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Research Article

Effects of Time and Rate of Nitrogen Fertilizer Application on Phenology, Growth and Yield of Maize at Jimma, Southwestern Ethiopia

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Abstract

Maize (Zea mays L.) is one of the most important crops in Ethiopia in general and in the Jimma area in particular. However, its productivity is low due to the inadequate management of nitrogen fertilizer rates and inappropriate timing of fertilizer applications. Hence, a field experiment was conducted during the 2020-2022 main cropping seasons to determine the effect of different rates and times of nitrogen applications on phenology, growth, yield, and yield components of maize and to estimate the most economical rate and time of nitrogen fertilizer application. The experiment was laid out in a factorial randomized complete block design with three replications. The experiment consisted of five rates of nitrogen (0, 46, 92,138 and 184kg N ha^{-1}) and three times of application (Full at planting, 1/2 at planting +1/2 at the 5-leave stage, and 1/3 at planting+1/3 at 5-leave stage + 1/3 at booting). The result revealed that days to 50% tasseling, days to 90% physiological maturity, plant height, ear height, stem diameter, numbers of ears per plant, grain yield, above-ground dry biomass, and harvest index were significantly affected by either the main effects of N fertilizer rate or time of N application. The interaction of rates and time of nitrogen application affected considerably days to 50% silking. The highest mean grain yield (8355.60 kg ha^{-1}) was recorded with applied N in three splits (1/3 at planting, 1/3 at the 5-leave stage, and 1/3 at booting) and the highest grain yield (9213.5 kg ha^{-1}) was obtained from 184kg N ha^{-1}. Grain yield was positively and /highly/ significantly association with days to maturity (r=35), height (r=0.30), ear height (r=0.24), girth (r=0.55), number of ears per plant (r=0.62), biomass yield (r=0.91), harvest index (r=0.35) while grain yield was negatively and/highly/ significantly association with days to tasseling (r=0.20) and days to silking (r=0.23). Partial budget analysis revealed that N in three split applications and 184kg N ha^{-1} rate realized the maximum net benefit of 208,311.10 Birr ha^{-1} and 226,380.2 Birr respectively. Therefore, based on the highest net benefit applying N in three splits (1/3 at planting, 1/3 at 5-leave stage, and 1/3 at booting) and 184kg N ha^{-1} application an economic yield response and also acceptable for farmers of study areas and similar agroecology.

Keywords

Maize, Grain Yield, Partial Budget Analysis, Rate and Time of N Application

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1. Introduction

Maize (Zea mays L.) is the world's widely grown cereal and primary staple food crop in many developing countries [1]. In the world production of maize is ranked as the third major cereal crop after wheat and rice in area basis and total production [2]. According to Pingali and Pandey [3] Africa's share of global maize production is so small because low average yield per unit area. Maize in Africa is grown by small and medium-scale farmers who cultivate 10 ha or less [4]. About two thirds of all African maize is produced in eastern and southern Africa and it accounts for 53% of the total cereal area [5] and 30- 70% of total caloric consumption [6].

Maize is Ethiopia's most important cereal crop both in terms of level of production and area coverage. It is one of the largest maize producing countries in Africa [7]. The total land area of about 12, 677, 882.27 hectares is covered by grain crops and out of the total grain crop area, 80.71% was under cereals. Maize covered 16.79% about (2, 128, 948.91) hectares and gave 83, 958, 87.244 tons of grain yields [8]. It ranks second after Tef (*Eragrostis tef*) in area coverage and first in total national production and yield per hectare [9]. It is also among the major cultivated crops in Oromia accounting for 5,944,489.15 ha of area and 696,145.68 tons of production [10]. Moreover, Jimma is one of the major cultivated maize in the Oromia regional state. Despite the large area under maize, the national average yield of maize about 3.94 t ha^{-1} [8]. This is by far below the world's average yield which is about 5.2 t ha^{-1} [11]. 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 [12].

Among the various abiotic factors of production, nutrient management has been recognized as the most significant factor limiting the yield levels in maize growing areas of Ethiopia [13, 14]. The productivity of crops decreased in recent years because of a decline in soil fertility status. Farmers are facing difficulty in maintaining soil fertility because of a shortage of production and availability of Nitrogen. Ensuring a balanced quantity of nutrients in a given soil for good plant growth is the greatest challenge of the day as yield potentials vary among soils. Fertilizer management is crucial for maize cultivation [15]. Maize is the heavier feeder of nutrients; its nutrient requirements are high. The demand of nitrogen fertilizer is greater than that of the other nutrients. If nitrogen deficiency occurs at the tasseling and silking stages may significantly affect crop failure. However, the amount of nitrogen to be applied to maize plants depends upon maize variety, soil type, soil fertility status location and yield [16]. Nitrogen is responsible for major activities in the growth and development of maize crops [17]. Nitrogen availability influences the uptake, not only of itself but also of other nutrients [18]. Nitrogen use and demand are continuously increasing day by day. 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 [19]. The loss of N not only costs the farmer but also has a hazardous impact on the environment. Hence, the 4R (right source, right rate, right time and right place) nutrient stewardship also considers economic, social and environmental dimensions of nutrient management that enhance the sustainability of agriculture and the environment. Nutrient inputs from chemical fertilizers are needed to replace nutrients that are removed and lost during cropping, to maintain a positive nutrient balance [20]. Moreover, fine-tuning rate and time by split application in order to coincide nitrogen availability with crop needs is a best management practice that would result in better N use efficiency and yield. Nitrogen application timing affects plant height as well as an increase in leaf area. Mariga et al. [21] and Adhikari et al. [22] reported that the days to flowering, thousand-grain weight, ear height, ear length and yield of maize were considerably increased when N was applied up to the tassel initiation stage. Nitrogen supply positively enhances grain yield in all hybrids, primarily by increasing kernel number, ultimately increasing productivity [23].

In Southwestern Ethiopia, maize is produced in a main cropping season where high amounts and intensity of rainfall prevail. In high rainfall situations, leaching (loss of nitrogen) is unavoidable. Excessive rainfall after planting often results in N loss through denitrification and leaching [24]. The leaching loss is also causing a reduced nitrogen nutrient use efficiency of the maize production system and in turn a reduced grain yield production. Leaching of NO3-N is economically and environmentally undesirable. Most soils in Ethiopia are responsive to split application of nitrogen [25]. Time of nitrogen application at appropriate crop growth stage is also another main focus to enhance nitrogen use efficiency and increase maize productivity. Nitrate that leaches below the crop rooting zone represents the loss of a valuable plant nutrient, and hence an economic cost to agriculture. Nyamangara et al. [26] reported that efficient use of N fertilizer is of both agro-economic and environmental importance. Appropriate amount of nitrogen splitting and time of application is imperative for achieving higher yield and better economic advantage for maize production in Jimma areas. The inappropriate rate and time of nitrogen fertilizer application might have played a role in lowering the yield through a reduction in fertilizer use efficiency. All applied nitrogen is not absorbed by the crop since leaching. So that nutrient supply is synchronized with plant demand (Gehl et al., 2005) [27].

Some reports showed that there is no need to split the nitrogen and the whole fertilizer could be applied once. In contrast, numerous authors advised two split applications for maize production [24]. There are also a number of reports that recommend three and four-times split applications for maize production [28, 29]. Those findings might vary due to specific nitrogen fertilizer application time recommendations for different maize growing areas. Presently, nitrogen split application and rate recommendation of 1/3 of the total at planting and the remaining 2/3 at 30-35 days after emergence and 92 kg N ha^{-1} are being widely used in southwestern Ethiopia. However, some farmers in the region have observed good responses to the crop by reducing the amount of nitrogen at planting and applying more at later growth stages. Ferguson et al. [30] reported plant N use efficiency can be improved by matching application rate and timing with plant demands. The use of an optimum rate of nitrogen and timely application is beneficial to get higher maize production. Since nitrogen is highly mobile, it is subjected to greater loss from the soil-plant system. Therefore, matching the optimum rate of nitrogen and timing of nitrogenous fertilizer application is essential to achieve the targeted yields. Therefore, the objectives of this research were (1) to determine the effect of different rates and time of nitrogen applications on phenology, growth, yield and yield components of maize and (2) to estimate the most economic rate and time of nitrogen fertilizer application for maize production at Jimma area.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted for three consecutive cropping seasons at Jimma Agricultural Research Centre in southwest Ethiopia. The site is located 368 km southwest of Addis Ababa. The geographical coordinate of the site is at 7040' N latitude and 360 E longitudes and altitude of 1753 meters above sea level with agroecology characterized by humid mid-latitude. The soil type of the experimental area was Eutric Nit soil (Reddish brown) with a pH of around 5.3. The long-term mean annual rainfall of the study area is 1714.0 mm with a maximum and minimum temperature of 26.6 ℃ and 12.34 ℃ respectively (JARC, 2021).

2.2. Treatments and Experimental Design

The experiment consisted of five rates of nitrogen (0, 46, 92,138 and 184kg N ha^{-1}) and three times of application (Full at planting, 1/2 at planting +1/2 at the 5-leave stage and 1/3 at planting+1/3 at 5-leave stage + 1/3 at booting) resulting in 15 treatments combinations. The experiment was laid out in a factorial randomized complete block design with three replications. The treatments were tested on maize variety Bako Hybrid "BH-546". The seeds of the test variety were sown in a gross plot size of 4.5 m × 4.0 m= (18 m^2) consisting of six rows having intra and inter row spacing of 0.4 and 0.75m to attain a population of 66,666 per hectare. Three seeds were sown per hill and two weeks after emergence and at 4-5 leaves stage thinned to two plants per hill. The blocks were separated by 1.5 m wide space and each plot was separated by 1 m space. The outermost rows at both sides of the plots were considered as borders. Urea (46% N) as N source and Triple Super Phosphate (46% P_2O_5) as P source were used for the study where total phosphorus and amount of nitrogen treatment were applied at the time of sowing and the remaining rates were top dressed as per the time scheduled.

Table 1. *Details of treatments combination of rates and time of nitrogen applications.*

Time of nitrogen applications	Nitrogen fertilizer rates (kgha^{-1})
Full at planting	0
	46
	92
	138
	184
1/2 at planting and 1/2 at 5-leave stage	0
	46
	92
	138
	184
1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting	0
	46
	92
	138
	184

2.3. Experimental Procedure and Crop Management

All field activities were carried out with the following standards. The site was cleared and cultivated four times in 15 days difference. After the selected site was ploughed four times in 15 days interval, cleaned and prepared, leveling, block and plot making activities have been, followed. Maize was planted on the 2^{nd} to 3^{rd} week of April 2020, 2021 and 2022. The recommended rate of P (TSP) fertilizer (150 kg/ha) was equally applied to all plots at the time of sowing. For the N fertilizer application urea was applied at the specified rates and timing. Weeds were managed by hand weeding after weed emergence and late emerging weeds were removed by hoeing to avoid interference with the maize plant for the N applied. All other agronomic practices were applied uniformly to all experimental plots as per their respective recommendations for maize in the study area.

2.4. Data collection

2.4.1. Crop Phenology

Days to tasseling [days]: Count and record the number of days from planting until the date on which 50% of the plants in a plot have started tasseling for maize. Days to silking [days]: Count and record the number of days from planting until the date on which 50% of the plants in a plot have started silk. Days to physiological maturity [days]: Record the number of days from planting until the date on which 90% of the plants in a plot have physiologically matured.

2.4.2. Growth Parameters

Plant height [cm]: This is the mean height of 10 randomly selected plants at physiological maturity measured from the base of the stem of the main plant to where tassel branching begins for maize. Ear height [cm]: This is the mean height of 10 randomly selected plants at physiological maturity measured from the base of the stem of the main plant to where ears begins for maize. Stem diameter [cm] is measured in cm using a caliper at 50cm height of the stem from the ground level and ten randomly taken plants per plot were used for this data measurement.

2.4.3. Yield And Yield Components

Number of cobs per plant [number per plant]: The mean number of cobs of 10 randomly selected maize plants is counted from a net plot area at physiological maturity. Aboveground biomass [kg/ha]: This is measured by obtaining the weight of the aboveground biomass for plants in a net plot area at harvest maturity and converting it to kg per hectare. This is also called biological yield. Grain yield [kg/ha]: This is measured by obtaining the weight of the grains for plants in a net plot area at harvest maturity and converting it to kg per hectare after adjusting the grain to 12.5% moisture content. Harvest index [ratio] is calculated on a plot basis as the ratio of grain yield to total aboveground biomass yield.

2.5. Statistical Analysis

The collected data were subjected to Analysis of variance (ANOVA) using general linear model (GLM) procedure of SAS software version 9.3 software (SAS, 2014) to test the significance level at 5% probability level. The least significant difference was used to separate treatment means. The degree of association between growth, yield and yield components of maize was studied with correlation analysis of association between growth, yield and yield components of maize was studied with correlation analysis. The mean grain yield of the selected treatment was used for partial budget analysis [31].

Table 2. *Soil chemical properties of the experimental site at a depth of 0–20 cm soil before planting.*

Chemical Properties	value
PH	5.3
OC (%)	1.84
Total N (%)	0.22
Av. P (ppm)	5.76
K(mg/kg)	61.29
CEC (meq/100g	15.04

3. Result and Discussion

3.1. Phenological Parameters of Maize as Affected by Nitrogen rate and It Time Applications

3.1.1. Number of Days to 50 % Tasseling

Analysis of variance revealed that days to 50 % tasseling was significantly ($P<0.001$) affected due to the rate and time of nitrogen application. However, the interaction effect of the rate and time of N application was not significant($P>0.005$) (Table 4). The number of days required to attain tasseling ranged from 71.97 to 80.07 days due to the rate and time of nitrogen application. Maximum days to tassel (77.27 days) were recorded when full nitrogen was applied at planting as compared to the rest treatments (Table 4). The result showed that application of N from 0 to 184 kg N ha^{-1} consistently increased days to tassel which ranged from 71.97 to 80.07 days (Table 4). The maximum number of days to tassel was obtained from 184 kg N ha^{-1} while the minimum number of days (71.97 days) was recorded from an unfertilized plot (Table 4). The delay in days to anthesis of maize plants in response to the increased N rate application might be because of high N rate application promoted vigorous vegetative growth and development of the plants possibly due to synchrony of the time needed of the plant for uptake of the nutrient and availability of the nutrient in the soil. The results agreed with Akmal et al. [32], Erkeno [33] and Hafiz et al. [34] who observed that maize took a higher number of days to tassel with the application of high amounts of nitrogen fertilizer rates from 100 to 300 kg ha^{-1}. Kawsar et al. [35] also reported that maize took a high number of days (53.1) to tasseling with the application of high amounts of N fertilizer (150kg N ha^{-1}).

3.1.2. Number of Days to 50% Silking

Analysis of variance revealed that both main effects of rate, time of N application and interaction of the two factors showed a significant ($P<0.001$) effect on days to 50% silking of maize (Table 3). The maximum number of days to 50%

silking (89.78 days) was obtained when applying 184 kg N ha^{-1} in two splits (1/2 at planting and 1/2 at the 5-leave stage) while the minimum number of days to attain silking (78.11 days) was recorded from unfertilized plot with three splits (1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting) (Table 3). Days to 50% silking delayed by about 11.67 days (14.94%) in the 184 kg N ha^{-1} in two splits (1/2 at planting and 1/2 at 5-leave stage) as compared with unfertilized with three splits (1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting) (Table 3). As the nitrogen rates increased the days to 50% silking were prolonged. This might be due to delayed leaf senescence, sustained leaf photosynthesis during the active crop growth stage and extended duration of vegetative growth, development and yield parameters. It also the more nutrients in the soil and is utilized efficiently thereby prolonging the silking dates. The result is in agreement with the findings by Nemati and Sharifi [36] and Alok [37] reported that an increased amount of nitrogen fertilizer resulted in more days to attain silking.

Table 3. *Number of days to 50% silking of maize as affected by the interaction between rate and time of N application during 2020-2022 cropping season.*

Timing of application	**Nitrogen fertilizer rates (kg ha^{-1})**				
	0	**46**	**92**	**138**	**184**
Full at planting	78.33bc	82.89abc	87.44abc	88.11ab	88.56a
1/2 at planting and 1/2 at 5-leave stage	78.33bc	82.00abc	80.22abc	86.78abc	89.78a
1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting	78.11c	81.11abc	80.78abc	83.44abc	88.22a
Mean	83.61				
LSD (0.05)	9.89				
CV (%)	12.67				

3.1.3. Number of Days to 90% Physiological Maturity

The result indicated that days to physiological maturity were significantly affected by the rate and time of nitrogen application ($P<0.005$). However, the interaction of time and rate of nitrogen application was not significant for days to physiological maturity ($P>0.005$) (Table 4). The mean number of days required to attain maturity ranged from 168.73 to 170.20 days due to the time of nitrogen application. The result showed application of N fertilizer in full at sowing resulted in a high number of days to attain physiological maturity when compared to the rest of the application time (Table 4). The maximum number of days to attain physiological maturity (170.19 days) was recorded from a nitrogen level of 184 kg ha^{-1} while the minimum physiological maturity (167.89 days) was recorded from the unfertilized plot (Table 4). This might be due to maize crops with no fertilizer application maturing earlier than maize crops receiving nitrogen fertilizer suggesting a crop stress-escaping mechanism. The results were consistence with the findings by Akbar et al. [38], who reported that the number of days to maturity of maize increased as fertilizer rate increased. This result was also similar to the finding of Moges [39] who reported that as the nitrogen rates increased from 0 to 128 kg N ha^{-1}, the days to physiological maturity of maize was also prolonged from 130.08 to 135.5 days consistently.

Table 4. *Phenological parameter as influenced by rate and time of nitrogen application of maize at Jimma during 2020-2022 cropping season.*

Treatments	**Number of days to 50% tasseling**	**Number of days to 90% physiological maturity**
Time of nitrogen applications		
Full at planting	77.27a	170.2a
1/2 at planting and 1/2 at 5-leave stage	76.24b	168.7778b

Treatments	Number of days to 50% tasseling	Number of days to 90% physiological maturity
1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting	74.64c	168.7333b
LSD (0.05)	0.96	1.0675
Nitrogen fertilizer rates (kgha-1)		
0	71.97d	167.8889c
46	74.85c	168.7037bc
92	75.15c	169.3704ab
138	78.22b	170.037ab
184	80.07a	170.185a
Mean	76.05	169.237
LSD (0.05)	1.24	1.38
CV (%)	3.01	1.503465

3.2. Growth Parameters of Maize as Affected by Rate and Time of Nitrogen Application

3.2.1. Plant Height

The results of the analysis of variance showed that plant height was significantly ($P<0.05$) affected by the rate of nitrogen application. However, the time of nitrogen application and the interaction between the rate and time of nitrogen application were not significant ($P > 0.05$) (Table 5). The comparison of means indicated that plant height was not influenced by time N application. The nitrogen rate had a significant ($P<0.05$) effect on the plant height of maize. The maximum plant height (226.35 cm) was obtained with the highest N rate (138 kg N ha^{-1}) while the lowest value (211.41 cm) was recorded in plots without N application (Table 5). This might be due to an increase in N rates extended vegetative growth period of maize that increases photosynthetic assimilate production and its partitioning to stems that might have favorable impacts on the heights of maize. The result was in line with Moges [39] who described when the nitrogen level was increased from 0 to 128 kg N ha, plant height increased from 176.88 cm to 194.53 cm. Similarly, Kidist [40] reported that increasing the rate of N from 0 to 174 kg N ha^{-1} linearly increased plant height from 250.1cm to 265cm in maize.

3.2.2. Ear Height

The nitrogen rate had a significant ($P <0.01$) effect on the ear height while the time of nitrogen applications and their interaction had non- significant ($P >0.05$) effect on the ear height (Table 5). The maximum ear height (120.07 cm) was obtained with the highest N rate (138 kg N ha^{-1}) while the minimum ear height (109.74 cm) was recorded in plots without N application (Table 5). This might be due to the fact that highest nitrogen rates produced maximum ear height as compared to its lower rate thus resulting in higher plant height.

3.2.3. Stem Diameter

The time of nitrogen applications had a significant ($P <0.05$) effect on stem diameter, but nitrogen fertilizer rates, their interaction had non-significant ($P>0.05$) effect on stem diameter of maize (Table 5). Maximum Stem diameter (2.31 cm) was obtained when full nitrogen applied at planting while the minimum stem diameter (2.19 cm) was recorded at three split (1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting) (Table 5). Similar result was confirmed Hassan *et al.* [41].

Table 5. *Plant height, stem diameter and ear height of maize as influenced by rates and time of nitrogen fertilizer application at Jimma during 2020-2022 cropping season.*

Treatments	Plant height (cm)	Stem diameter (girth) cm	Ear height (cm)
Time of nitrogen applications			
Full at planting	222.14	2.31a	114.78
1/2 at planting and 1/2 at 5-leave stage	223.31	2.26ab	119.73

Treatments	Plant height (cm)	Stem diameter (girth) cm	Ear height (cm)
1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting	221.91	2.19b	118.40
LSD (0.05)	NS	0.91	NS
Nitrogen fertilizer rates (kgha-1)			
0	211.41b	2.24	109.74b
46	227.63a	2.24	121.48a
92	221.67a	2.22	118.63a
138	226.35a	2.30	120.07a
184	225.22a	2.26	118.26a
Mean	222.45	2.25	117.64
LSD (0.05)	9.83	NS	5.62
CV (%)	8.15	9.66	11.37

3.3. Yield of Maize Affected by Rate and Time of Nitrogen Application

3.3.1. Number of Ears Per Plant

The result indicated that the number of ears per plant was significantly (P <0.05) affected by the rate and time of nitrogen application. However, the interaction of time and rate of nitrogen application was not significant for a number of ears per plant (P >0.05) (Table 6). The maximum number of ears per plant (0.86) was produced when N was applied in three splits that is, 1/3 at planting, 1/3 at the 5-leave stage and 1/3 at booting stage suggesting time and amount of nutrient application matter crop growth requirements. Numerically the maximum number of ears per plant (0.89) was produced from the treatment 184 kg N ha^{-1}. However, its effect was not statistically significant from treatment 46 and 138 kg N ha^{-1} while the minimum number of ears per plant (0.70) was obtained from the control treatment (without N application) (Table 6). The increased number of ears per plant with increasing nitrogen up to optimum levels might be attributed to the synchrony of the higher application rate with higher demand of the plant for the nutrient and contribution of the high uptake of nutrients by the plant to maximum ear production and survival. The results were lined with Matusso [42] reported that increasing the nitrogen rate from 50 to 300 kg ha^{-1} significantly increased the number of ears per plant from 1.2 to 2.05.

3.3.2. Above Ground Dry Biomass

The analysis of variance showed that the main effects of nitrogen rate had a significant (p<0.05) effect on above ground dry biomass while the time of nitrogen application and their interaction had non- significant (p >0.05) effect on above ground dry biomass (Table 6). The maximum above dry biomass yield (17925.20 kg ha^{-1}) was recorded from the application of nitrogen rate 138 kg N ha^{-1}. But its effect was not statistically significant from the treatment of 92 and 184 plants 138 kg N while the minimum above dry biomass yield (10591.8 kg ha^{-1}) was obtained from the control treatment (Table 6). When the nitrogen rate increases from 0 to 92 kg N ha^{-1} above dry biomass yield also increases. The nitrogen rate applied 92 kg N ha^{-1} was statistically at parity with the treatment which received 138 and 184 kg N ha^{-1} (Table 6). The increase in above ground biomass yield with the application of N fertilizer over the control may be due to an increase in plant height, number of leaves and leaf area available for assimilate production, translocation and storage. It also might be due to N playing a vital role in the buildup of new cells and consequently better growth. The increase in yield and dry matter with applied N was expected [43]. Abeba [44] reported that the increase in above ground dry biomass (21020 kg ha^{-1}) with the increase in the rate of N (128 kg ha^{-1}) might be due to higher plant height, leaf area index and late maturity that enabled the plants to accumulate more biomass. The highest mean value of above ground biomass (23.91 t ha^{-1}) was obtained at 130.5 kg N ha^{-1} [45]. The result is consistent with the findings of Amanullah et al. [46] in which biological yields of 14.70 t ha^{-1} were attained in maize in response to the N application at the rate of 180 kg^{-1}.

3.3.3. Grain Yield

Grain yield is the main target of crop production. The main effects of nitrogen rate and time of application had significant (P<0.05) influence on the grain yield of maize while their interaction was not significant(P>0.05) (Table 6). The highest mean grain yield (8355.60 kg) was recorded with applied N in three splits (1/3 at planting, 1/3 at the 5-leave stage and 1/3 at booting) and it was statistically at par with the grain yield (7886.90 kg) was obtained from two splits at 1/2 at planting and 1/2 at 5-leave stage (Table 6). The result showed that the amount of nitrogen split and times of applications did not coincide with the plant's physiologically active uptake and utilization. Any fertilizer applied at planting will, therefore, be subjected to leaching losses since absorption by the maize up to 10 - 15 days after sowing maize seed is rare [47]. Gehl et al. [27] reported that maize grain yield increased with the split application of fertilizer compared to one single application at planting. On the other hand, the highest grain yield (9213.5 kg ha^{-1}) was obtained from treatments supplied with 184kg N ha^{-1} (Table 6). However, it was statistically at par with grain yield (8990.9 kg ha^{-1}) and (8382.6 kg ha^{-1}) recorded from treatment received 92 and 138 kg N ha^{-1} respectively while the lowest grain yield (4944.80 kg ha^{-1}) was obtained from treatments grown under control (Table 6). Increased grain yield with increasing nitrogen up to optimum levels might be due to the efficient use of nutrients and this led to the formation of more leaf area which might have intercepted more light and produced more carbohydrates in the source which was probably translocated into the sink (grain) and resulted in more grain yield. Maize grain increases with an increase in the rate of nitrogen, but no further increase when the rate of nitrogen application is beyond optimum which could be excess supply of nitrogen favored more growth of plant parts which increases biomass yield rather than grain yield. Therefore, the 184kg N ha^{-1} and three split (1/3 at planting, 1/3 at the 5-leave stage and 1/3 at booting) showed a favorable advantage overall rate and time of nitrogen tested. But it needs to perform economic analysis. The result is consistent with the findings of Hammed et al. [48] reported that N application had a much greater effect on maize grain yield; this could be because the application of N fertilizer in plants increases the uptake of other nutrients. In conformity with this result, Khan et al. [49] and Amanullah et al. [46] reported that increased N positively contributed to yield where nitrogen rate increase from 90 to 150 kg ha^{-1} showed a significant increase in grain yield. A similar trend in yield differences across N rates has been reported by Zeidan et al. [50]. Lawrence et al. [51] reported that grain yield increased with increasing N rates.

3.3.4. Harvest index (%)

The harvest index indicates the physiological efficiency and ability of a crop to convert the total dry matter into economic yield. The analysis of variance showed that the main effects of nitrogen rate had significant ($p<0.05$) effect on the harvest index while the time of nitrogen application and their interaction had non- significant ($P >0.05$) effect on the harvest index (Table 6). The highest harvest index (51.30 %) was recorded from treatments supplied with 184 kg N ha^{-1}. However, its effect was not statistically significant from treatment of 46,92 and 138 kg N ha^{-1} while the lowest harvest index (46.41%) was obtained from treatments grown under control (Table 6). The higher harvest index at the highest N application rate might be due to more biomass partitioning to grain production. The results line with Lawrence et al. [51] and Zeidan et al. [50] reported that the harvest index in corn increases when N rates increase. However, this result contradicts the result obtained by Abdo [52] reported the highest harvest index (34%) from treatments with the lowest rate of nitrogen application 23kg N ha^{-1}.

Table 6. *Main effects of rate and time of nitrogen application on number of ears /plant, above ground biomass, grain yield and harvest index of maize at Jimma during 2020-2022 cropping season.*

Treatments	**Number of ears /plants**	**Above ground dry biomass (kg ha^{-1})**	**Grain yield (kg ha^{-1})**	**Harvest index (%)**
Time of nitrogen applications				
Full at planting	0.77b	15398.90	7255.3b	47.49
1/2 at planting and 1/2 at 5-leave stage	0.82ab	15818.30	7886.9ab	50.01
1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting	0.86a	16252.90	8355.60a	51.11
LSD (0.05)	0.06	NS	704.35	NS
Nitrogen fertilizer rates (kgha-1)				
0	0.70c	10591.80c	4944.80c	46.41b
46	0.84ab	15326.30b	7631.20b	51.20a
92	0.78b	17380.50a	8382.60ab	48.38ab
138	0.88a	17925.20a	8990.90a	50.40ab
184	0.89a	17893.20a	9213.50a	51.30a
Mean	0.82	15823.39	7832.61	49.54

Treatments	Number of ears /plants	Above ground dry biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
LSD (0.05)	0.08	1666.20	909.32	4.73
CV (%)	17.66	19.44	21.43	17.62

3.4. Correlation Analysis

Correlation analysis was worked out among growth, yield and yield components of maize (Table 7). The number of ears per plant was /highly/ significant and positively correlated with grain yield (0.62), biomass yield (0.58) and harvest index (0.21) Table 7).

Grain yield was positively and /highly/ significantly association with days to maturity (r=35), height (r=0.30), ear height (r=0.24), girth (r=0.55), number of ears per plant (r=0.62), biomass yield (r=0.91), harvest index (r=0.35) while grain yield was negatively and/highly/ significantly association with days to tasseling (r=0.20) and days to silking (r=0.23) (Table 7). Generally, Pearson's moment correlation coefficients between grain yield and nine other agronomic traits considered in the study are shown in Table 7. Therefore, significant and positively correlated parameters move in the same direction this means that as one variable increases, so does the other one while significant and negatively correlated parameters move in the inverse or opposite direction. In other words, as one variable increases the other variable decreases. Similarly, positive and significant correlation between yield and its components was documented by Dinh *et al.* [53]. The results suggested that the change in grain yield due to varied nitrogen levels was related to and accounted for the effect of nitrogen on plant height and yield of maize.

Table 7. *Pearson Correlation Coefficients of different phenology, growth, yield and yield component parameters*

	DT	DS	PM	PH	EH	Girth	NEP	GY	AGB	HI
DT	1	0.96**	0.25**	0.29*	0.15*	-0.22**	-0.10ns	-0.20*	-0.33**	0.23**
DS		1	0.19*	0.23**	0.10ns	-0.27**	-0.16ns	-0.23**	-0.35**	0.20*
PM			1	0.21*	0.10ns	0.44**	0.22**	0.35**	0.29**	0.13ns
PH				1	0.76**	0.10ns	0.40**	0.30**	0.22*	0.29**
EH					1	-0.09ns	0.38**	0.24**	0.19*	0.22*
Girth						1	0.36**	0.55**	0.58**	-0.02ns
NEP							1	0.62**	0.58**	0.21*
GY								1	0.91**	0.35**
AGB									1	-0.03ns
HI										1

*=Significant at P < 0.05; ** = Significant at P < 0.01; ns=non-significant; DT=Days to tasseling; DS=Days to silking; PM=Physiological to maturity; PH=plant height; EH= Ear height; NEP= number of ears per plant; GY=grain yield; ABY=Above ground biomass yield and HI= Harvest index.

3.5. Economic Analysis

The interest of producers in applying fertilizer is not limited to increasing yield alone, but also to make profit out of it. Towards maximizing profit, the amount and time of fertilizer application as well as costs of fertilizer are determining factors. Therefore, partial budget analysis under varied rate and time of nitrogen application were performed by considering the cost of labor and N fertilizer rate as the main input and the mean grain yield obtained as the main output. The gross field benefit (GFB) ha^{-1} (the product of field price of the mean yield for each treatment), the total costs that varied (TCV) which included the sum of field cost of the rate and time of nitrogen application. The net benefit (NB) was calculated as the difference between the GFB and TCV, MRR (%) was calculated by dividing the change in a net benefit by the change in variable costs [31]. Grain yield was adjusted by 10% for management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment [54, 31]. The costs of urea = 14.50 ETB kg^{-1} and sale of grain maize at around Jimma (Melko) open market average price (28.00 ETB kg^{-1}) was used.

The dominance analysis procedure as detailed in [31] was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of un-dominated treatments was the return per unit of investment in rate and time of nitrogen application. The partial budget analysis revealed that highest net benefit of 208311.10 Birr ha^{-1} was obtained from three split (1/3 at planting, 1/3 at 5-leave stage and 1/3 at booting) (Graph 1). Concerning nitrogen rate the maximum net benefit of 226380.2 Birr ha^{-1} was recorded from 184kg N ha^{-1} with acceptable MRR of 286.86%. However, the lowest net benefit of 124609 Birr ha^{-1} was obtained from unfertilized maize plot (control) (Tables 8). The maximum net benefit of was obtained from N applied at 184kgha^{-1} in three split and is recommended for farmers in Jimma and other areas with similar agro-ecological conditions.

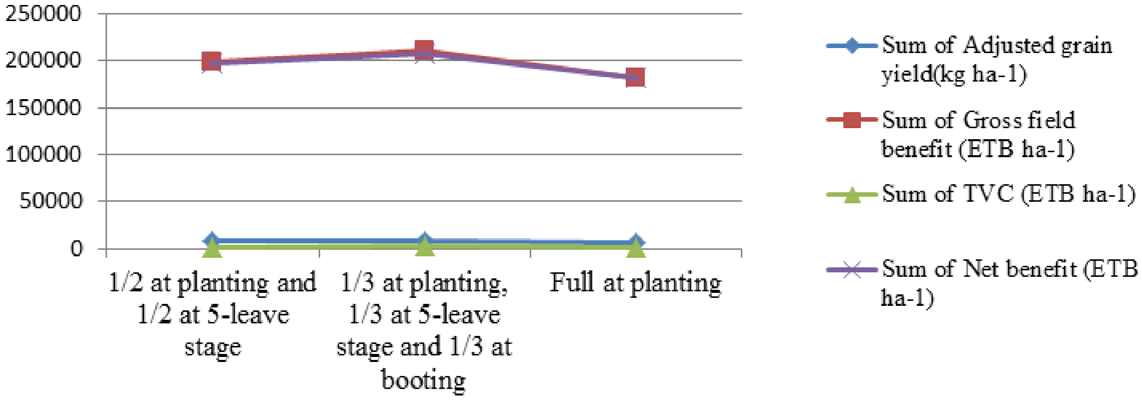

Figure 1. *Graphs of time application of nitrogen on adjusted grain yield, gross field benefit, total cost that varied and net benefit of maize during 2020-2022 cropping season.*

Table 8. *Results of partial budget analysis effect of rate N fertilizer application of maize during 2020-2022 cropping season.*

Nitrogen fertilizer rates (kgha-1)	Grain yield (kg ha^{-1})	Adjusted grain yield (kg ha^{-1})	Gross field benefit (ETB ha^{-1})	TVC (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Value to cost ratio	MRR (%)
0	4944.8	4450.32	124609	0	124609	-	-
46	7631.2	6868.08	192306.2	1450	190856.2	131.62	4568.78
92	8382.6	7544.34	211241.5	2900	208341.5	71.84	1205.88
138	8990.9	8091.81	226570.7	4350	222220.7	51.09	957.18
184	9213.5	8292.15	232180.2	5800	226380.2	39.03	286.86

TVC = total variable cost, MRR= Marginal rate of return, Market price of maize 28 ETB kg, Labour cost for application of nitrogen= 15 persons ha^{-1} at each time of application, each 50 ETB per day, Cost of Urea = 14.50 ETB kg^{-1} and ETB=Ethiopian birr.

4. Summary and Conclusions

Fertilization of maize crops with different rates and times of nitrogen application could substantially increase grain yield. Since nitrogen is the primary factor which is responsible for higher yield and also for improving yield components of maize cob length, no. of grains per cob, number of ears per plant, and time of N application used as a basal dosage at planting time, split doses at critical growth stages like tasseling or silking stage for increasing yield and production of maize. The use of nitrogen in sufficient and balanced amounts is one of the key factors in increasing crop yield and decreasing adverse environmental effects and pollution arising from nonpoint fertilizer usage. Therefore, a field experiment was conducted during the 2020-2022 main cropping seasons to determine the effect of different rates and times of nitrogen fertilizer application on phenology, growth, yield and yield components of maize; and to determine economically appropriate rates of nitrogen and time of application for maize production. The results revealed that increasing the nitrogen rate from unfertilized plot (N0) to 184 N kg ha^{-1} significantly increased the growth attributes viz, plant height, stem diameter, ear height, yield attributes viz, number of ear per plant, grains yield per ha and biomass per ha. It also phenological maize attributes viz, days to 50% tasseling, days to 50% silking and days to 90% physiological maturity was delayed as the nitrogen rate increased from unfertilized plot (N0) to 184 N kg ha^{-1}. The partial budget analysis revealed that the highest net benefit of 208,311.10 Birr ha-1was obtained from three splits (1/3 at planting, 1/3 at the 5-leave stage and 1/3 at booting) and the maximum net benefit of 226,380.20Birr ha^{-1} was recorded from 184 kg N ha^{-1} with acceptable MRR of 286.86%. Based on the results, it can be concluded that application of the highest N fertilizer rate (184 kg N ha^{-1}) in three equal splits (1/3 at planting, 1/3 at the 5-leave stage and 1/3 at booting) can be recommended for profitable maize production in Jimma and other areas with similar agro-ecological conditions.

Author Contributions

Eshetu Yadete: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Sisay Gurmu: Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing

Muhidin Biya: Formal Analysis, Methodology, Software, Supervision, Visualization, Writing – review & editing

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Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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