest nitrogen fertilizer rate (200 kg ha^{-1}) which applied 1/3 at planting + 2/3 at knee height time. While the least value (4.413 t ha^{-1}) was recorded in plots that receive (50 kg ha^{-1}) which applied 1/3 at planting + 2/3 at near taseling. Like grain yield, the total biomass yield of maize also increased linearly with an increase in nitrogen fertilizer rates. Thus, the results suggested that the use of the high amount of nitrogen fertilizer rate with an appropriate time of application was increased the yield of maize in the study area.

Keywords: *Grain Yield, growth, productivity, kernel weight*

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop in the world next to rice and wheat and has the highest production potential among the cereals [1]. It is the most important food for humans in South America, Africa, and China [2]. In Ethiopia, maize is grown from moisture stress to high rainfall regimes and from lowland to the highlands. It is an important cereal in human diets and animal feed, providing adequate amounts of energy and protein. It 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 [3].

The average productivity of maize is 6.7 t ha^{-1} in developed countries and 2.4 t ha^{-1} in developing countries [2]. Even though 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 t ha^{-1} at the research field and 6–8.5 t ha^{-1} at an on-farm field [4]. Whereas the national average productivity is 3.4 t ha^{-1} while in the SNNPRS is 3.075 t ha^{-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].

Poor soil fertility is one of the principal factors that limit maize productivity in maize growing areas of Ethiopia [7]. Nutrient inputs from chemical fertilizers are needed to replace nutrients that are exported and lost during cropping, to maintain positive nutrient balances [8]. Nitrogen and phosphorous are the major macronutrients that are most limiting in maize grain Production worldwide [9]. Nitrogen availability influences the uptake, not only of itself but also other nutrients [10]. This is partly attributed to better plant growth by which N-fertilized plants have larger root systems for the capture of other nutrients [11]. Nitrogen use and demand are continuously increasing day by day [12]. Since it is highly mobile, it is subject to greater losses from the soil-plant system. Even under the best management practices, 30-50% of applied nitrogen (N) is lost through different agencies and, hence, the farmer is compelled to apply more than the actual need of the crop to compensate for the loss [12]. N is the most important nutrient for maize production. While [13] observed that the application of 200 kg N ha^{-1} increased the grain yield of maize. However, a substantial percentage of applied N is also lost due to volatilization, leaching, and denitrification. Therefore, N should be applied at an optimum level that would maximize its utilization for grain production.

Timing of fertilizer application is another low-cost strategy to reduce nutrient leaching, so that nutrient supply is synchronized with plant demand [14]. Split application of nitrogen is one of the methods to improve nitrogen use by the crop while reducing nutrient loss through leaching and volatilization. Split-application is an essential approach to increase the N use efficiency in crops including maize. 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 [15]. 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 [16]. 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 [15]. The reasons for low crop productivity are low soil fertility and indiscriminate use of chemical fertilizers by smallholders [17]. According to [18] the major problems in the way of increasing yield at farmer's fields are the inappropriate nutrient supply. Among the plant nutrients, nitrogen (N) management is one of the most important factors required for improving crop productivity and profitability at the farmer's level. Therefore the objective of this study was to investigate the optimum N rate and its time of application to increase the productivity of maize crops in the study area.

MATERIAL AND METHODS

Description of the Experimental Site

The study was conducted in Hadero Tunto Zuria District, Kambata Tambaro Zone, Southern Nations Nationalities, and People Regional State at Ajora Kebele farmers training center’s field during the main cropping season of 2019. The district is located at about 343 km and 151 km South of Addis Ababa and South West of Hawassa, the capital, and regional city, respectively. The Hadero Tunto Zuria District is composed of 16 administrative kebeles and bordered by Wolaita Zone in the South, Qachabira District in the East, Hadiya Zone in the North, and Tambaro District in the West. Astronomically, it is situated between 7^0 7’30’’ to $7^0$19’30’’ N latitude, 37^0 34’ 30’’ to37^0 43’30’’E longitude at an altitude of 1300m – 2600 meters above sea level (Hadero Tunto Zuria district of Agricultural Office, 2019). The study area consists of three distinct agro-climatic zones, Dega (12%), Weyna dega (87%), and Kolla (1%). The mean annual rainfall ranges from 800mm - 1200mm with a mean annual temperature of 18ºC-32ºC. The dominant crops growing around the experimental area are enset (*Enset ventricosum)*, wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare*), teff (*Eragrostis tef*), ginger (*Zingiber officinale*), and legumes.

Experimental Materials

The variety P3506W (Damote Pioneer) seed was obtained from the southern agricultural seed multiplication center which was used as experimental materials and considered as quality seed. The seeds of the variety were used from the 2018 cropping season harvest.

Treatments and Experimental Design

The treatments consisted of two factors, namely, four levels of nitrogen rates (50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1}, and 200 kg ha^{-1} of N in the form of urea) and five different application times (½ N at planting + 1/2 at knee height, 1/2 at planting + 1/2 at near tasseling, 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 1/3 at planting + 2/3 at knee height, 1/3 at planting + 2/3 at near tasseling). The experiment was laid in a randomized complete block design (RCBD) in 4 x 5 factorial arrangements with three replications. In this experiment, the total number of treatments and plots was 20 and 60; respectively. The size of each experimental plot was 3 m long and 3 m wide, Plant population for all experimental plots was 2400 plants, 75 cm between rows, and 30 cm between plants with 4 rows of 75 cm apart, giving a gross plot area of 9 m^2. Spacing of 1.5 m and 1 m was maintained between adjacent blocks and plots, respectively. All data except phenology of crop were collected from the middle two rows leaving the outermost two rows in both sides and plants that were grown in 37.5 cm extreme most distance at both ends of rows. Thus the net harvestable plot area was 6.89 m^2 (2.625 m x 2.625 m) and the total harvestable area was 224.64 m^2. The total size of the plot and area of the field was 540 m^2 (9 m^2 x 60) and 948 m^2 (79 m x 12 m) respectively.

Management of Experiment

Land preparation

The experimental field was prepared following the conventional tillage practice which includes 2-3 times plowing before planting of the maize variety P3506W (Damote Pioneer) seeds. As per the specifications of the design, a field layout was prepared; the land was cleared, leveled, and was made suitable for crop establishment.

Planting and field management

Planting was done on May 15, 2019, and it was made by keeping two seeds in one hill at a distance of 30 cm within a row. Two weeks after emergence, plants were thinned to one plant per hill. Recommended phosphorus (100 kg P ha^{-1}) in the form of triple superphosphate (TSP) for all experimental plots including the control plot were equally and uniformly applied at the time of maize planting. Application time of nitrogen fertilizer was applied in the form of Urea as per treatment arrangements. The hybrid variety P3506W (Damote Pioneer) of maize was used for the execution of the treatments. While experimenting other necessary agronomic management practices such as weeding, disease, and insect pest control were carried out uniformly for all treatments to evaluate the performance of the productivity of maize variety.

Data Collection and Measurements

Data collection was carried out during the vegetative period, at maturity time, at harvest, and after harvest. The Data was collected on agronomic parameters (plant height, Days to tasseling, days to silking, tasseling and tasseling-silking interval, Days to physiological maturity), yield components (number of grain rows per ear, Numbers of grains per ear rows, and 1000-grain weight), yields (grain, dry biomass and harvest index).

Plant height

Plant height from the ground level up to the collar of the upper leaf with developed leaf sheath was measured at physiological maturity time.

Days to 50% tasseling

Tasseling was reached when 50% of the plants shed pollen from the main branch of the tassel and a few other branches.

Days to 50% silking

Silking refers to the stage when silk emerged on 50% of the observed plants. The silking date was recorded when 50% of the plants had extruded silks.

Days to tasseling-silking interval

The tasseling-silking interval (TSI) is the number of days from anthesis to silking. It was calculated as a difference between the recorded anthesis and silking dates. On the other hand, the ASI was estimated by counting the difference in the number of days required for 50% of the plants within each plot to present pollen shed and 50% of the plants to have visible silks.

Days to physiological maturity

The appearance of a black layer underneath the tip of the kernel that is attached to the cob was used as a criterion for physiological maturity. It was determined by counting the number of days from the planting date to harvesting time.

Numbers of grain rows per ear

Five randomly selected ears were harvested in each plot and numbers of rows per ear were counted and averaged.

Number of grains per ear row

The number of grains per ear row was determined by counting the number of grains in one row of each harvested ear and averaged.

Thousand-grain weights

Thousand-grain weight was determined by weighing with analytical balance the weight of 1000 sampled grains from the bulk harvest and adjusting to 12.5 % moisture level.

Grain and biomass yield

Grain and stubble yield data were collected from the two harvestable rows by excluding over-favored plants (plants that stand at a spacing exceeding the required distance due to missing plants in a row). The harvested biomass was weighed for fresh biomass weight after which the ears and the stubble are separated and weighed. The ears are shell and grain yield was determined by adjusting to 12.5 % moisture content. The stubble of two stands from each plot was collected from each plot at harvest. The stubble samples are sun-dried until a constant weight was attained so that it was possible to calculate the dry stubble yield per plot. The dried biomass yield was determined as the sum of dry grain and dry stubble yields.

The harvest index (HI)

It was computed as the ratio of grain yield (GY) to the total ground Dry-mass (DM) yield. The following formula was used: HI (%) = (grain yield/total biological yield) × 100.

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) as per the experimental designs for each experiment using GenStat version 15.1, 18th edition of the statistical software package. The Least Significance Difference (LSD) at the 5% level of probability procedure was used to determine differences between treatment means.

RESULTS AND DISCUSSION

Plant Height

The analysis of variance showed that the main factors (N rate and time of application) and their interaction of these factors significantly influenced plant height (Appendix table 1). It increased with increasing N rates. So, the maximum plant height (3.213 m) was obtained with the highest N rate (200 kg N ha^{-1}) 1/3 at planting + 2/3 at knee height. While the least value (2.720 m) was recorded in plots that receive (50 kg N ha–1) which applied 1/3 at planting + 1/3 at near tasseling (Table 1). Similar results have been reported by [19] who stated that an increase in plant height due to more N may be attributed to better vegetative development that resulted in increased mutual shading and internodal extension. [19] Suggested that higher N application increased cell division, cell elongation, nucleus formation as well as green foliage. An increase in plant height may also be due to prolonged vegetative growth which increased the plant height. This tendency can be attributed to the higher dose of N, which greatly helps the plant to expose its potential to grow vigorously.

Table 1. *Interaction effect of nitrogen fertilizer rate and its time of application on plant height of maize.*

	Time of N- fertilizer application				
N- Rate (kg ha-1)	T1	T2	T3	T4	T5
5o	2.733 d	2.857 ^{bcd}	2.843 ^{bcd}	2.717 ^{d}	2.720 ^{d}
100	2.807 ^{cd}	2.793 ^{d}	2.993 ^{abcd}	2.897 ^{abcd}	2.850 ^{bcd}
150	2.870 ^{abcd}	2.960 ^{abcd}	2.887 ^{abcd}	3.167 ^{ab}	2.957 ^{abcd}
200	3.140 ^{abc}	3.167 ^{ab}	3.010 ^{abcd}	3.213 ^{a}	3.017 ^{abcd}
LSD (5%)			0.1834		
CV (%)			3.8		

Means with the same letter (s) in the same column and rows of the trait are not significantly different at 5% probability level, T1 = nitrogen fertilizer applied at ½ at planting + ½ at knee height time, T2 = nitrogen fertilizer applied ½ at planting + ½ at near taseling time, T3 = nitrogen fertilizer applied 1/3 at planting + 1/3 at knee height + 1/3 near taseling time, T4 = nitrogen fertilizer applied 1/3 at planting + 2/3, at knee height time, T5 = nitrogen fertilizer applied 1/3 at planting + 2/3 at near taseling time, LSD (5%) = least significant difference at 5% probability level, CV(%) = coefficient of percent variation.

Days to 50% Tasseling

The analysis of variance (ANOVA) result indicated that day to 50% tasseling was significant (P<0.01) difference between N-rates (appendix table1). When increasing N-rates from 50 to 200 kg ha^{-1} increases days to 50% tasseling. The comparison of means indicated that the maximum of days to 50% tasseling (69.53 days) was recorded at application of 200 kg N ha^{-1} and the minimum (66.87 days) was recorded at 50 kg ha^{-1} (Table 2). Similar results are reported by [19]) who stated that higher nutrient availability and favorable soil conditions due to N fertilizer may cause vigorous crop growth and delay phenology such as tasseling and silking.

Table 2*. The main effect of nitrogen fertilizer rate on days to tasseling (days), days to silking (days), days to tasseling silking interval, days to physiological maturity, thousand kernel weight, and some grain rows per ear of maize.*

N- Rate (kg ha^{-1})	Mean values of parameters					
	DT (days)	DS (days)	STI (days)	DPM (days)	NGRPE	TKW (g)
5o	66.87 b	73.73 a	6.86 a	126.3 c	13.33 b	290.1 b
100	67.67 b	72.53 ab	4.86 b	129.7 b	14.20 a	295.8 b
150	68.00 b	72.40 ab	4.400 b	131.0 b	14.47 a	306.7 a
200	69.53 a	71.40 b	1.87 c	135.2 a	14.53 a	312.3 a
LSD (5%)	1.145	1.267	0.831	2.250	0.9119	5.69
CV (%)	2.3	2.4	25.2	2.4	3.9	2.6

Means with the same letter (s) in the same column and rows of each trait are not significantly different at 5% probability level, DT = days to tasseling, DS= days to silking, STI = silking teaseling interval, TKW = thousand kernel weight, DPM = days to physiological maturity NGRPE= Number of grain rows per ear, LSD (5%) = least significant difference at 5% probability level, CV (%) = Coefficient of percent variation.

Days to 50% silking

Statistical analysis of the data revealed that the interactions of N rates and its application time are not significant. But, the main effect of N-rates showed significant at ($P<0.05$) on days to 50% silking. The highest value was recorded at an N-rate of 50 kg ha^{-1} and the minimum value recorded at N-rate of 200 kg ha^{-1} (Table 2). The result indicated that increases N-rate shorten the duration of 50% silking time. This decrease may be due to enhanced growth rate and dry matter accumulation in an early stage. This decrease in a silking period in response to an increase in N rate might be attributed to rapidness in the growth period and promoting silk extrusion. Similar results also reported by [20] reported that the mean values for nitrogen rates showed that days to 50% silking delayed by 2 days in treatment with no N application compared to a treatment that fed with 115 kg N ha^{-1}. Thus the maximum days to 50% silking (84.67) were recorded in a plot with no N application. However, it was statistically similar with days to 50% silking recorded under treatment of 23, 46, and 69 kg ha^{-1} N-rates. The minimum days to 50% silking (82.67) were obtained under maximum N rate (115 kg N ha^{-1}) but statistically similar results were also obtained under application of 46, 69, and 92kg N ha^{-1}. However, there was a decreasing trend in days to 50% silking with increasing in nitrogen rates. But, the result was not agreed with that of [19] who reported that the maximum days to silking (56.37 DAS) were taken by the crop when N dose was applied at the rate of 250 kg ha^{-1}, followed by N5 (300 kg N ha^{-1}) while minimum days to silking (52.50 DAS) were observed for N1 (100 kg ha^{-1}) treatment, mean days to silking was 54.62 DAS.

Days to 50% Tasseling-Silking Interval

The analysis of variance showed that the main factor N rates significantly affected the tasseling-silking interval. The maximum tasseling-silking interval (6.86 days) was recorded at the application of N rate of 50 kg ha-[1] and the minimum tasseling-silking interval (1.87 days) was recorded at the application of N rate of 200 kg ha^{-1}. A shorter tasseling-silking interval with a higher N rate was because of inducing early and rapid growth of the crop. Similarly, [21] reported that there will be more synchrony in flowering with a higher nitrogen rate. So, the above (Table 2) indicated that when we increased the N rate it decreased the prolonged period of 50% tasseling and silking of maize variety.

Days to Physiological Maturity (DPM)

The data along with the comparison of means are presented in Table 2, which indicates that Days to 90% physiological maturity showed significant ($P<0.01$) differences between N- rates (appendix table 1). But the interaction of N-rate and time of N-application showed no significant variation on days to 90% physiological maturity. In addition, N- fertilizer applied at the rate of 200 kg ha^{-1} was found late-maturing which took the longest duration (135.2 days), and N-fertilizer applied at the rate of 50 kg ha^{-1} took the shortest duration (126.3 days). This might be due to the loss of water content in seeds obtained from N- fertilizer applied at the rate of 50 kg ha^{-1} as it was observed from the rapid change of plants from a green color to yellowish at field evaluation and the appearance of a black layer underneath the tip of the kernel that is attached to the cob early appeared than the other rate of application. This result was in agreement with that of [22] who reported that the maximum days to physiological maturity (141.7 days after sowing, DAS) was achieved by, N3 (69 kg ha^{-1}), followed by N2 (135 days) where N was applied at the rate of 46 kg ha-1. Delay in the maturity of maize was greater at the higher rate of N, as about 16 more days were required for the 69 kg ha-1 treatment compared to the control which took 125days to maturity. This might be attributed to the behavior of N- fertilizer, which increases the vegetative growth of the cob when more N is applied.

Number of Grain Rows Ear^{-1}

Statistical analysis of the data revealed that the number of grain rows ear^{-1} was highly significantly affected by nitrogen rates (appendix table 2). The high number of grain rows ear^{-1} (14.53) was recorded in the plots treated with 200 kg ha^{-1} followed by 150 kg N ha^{-1} (14.47) and the Minimum number of grain rows ear^{-1} (13.33) was recorded in 50 kg N ha^{-1}. Interaction between nitrogen rates and its time of application was non-significant. Similar results have been reported by [19] who reported that N rates and their application time had no significant effect on the number of grain rows ear^{-1}. This indicated that environmental factors have a low influence on the number of grain rows and this trait is significantly affected by genetic factors rather than other sources.

Number of Grains per Ear Row

The analysis of data regarding the effects of rates and N application time on the number of grains per ear row is given in Table 3. The comparison of means of rates × N application time indicated that the highest value (44.67) was recorded at application of 200 kg N ha^{-1} as T5, and the minimum number of grains per ear row (35.33) was recorded at application of 50 kg N ha^{-1} as both T2 and T5. A greater number of grains per ear row with higher N rates might have resulted from the greater assimilates partitioning to the seeds as a result of the longer growth period and higher photosynthetic availability during the grain filling period [23]. Similar results have been reported by [24] suggested that a decrease in the number of grains per ear row under lower N application might be attributed to poor development of sinks and reduced translocation of photosynthesis. In this study, high N rates delayed the appearance of phonological stages, and it seems that can be one of the reasons for increasing the number of grains per ear row.

Table 3. *Interaction effect of nitrogen fertilizer rate and its time of application on Number of grains per ear row of maize.*

	Time of N- fertilizer application				
N- Rate (kg ha^{-1})	T1	T2	T3	T4	T5
5o	37.33 cde	35.33 e	37.33 cde	39.00 abcde	35.33 e
100	42.33 abcd	38.00 bcde	41.33 abcd	42.67 abc	37.00 cde
150	36.67 de	37.33 cde	37.00 cde	43.33 ab	40.00 abcde
200	41.00 abcde	42.00 abcd	42.00 abcd	42.00 abcd	44.67 a
LSD (5%)			3.089		
CV (%)			4.7		

Means with the same letter (s) in the same column and rows of the trait are not significantly different at 5% probability level, T1 = nitrogen fertilizer applied at ½ at planting + ½ at knee height time, T2 = nitrogen fertilizer applied ½ at planting + ½ at near taseling time, T3 = nitrogen fertilizer applied 1/3 at planting + 1/3 at knee height + 1/3 near taseling time, T4 = nitrogen fertilizer applied 1/3 at planting + 2/3, at knee height time, T5 = nitrogen fertilizer applied 1/3 at planting + 2/3 at near taseling time, LSD (5%) = least significant difference at 5% probability level, CV (%) = coefficient of percent variation.

Thousand Kernel Weight (g)

The analysis of variance of N rates showed a highly significant difference ($P<0.01$) in one thousand kernel weight of treatment means (appendix table 2). But, the time of N application and the interaction effect showed no significant variation between treatment means. The comparison of means indicated that the maximum thousand kernel weight (312.3 g) was recorded at the application of 200 kg N ha^{-1} and the minimum value of thousand kernel weight (290.1 g) was recorded at the application of 50 kg N ha^{-1}. This is due to a higher photosynthesis rate which increases the size of kernel weight and leads to increased grain yield. Similarly, [25] indicated that a higher rate of N level increased kernel weight in maize. Also, [26] reported that the increase in thousand grains weight with an increase in N rates might be due to a relatively higher amount of photosynthesis to the grains.

Grain Yield

The analysis of variance revealed that the main factors (N rate and its time of application) and their interaction of these factors were highly significantly influenced grain yield (Appendix table 2). It increased with increasing N rates. So, the maximum grain yield (6.417 t ha^{-1}) was obtained with the highest N rate (200 kg N ha^{-1}) which applied 1/3 at planting + 2/3 at knee height time. While the least value (4.413 t ha^{-1}) was recorded in plots that receive (50 kg N ha^{-1}) which applied 1/3 at planting + 2/3 at near taseling (Table 4). The result is in agreement with the result of [27, 28] who reported that yield and yield components of maize increase by increasing of applied N rate. Similarly, [19] gained the yield variation between 4744.8 kg ha^{-1} without N application to 7355.5 kg ha^{-1} at the application of 225 kg N ha^{-1}. These results indicated that N application with the increase in split application proved an additional source for a higher rate of photosynthesis and transport of photo-assimilates during grain filling that resulted in a higher grain yield of maize. Delayed time of application after root development significantly enhanced the yield of maize compared to at the time of planting. So these results indicated the split application of N-fertilizer was for the productivity of maize crop in the study area.

Table 4. *Interaction effect of nitrogen fertilizer rate and its time of application on grain yield of maize.*

	Time of N- fertilizer application				
N- Rate (kg ha-1)	T1	T2	T3	T4	T5
5o	4.607 ghi	4.460 i	4.490 hi	4.873 fghi	4.413 i
100	5.510 bcdef	4.860 fghi	5.193 cdefgh	5.627 bcde	4.957 efghi
150	4.943 efghi	5.263 cdefg	5.310 cdefg	6.200 ab	5.780 abcde
200	6.150 abc	5.117 defghi	5.573 bcdef	6.417 a	5.920 abcd
LSD (5%)			0.3875		
CV (%)			4.4		

Means with the same letter (s) in the same column and rows of the trait are not significantly different at 5% probability level, T1 = nitrogen fertilizer applied at ½ at planting + ½ at knee height time, T2 = nitrogen fertilizer applied ½ at planting + ½ at near taseling time, T3 = recommended nitrogen fertilizer applied 1/3 at planting + 1/3 at knee height + 1/3 near taseling time, T4 = nitrogen fertilizer applied 1/3 at planting + 2/3 at knee height time, T5 = nitrogen fertilizer applied 1/3 at planting + 2/3 at near tasseling time, LSD (5%) = least significant difference at 5% probability level, CV(%) = coefficient of percent variation.

Biomass Yield (t ha^{-1})

Biomass yield was determined from plants harvested from net plots those at the point of being attached to the ground and sun-dried until the constant weight was attained. Data subjected to analysis of variance and the result indicated that the main factors (N- rate and time of application) and their interaction was significantly influenced biomass yield of maize crop (Appendix table 2). It increased with increasing N rates. So, the maximum biomass yield (22.33 t ha^{-1}) was obtained with the highest N rate (200 kg N ha^{-1}) of 1/3 at planting + 2/3 at knee height. While statistically the least value (15.73 t ha^{-1}) was recorded in plots that receive (50 kg N ha^{-1}) which applied 1/2 at planting + 2/3 at near tasseling (table 5). The biomass yield production was largely a function of the photosynthetic surface, which was favorably influenced by N-fertilization. So, the increasing fertilization of N-rate from 50 to 200 kg ha^{-1} relatively increases the biomass yield production in the study area. Like grain yield, the total biomass yield of maize also increased linearly with an increase in N rates from 50 to 200 kg N ha$^{-1,}$ showing more dry matter allocation in favor of the Stover under heavier N rates. Also, the increase in total biomass is directly related to the increase in plant height, leaf area, and vegetative growth which is due to sufficient availability of N to the plants. In agreement with the results of this study, [25, 29] reported significantly higher biomass yield at higher N rates. [30] Also reported that the grain yield of maize increases progressively with added nitrogen fertilizer up to a certain rate. Biological yield increase with an increase in N-levels because more growth occurs which increases biological yield. The other result from [31] reported that the highest significant biomass yield (21.2 t/ha^{-1}) was obtained at 115 N kg ha−1 and T4 (four times split application of equal doses) followed by 69 N kg ha^{-1} at T1 and T2. However, the application of 46 kg ha^{-1} at T2 (two times split application of equal doses) showed the lowest yield, except the control plot without N, compared to other treatment combinations.

Table 5. *Interaction effect of nitrogen fertilizer rate and its time of application on biomass yield of maize (t ha^{-1}).*

	Time of N- fertilizer application				
N- Rate (kg ha-1)	T1	T2	T3	T4	T5
5o	15.75 e	17.41 cde	17.40 cde	16.50 e	15.73 e
100	16.64 cde	16.07 de	19.05 bcd	19.03 bcd	15.77 e
150	15.82 e	17.50 cde	18.00 cde	21.30 ab	19.45 abc
200	21.14 ab	18.61 bcde	17.66 cde	21.62 ab	22.33 a
LSD (5%)			1.661		
CV (%)			5.5		

Means with the same letter (s) in the same column and rows of the trait are not significantly different at 5% probability level, T1 = nitrogen fertilizer applied at ½ at planting + ½ at knee height time, T2 = nitrogen fertilizer applied ½ at planting + ½ at near taseling time, T3 = recommended nitrogen fertilizer applied 1/3 at planting + 1/3 at knee height + 1/3 near taseling time, T4 = nitrogen fertilizer applied 1/3 at planting + 2/3 at knee height time, T5 = nitrogen fertilizer applied 1/3 at planting + 2/3 at near taseling time, LSD (5%) = least significant difference at 5% probability level, CV(%) = coefficient of percent variation.

Harvest Index

The analysis of variance of N rates and interaction with the time of N application showed a significant difference for the harvest index. But, the time of N application showed no significant variation between treatment means. The comparison of means indicated that the maximum harvest index (31.61 %) was recorded at the application of 200 kg N ha^{-1} as T3, followed by 100 kg N ha^{-1} as T5 and the minimum of it (24.68 %) was recorded at the application of 50 kg N ha^{-1} as T2 (Table 6). The analysis of variance in these study harvest index (HI) was not significantly increased as the function of time of N- application. The result is in line with the result of [32] who reported that the harvest index in corn increases when N rates increase. However, delayed application of N after crop establishment (split application) significantly increased HI compared to N application at the time of planting (Table 4). The other result [33] also reported that the maximum harvest index (36.1%) was recorded from 120 kg ha^{-1} nitrogen application, followed by 90 kg N ha^{-1} (33.6%) over the minimum (31.6%) observed from control. The increased harvest index with higher levels of N might be due to efficient portioning of assimilates towards the economic portion.

Table 6. *Interaction effect of nitrogen fertilizer rate and its time of application on harvest index of maize.*

	Time of N- fertilizer application				
N- Rate (kg ha-1)	T1	T2	T3	T4	T5
5o	29.42 ab	24.68 c	25.85 bc	29.37 abc	28.04 abc
100	29.92 ab	30.30 ab	27.28 abc	29.56 ab	31.47 a
150	31.24 a	30.08 ab	29.57 ab	29.26 abc	29.72 ab
200	29.14 abc	29.60 ab	31.61 a	29.69 ab	30.20 ab
LSD (5%)			2.515		
CV (%)			5.2		

Means with the same letter (s) in the same column and rows of the trait are not significantly different at 5% probability level, T1 = nitrogen fertilizer applied at ½ at planting + ½ at knee height time, T2 = nitrogen fertilizer applied ½ at planting + ½ at near taseling time, T3 = recommended nitrogen fertilizer applied 1/3 at planting + 1/3 at knee height + 1/3 near taseling time, T4 = nitrogen fertilizer applied 1/3 at planting + 2/3 at knee height time, T5 = nitrogen fertilizer applied 1/3 at planting + 2/3 at near taseling time, LSD (5%) = least significant difference at 5% probability level, CV (%) = coefficient of percent variation.

CONCLUSION

Maize (*Zea mays* L.) is the third most important cereal crop in the world next to rice and wheat and has the highest production potential among the cereals. It is an important cereal in human diets and animal feed, providing adequate amounts of energy and protein. Even though its current productivity is higher than other major cereal crops, the yield is below its potential. Therefore, the general objective of the research was to investigate the optimum nitrogen fertilizer rate and its time of application to increase the productivity of maize crops in the study area. The treatments consisted of two factors, namely, four levels of nitrogen fertilizer rates (50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1}, and 200 kg ha^{-1} of in the form of urea) and five different application times (½ N at planting + 1/2 at knee height, 1/2 at planting + 1/2 at near tasseling, 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 1/3 at planting + 2/3 at knee height, 1/3 at planting + 2/3 at near tasseling). The experiment was laid in a randomized complete block design (RCBD) in 4 x 5 factorial arrangements with three replications.

The results of the analysis indicated that nitrogen fertilizer rate application with an increase in split application proved an additional source for a higher rate of photosynthesis and transport of photo-assimilates during grain filling that resulted in a higher grain yield of maize. And, the biomass yield production was also largely a function of the photosynthetic surface, which was favorably influenced by N-fertilization. So, the grain yield, total biomass yield of maize increased linearly with an increase in N rates from 50 to 200 kg N $ha^{-1,}$ showing more dry matter allocation in favor of the Stover under heavier N rates. Thus, the results suggested that use of 200 kg N ha^{-1} within an appropriate time of application was increased the yield of maize in the study area.

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APPENDICES

Appendix table A. 1. Mean squares of analysis of variance for crop phenological and growth parameters of maize from different N-rate and time of application

Source of Variation	DF	Mean squares				
		DT	DS	TSI	PH	DPM
Replication	2	4.317	3.017	0.600	0.00188	25.55
NR	3	18.728**	13.706*	63.400**	0.30892**	201.93**
TNA	4	1.725^{ns}	2.558^{ns}	0.292^{ns}	0.00723^{ns}	3.36 ^{ns}
NR×TNA	12	2.714 ^{ns}	1.858^{ns}	1.247^{ns}	0.03136*	9.52 ^{ns}
Residual	38	2.439	3.403	1.407	0.01230	10.06
CV (%)		2.3	2.5	13.4	3.8	2.4

* and **, significant at 5% and 1% level of significance, respectively, ns = None significant difference, CV (%) = coefficient of variation in percent, DF = degree of freedom, NR = nitrogen fertilizer rate, TNA = time of nitrogen fertilizer application, DT = days to 50% tasseling, DS = days to silking, TSI = days to 50% tasseling –silking interval, PH = plant height and DPM = days to physiological maturity.

Appendix table A. 2. Mean squares of analysis of variance for yield components and yield parameters of maize from different N-rate and time of application

Source of Variation	DF	Mean squares					
		NRPE	NGRPE	TKW	GY	BY	HI
Replication	2	0.2167	8.317	0.22	0.32883	1.765	2.709
NR	3	4.5778**	79.617**	1534.73**	4.32512**	40.786**	22.663**
TNA	4	0.1083^{ns}	20.708**	191.44*	1.18482**	9.021**	4.984^{ns}
NR×TNA	12	0.3972 ^{ns}	12.131*	63.57^{ns}	0.25124**	8.738**	6.717*
Residual	38	0.3044	3.492	45.60	0.05496	1.009	2.315
CV (%)		3.9	4.7	2.2	4.4	5.5	5.2

* and **, significant at 5% and 1% level of significance, respectively, ns = None significant difference, CV (%) = coefficient of variation in percent, DF = degree of freedom, NR= nitrogen fertilizer rate, TNA= time of nitrogen fertilizer application, NGRPE = number of rows per ear, NGRPE = number of grain rows per ear, TKW = thousand kernel weight, GY = grain yield, BY = biomass yield and HI = harvest index.