RESEARCH ARTICLE

Maize yield improvement by optimal rate and timing of nitrogen fertilizer application in Southwest Ethiopia

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Maize (*Zea mays L.*) is a highly valued crop in the national diet of Ethiopia, in general and southwest Ethiopia in particular. However, its productivity is constrained by low plant-available soil nitrogen due to depleting soil organic matter content and high leaching losses of mineralized nitrogen during the growing seasons. This problem is compounded by low rates and ill-timing of nitrogen fertilizer applications in the country. Therefore, a field experiment was carried out during the 2017 main cropping season in Yeki, Menit Goldia and Adiyokaka districts on a farmer's field in southwest Ethiopia with the objectives to evaluate the effects of time and rate of nitrogen application on yield and yield components of maize. The treatments consisted of three levels of nitrogen rates, i.e. 23, 46 and 69 N kg ha^{-1} and five levels of nitrogen application timing, i.e. 1/2 at planting+1/2 at knee height, 1/3 at planting+1/3 at knee height+1/3 at near tasseling, 1/3 at planting+2/3 at knee height, 1/4 at planting+2/4 at knee height+1/4 at tasseling and 1/4 at planting+1/4 at knee height+2/4 at near tasseling time of nitrogen application and unfertilized plot as an absolute control treatment were arranged in factorial combinations. Cob number per plants did not respond to the rates, time of N fertilizer application and their interactions. Days to tasseling, slicking and physiological maturity were delayed as the rate of nitrogen fertilizer was increased. The highest biomass yield, grain yield, straw yield, total nitrogen uptake, apparent nitrogen recovery, and agronomic efficiency were recorded at 46 kg N ha^{-1} applied 1/4 dose at sowing, 2/4 dose at knee height growth stage and 1/4 dose at tasseling stage. Most of the parameters including the grain and straw yields exhibited maximum performance under this N treatment level. Thus, application of N fertilizer at a rate of 46 kg ha^{-1} by splitting the dose into three and applying 1/4 dose at sowing 2/4 dose at knee height growth stage and 1/4 dose at tasseling stage of the maize crop can be recommended for the study areas and similar agro ecologies.

Key Words: *Maize; Rate and timing of nitrogen fertilizer; Yield*

INTRODUCTION

In Ethiopia, maize ranks first in productivity per hectare and also in total grain production and second in total hectarage after teff [1]. It grows from moisture stress areas to high rainfall areas and from lowlands to the highlands [2]. It is cultivated on about 1.4 million hectares accounting for 20.6% of nearly 6.8 million hectares of all land allocated to all cereals [1]. Southern, southwestern, western and highlands of Hararghe in the east are major maize producing areas of the country and it is one of the most important cereal crops in the country, in general and in the southern Ethiopia in particular. In the southern region, cereals account for 75% of the area allocated for food crops. Out of this, maize accounts for 33% of the area allocated for cereals.

Nutrient supply from chemical fertilizers is needed to replace nutrients which are removed and lost during cropping, to maintain positive nutrient balance [3]. Nitrogen, together with phosphorous, is one of the most limiting macronutrients to maize grain yield worldwide [4]. Nitrogen availability influences the uptake, not only of itself, but also of other nutrients [5] as N-fertilized plants usually have larger root systems, which enhances the capture of other nutrients [6]. Since nitrogen is highly mobile, its use and demand is continuously increasing as it is subjected to high loss from the soil plant system [7]. The loss of N not only costs the farmer but it also has hazardous impact on the environment. In high and medium altitude maize growing areas where rainfall is high, most of the nitrogen is lost through leaching and denitrification making the nutrient unavailable during the critical stages of crop growth.

Ideal nitrogen management optimizes yield, farm profit and nitrogen use efficiency while it minimizes the potential for leaching of nitrogen beyond the crop rooting zone [8]. Raun [9] reported that nitrogen use efficiency is variable with mean of only 33% of applied nitrogen recovered by cereal crops. Nitrogen use efficiency may be affected by crop species, soil type, and application rate of N fertilizer [10]. Lopez-Bellido [11] showed that nitrogen efficiency indices were significantly affected by N fertilizer rates. Reduction of applied N fertilizer rate to an optimized level can reduce soil nitrate leaching [12]. According to Sowers [13], the application of high N rates may result in poor N uptake and low nitrogen use efficiency due to excessive N losses. The most logical approach to increasing N fertilizer use efficiency is to supply nitrogen when it is needed by the crop. Ferguson [14] also reported Plant N use efficiency can be improved by matching application rate and timing with plant demands. Maize begins to rapidly take up N during the middle of vegetative growth period with the maximum rate of N uptake occurring near silk formation [15].

Only few farmers in the study area (Bench Maji, Kaffa and Sheka zone) apply nitrogenous fertilizer while the average yield remain very low 23.7, 23.5 and 30.4 quintal respectively and the total nitrogen in soil is high in all area. Investigating response of N fertilizer, rate of N fertilizer and application at a time when it is most efficiently and effectively utilized is imperative. Therefore this research was aimed with the objectives to identify the optimum rates and appropriate time of nitrogen application for maximum yield of maize in the study areas.

MATERIALS AND METHODS

Description of the study area and site

The research project had covered the three SNNPR States administrative Zones namely, Bench Maji, Kaffa, and Sheka Zones of the southwest of Ethiopia. They have different agro-ecological zones with highly varied soil types and fertility status, climate, rainfall, altitude, topography, crop growing periods. The rainfall is high and it is distributed in a bimodal rainfall pattern, the wet season being between April/May and October/November. Temperature ranges from 12°C (in cold season) to 40°C (in dry season) the average being around 25°C (Tezera, 2008; SNNPR Livelihood Profile, 2005; NTFP, 2004).

A corollary is that agricultural crop production and practices are depending upon the Agro-ecological type and biophysical characteristics of each Zone in addition to socioeconomic condition of societies live in these areas. In generally, the predominant agricultural practice is mixed farming, crop production, livestock and other economically important activities such

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as, beekeeping for honey production (traditionally in the forest), spices collection and coffee harvesting.

Experimental designs, treatments and procedures

Maize variety (Shone and BH-660) was used for the study as a test crop. The field experiment was laid out in Randomized Complete Block Design (RCBD) in factorial arrangement and each treatment was replicated three times. Application of N was done based on growth stages of maize plants. The five nitrogen application timing T1 (1/2 at planting+1/2 at knee height, T2 (1/3 at planting+1/3 at knee height+1/3 at near tasseling), T3 (1/3 at planting+2/3 at knee height), T4 (1/4 at planting+2/4 at knee height+1/4 at tasseling,) and T5 (1/4 at planting+1/4 at knee height+2/4 at near tasseling) were combined in factorial arrangement with three rates of nitrogen fertilizer N1 (23 kg ha^{-1}), N2 (46 kg ha^{-1}) N3 (69 kg ha^{-1}) and + N0 (0 kg ha^{-1} as absolute control).

The experimental field was prepared following the conventional farmers' practices. The full dose of phosphorus fertilizer was applied at sowing as blanket recommendation (100 kg/ha). Lime was applied uniformly to all plots which was determined by the following lime requirement formula:

LR (Kg/ha)=LRF [Ex.acidity-(ECEC×PAS)

Where:

LR=Lime Requirement

LRF=Lime requirement factor (3000 kg lime/ha/cmole) for Ethiopian soils (Farina, 1991).

Ex. acidity=Exchangeable Acidity

PAS=Permissible Acid Saturation

ECEC=Ex. acidity+Ex. bases

Soil physical and chemical analysis

Particle size distribution was analyzed using hydrometer method. The pre-planting soil samples were analyzed for available nitrogen (nitrate and ammonium contents) according to the method described by Bremner [16], available phosphorus [17], organic carbon, soil pH [18]. CEC and exchangeable bases (Ca, Mg, K and Na) were analyzed as described by Mhelich [17]. Exchangeable acidity was determined according to Rowell [19], percent base saturation and exchangeable acidity were calculated by Lindsay [20].

Nitrogen concentration, uptake and utilization in the plant tissues of maize

The nitrogen contents of the grain (GN%) and straw (SN%) were determined by the micro-Kjeldahl method using grain and straw sub-samples [21]. Straw and grain N uptake values, SNU and GNU, respectively, were calculated by multiplying the grain and straw yields by the respective Kjeldahl N contents. Total N uptakes (TNU) of each sample were calculated as the sum of the respective GNU and SNU values. Nitrogen harvest indexes (NHI), the ratio of GNU to TNU were expressed as a percentage. Apparent N recovery (AR) is the above-ground biomass for each treatment was calculated as TNU of each fertilized treatment minus TNU of control divided by the fertilizer N applied. Agronomic efficiency (AE) of fertilizer N was calculated as grain yield of each fertilized treatment minus grain yield of control divided by the fertilizer N applied. Physiological efficiency (PE) was calculated as the ratio of AE and AR [22-24].

Data collected

Major phenological events such as days to 50% tasseling, days to 50% silking, and days to 90% maturity were recorded. Growth parameters like plant height at and number of cobs per plant were recorded from 10 randomly selected plants per plot, whereas ear lengths were measured from 10 randomly selected ears per plot after harvest. Harvest index (HI), biomass at harvest, 100 grain weight and grain yield were obtained from the central rows. Grain yield was adjusted at 12.5% moisture content.

The total N (kg/ha) uptake by the crop during the season was obtained by multiplying the straw and grain yield (kg/ha) by the N concentrations within each. The nitrogen use efficiency (NUE) was expressed as the increase in grain yield obtained for a given amount of applied N (Napp), expressed as kg grain kg^{-1} [25] as shown below:

NUE=Yn-Yc/Na

Where Yn (kg/ha) is the grain yield for treatments with applied N and Yc is grain yield

(kg/ha) for the control treatment.

Economic analysis

For economic analysis of the main effect, simple partial budget analysis approach was employed to estimate the economic feasibility of the main effects [26].

Statistical analysis

Data will be subjected to analysis of variance (ANOVA) using statistical analysis software. The mean separation was done using the LSD test at (5%) of probability level.

RESULTS AND DISCUSSION

Phenological attributes

<u>Days to 50% tasseling:</u> Days to 50% tasseling were significantly ($P<0.05$) affected by the interaction effect of time and rates of N application in all districts (Table 4). Accordingly, the minimum days (77.67, 95.0 and 98.20) to 50% tasseling were recorded from the control treatments of Yeki, Menit Goldia and Adiyyo Kaka districts, respectively. Whereas, the maximum days (84, 100.7 and 103.9) to 50% tasseling were recorded for the application of 69 kg N ha^{-1} in split as 1/2 at planting+1/2 at knee height, 1/3 at planting+2/3 knee height and 1/3 at planting+1/3 knee height+1/3 tasseling for Yeki, Menit Goldia and Adiyyo Kaka, respectively.

Increased nitrogen rates showed significant effects on number of days to 50% tasseling. Nitrogen application at the rate of 69 ha^{-1} delayed days to 50% tasseling by (6.3, 5.7 and 5.5 days) for Yeki, Menit Goldia and Adiyyo Kaka, respectively as compared to the control treatments. The crop had the maximum number of days to 50% tasseling might be due to application of N fertilizer at critical stages of the crop and the effects of nitrogen containing fertilizers in extends vegetative growth stages leading to delay the period of anthesis and tasseling in maize plants. However, it was statistically no significant with the application of 46 kg N ha^{-1}. The same result was reported by Valero et al. (2005) who concluded that maize crop accumulated 47 days for 50% tasseling when N was applied at the rate of 130 kg ha-1 under semiarid environment.

<u>Days to 50% silking:</u> Days to 50% silking was affected both by the time of N application and rates of N application in all districts (Tables 1-4). The maximum days (85.6, 1105.3 and 108.9) to 50% tasseling were recorded from the application of 69 kg N ha^{-1} in split as 1/4 at planting+2/4 at knee height and 1/4 tasseling, 1/4 at planting+2/4 at knee height and 1/4 tasseling and 1/3 at planting+1/3 knee height+1/3 tasseling, respectively for Yeki, Menit Goldia and Adiyyo Kaka districts.

When nitrogen containing fertilizer was applied in three split by means of quarter at planting, half at knee height and quarter at near tasseling stage with the rate of 69 kg N ha^{-1} then the crop took more days to 50% silking. Thus, days to 50% silking was delayed by (3.61, 5.4 and 6.4) days for Yeki, Menit Goldia and Adiyyo Kaka districts, respectively, when nitrogen application was increased 0 kg N ha^{-1} to 69 kg N ha^{-1}. However, statistically no significant difference was observed between the rates of 46 kg N ha^{-1} and 69 kg N ha^{-1} for most time of nitrogen application in all districts. The minimum (81.97, 99.9 and 102.5) days to 50% silking were observed in the absolute control treatments respectively, in Yeki, Menit Goldia and Adiyyo Kaka districts.

TABLE 1

Selected soil physicochemical properties of the study areas at a depth of 0-30 cm

S/N	Parameters	Woreda		
		Yeki	Menit Goldia	Adiyyo kaka
1	Texture	Clay	Clay	Clay
2	pH (H_2O)	6.50	5.89	5.31
3	Organic matter (%)	5.69	6.77	9.24
4	Total nitrogen	0.39	0.38	0.5
5	Available phosphorus (ppm)	12.51	9.5	21.02
6	CEC (meq/100 g)	55.49	39.21	52.15
7	Exchangeable Ca (meq/100 g)	17.08	11.71	11.63
8	Exchangeable K (meq/100 g)	0.96	0.81	1.75
9	Exchangeable Mg (meq/100 g)	4.62	2.5	2.88
10	Exchangeable Na (meq/100 g)	0.05	0.04	0.14
11	Exchangeable acidity (mg kg^{-1})	0.26	0.25	0.11

TABLE 2

Effect of rate and time of nitrogen fertilizer application on phenological parameters of maize

		Days to 50% Tasseling			Days to 50% Silking			Days to 90% physiological maturity		
TNA	RNA	Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka
0	0	77.67^{a}	95.00 ^{a}	98.2^{a}	81.97^{a}	99.9^{a}	102.5^{a}	117.0^{a}	151.7^{a}	156.2^{a}
1	1	80.67^{abc}	96.00^{ab}	99.4^{abc}	84.32^{ab}	100.6^{a}	104.7^{ab}	123.0^{abcde}	153.3^{abcd}	159.2^{abcd}
1	2	82.00^{bc}	97.33^{abcd}	101.3^{abcde}	85.22^{ab}	101.9^{a}	105.9^{ab}	122.0^{abcde}	156.7^{def}	161.4^{abcd}
1	3	84.00^{c}	100.00^{de}	102.3^{cde}	85.41^{b}	104.3^{b}	107.0^{bc}	126.7^{e}	160.0^{fg}	166.5^{d}
2	1	79.00^{ab}	96.67^{abc}	100.2^{abcd}	83.29^{ab}	100.6^{a}	104.6^{abc}	118.3^{ab}	152.0 ^{a}	160.3^{abcd}
2	2	78.67^{ab}	97.33^{abcd}	103.7^{e}	83.15^{ab}	101.5^{ab}	108.0^{bc}	125.7^{cde}	155.7^{bcde}	164.8^{bcd}
2	3	80.67^{abc}	100.33^{e}	103.9^{e}	85.14^{ab}	104.8^{b}	108.9^{c}	127.3 ^{e}	161.3 ^{g}	166.4^{d}
3	1	79.33^{ab}	96.00^{ab}	98.9^{ab}	83.22^{ab}	101.2^{a}	103.2^{ab}	120.1^{abc}	153.7^{cd}	156.2^{a}
3	2	80.33^{abc}	98.00^{bcde}	99.6^{abc}	84.62^{ab}	102.4^{a}	107.3^{bc}	122.0^{abcde}	156.7 ^{def}	158.3^{abc}
3	3	82.33^{bc}	100.67^{e}	102.0^{bcde}	85.38^{b}	105.1^{b}	103.9^{ab}	125.6^{cde}	160.0^{fg}	161.0^{abcd}
4	1	78.67^{ab}	95.67^{ab}	99.2^{abc}	82.62^{ab}	100.5^{a}	103.6^{ab}	119.6^{abcd}	152.3 ^{ab}	157.6^{ab}
4	2	78.67^{ab}	99.00^{cde}	99.6^{abc}	83.88^{ab}	103.6^{ab}	104.2^{abc}	125.0^{bcde}	161.0^{g}	165.7^{cd}
4	3	81.33^{abc}	100.67^{e}	103.4^{de}	85.58^{b}	105.3^{b}	107.7^{bc}	127.6^{e}	158.0^{efg}	166.7^{d}
5	1	80.67^{abc}	96.67^{abc}	99.6^{abc}	84.82^{ab}	98.9^{a}	104.9^{abc}	118.1^{abcd}	152.3 ^{ab}	157.6^{ab}
5	2	81.33^{abc}	96.67^{abc}	99.9^{abc}	84.75^{ab}	100.7^{ab}	104.6^{abc}	119.3^{bcd}	153.0^{abc}	157.9^{abc}
5	3	80.33^{abc}	100.33 ^{e}	103.3^{de}	84.05^{ab}	104.0^{b}	107.7^{bc}	119.7^{abcd}	156.0^{cde}	165.8^{cd}
CV%		3.2	7.1	5.2	10.7	8.1	8.1	9.4	3.4	4.1
LSD 5%		4.277	1.375	3.306	3.78	3.35	4.53	3.834	6.882	3.53
Significance		*	*	*	*	*	*	*	*	*

Where, TNA=Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2=1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height , 4= 1/4 at planting + 2/4 at knee height + 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling Whereas, RNA= Rate of Nitrogen Application; 1=23 kg ha^{-1}, 2=46 kg ha^{-1}, 3=69 kg ha^{-1} and 0=0 kg ha^{-1} as absolute control.

TABLE 3

Effect of rate and time of nitrogen fertilizer application on growth parameters of maize

TNA	RNA	Plant height in (cm)			Ear length(cm)			Cob numbers per plant		
		Yeki	M. Goldia	A. Kaka	Yeki	M. Goldia	A. Kaka	Yeki	M.Goldia	A. Kaka
0	0	216.4^{a}	227.7^{a}	195.6^{a}	15.22a	22.00^{a}	19.49^{a}	1.13^{a}	1.100^{a}	1.444 ^{a}
1	1	257.9^{bcd}	288.9^{b}	220.0^{abc}	16.33^{ab}	24.67^{bc}	21.22^{bc}	1.03^{a}	1.100^{a}	1.444^{a}
1	2	253.7^{bcd}	269.4^{b}	224.4^{abc}	16.89^{ab}	24.11^{abc}	23.11^{def}	1.67^{a}	1.200^{a}	1.444 ^{a}
1	3	254.2^{bcd}	279.4^{b}	244.0^{bcd}	17.78^{ab}	25.29^{bc}	23.33 ^{ef}	1.67^{a}	1.200^{a}	1.444 ^{a}
2	1	254.9^{bcd}	269.4^{b}	209.4^{ab}	16.56^{ab}	23.22^{ab}	21.56^{bcd}	1.10^{a}	1.100^{a}	1.333 ^{a}
2	2	238.0^{abc}	287.2^{b}	250.0^{bcde}	18.00^{ab}	24.4^{4bc}	23.40^{ef}	1.23^{a}	1.100^{a}	1.667^{a}

2	3	227.^{8ab}	262.9^{b}	253.9^{bcde}	18.56^{ab}	24.87^{bc}	23.48^{ef}	1.10^{a}	1.100^{a}	1.444 ^{a}
3	1	244.8^{abcd}	256.7^{b}	225.6^{abc}	16.56^{ab}	21.97 ^{a}	20.55 ^{ab}	1.13^{a}	1.100^{a}	1.444 ^{a}
3	2	237.4^{abc}	266.1^{b}	245.0^{bcd}	17.67^{ab}	26.22^{c}	22.19^{cdef}	1.20^{a}	1.100^{a}	1.333^{a}
3	3	274.8^{d}	289.1^{b}	293.0^{e}	18.11^{ab}	26.13^{c}	22.83^{def}	1.23^{a}	1.100^{a}	1.333 ^{a}
4	1	264.2bcd ^{cd}	257.0^{b}	222.8^{abc}	17.89^{ab}	23.11^{ab}	20.9^{abc}	1.20^{a}	1.200^{a}	1.667^{a}
4	2	239.6ab^{c}	278.4^{b}	281.1 d^{e}	18.11^{ab}	28.74^{d}	26.89^{g}	1.20^{a}	1.100^{a}	1.333^{a}
4	3	244.8a^{bcd}	258.7^{b}	260.0^{cde}	20.33^{b}	26.44^{cd}	26.02^{g}	1.67^{a}	1.100^{a}	1.333 ^{a}
5	1	240.0^{abc}	287.2^{b}	224.4^{abc}	17.22^{ab}	23.33^{ab}	21.95^{bcde}	1.20^{a}	1.100^{a}	1.556 ^{a}
5	2	242.2^{abcd}	268.9^{b}	231.1^{abc}	17.67^{ab}	24.56^{bc}	23.60 ^{f}	1.13^{a}	1.100^{a}	1.556 ^{a}
5	3	244.1^{abcd}	274.6^{b}	233.9^{abc}	18.44^{ab}	25.15^{bc}	23.43 ^{ef}	1.10^{a}	1.100^{a}	1.444 ^{a}
CV%	8.4	7.4	5.8	14	5.7	4.2	10.7	15.9	14.7	4.1
LSD 5%	34.49	33.45	23.18	4.09	2.34	1.59	0.21	0.3	0.35	3.53
Significance	*	*	*	*	*	*	NS	NS	NS	*

Where, TNA= Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2= 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height, 4= 1/4 at planting + 2/4 at knee height + 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling Whereas, RNA= Rate of Nitrogen Application; 1= 23 kg ha^{-1}, 2= 46 kg ha^{-1}, 3= 69 kg ha^{-1} and 0= 0 kg ha^{-1} as absolute control

TABLE 4

Effect of rate and time of nitrogen fertilizer application on yield and yield component parameters of maize

TNA	RNA	Above Ground Biomass in t/ha			Grain Yield t/ha			Harvesting index %		
		Yeki	M. Goldia	A. Kaka	Yeki	M. Goldia	A. Kaka	Yeki	M. Goldia	A. Kaka
0	0	4.83^{a}	6.94^{a}	4.37^{a}	1.50a	2.30^{a}	1.43^{a}	31.33^{a}	33.09^{a}	33.00^{a}
1	1	7.53^{ab}	10.54^{abc}	6.81^{bc}	2.95^{bc}	4.25^{abc}	2.630^{b}	39.33^{bcd}	39.96^{abc}	39.00^{abc}
1	2	10.10^{de}	15.46^{de}	10.26^{d}	4.30^{de}	6.66^{def}	4.12^{c}	39.33^{bcd}	43.15^{bcd}	40.00^{bc}
1	3	11.90^{ef}	16.00^{de}	10.98^{de}	5.10^{efg}	7.03^{efg}	4.75^{cd}	42.67^{cd}	44.08^{bcd}	43.33^{bcd}
2	1	11.13^{de}	12.07^{bcd}	11.00^{de}	4.54^{ef}	4.70^{bcd}	4.42^{c}	40.67^{bcd}	38.94^{abc}	40.00b^{c}
2	2	14.30^{gh}	14.64^{cde}	12.92^{fg}	7.27^{h}	6.68^{def}	6.10^{ef}	50.67^{e}	45.75^{cd}	47.00 ^{def}
2	3	13.94^{fgh}	14.90^{cde}	13.15^{fg}	7.31^{hi}	7.28^{fg}	6.35^{f}	52.67^{e}	49.02^{d}	48.33^{def}
3	1	9.33^{cd}	12.47^{bcde}	7.23^{c}	3.52^{cd}	4.81^{bcd}	2.79^{b}	38.00^{bc}	38.05^{abc}	38.67^{ab}
3	2	12.16^{efg}	14.82^{cde}	11.93^{ef}	5.45f^{g}	5.82^{cdef}	5.36^{de}	44.67^{d}	38.99^{abc}	45.33^{cde}
3	3	14.05^{fgh}	16.60^{e}	12.92^{fg}	5.74^{g}	6.57^{def}	5.40^{de}	42.00^{cd}	39.50^{abc}	42.00^{bcd}
4	1	11.33^{de}	10.59^{abc}	10.93^{de}	4.87^{efg}	4.61b^{cd}	4.70^{cd}	43.00^{cd}	43.47^{bcd}	43.00^{bcd}
4	2	15.93^{h}	15.59^{de}	14.12^{g}	8.80^{ji}	8.04^{gh}	7.38^{g}	55.24^{e}	51.62	52.27f
4	3	16.04^{h}	16.82^{e}	14.20^{g}	8.30^{ij}	8.62^{h}	7.22^{g}	51.74^{e}	51.23^{d}	50.84 ^{ef}
5	1	5.17^{ab}	9.94^{ab}	5.08 ^{a}	1.92^{a}	3.62^{ab}	2.04^{ab}	35.33^{ab}	36.49^{ab}	40.33^{bc}
5	2	6.02^{ab}	11.71^{bcd}	5.31^{ab}	2.18^{ab}	4.31^{abc}	2.12^{ab}	36.00^{ab}	36.88^{ab}	39.33^{abc}
5	3	6.27^{ab}	13.14^{bcde}	5.68^{abc}	2.18^{ab}	4.92^{bcde}	2.30^{b}	35.67^{ab}	37.49^{abc}	39.33^{abc}
CV%		12.3	11.1	9.6	12.17	12.7	11.7	7.8	6.7	9.1
LSD 5%		2.187	2.45	1.56	1.01	1.19	0.84	5.533	4.7	6.48
Significance		*	**	*	**	**	*	*	*	*

Where, TNA= Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2= 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height , 4= 1/4 at planting + 2/4 at knee height 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling Whereas, RNA= Rate of Nitrogen Application; 1= 23 kg ha^{-1}, 2= 46 kg ha^{-1}, 3= 69 kg ha^{-1} and 0= 0 kg ha^{-1} as absolute control.

In the control treatment during silking stage, the crop might be faced nitrogen fertilizer stress. This might be the reason for early days to silking in crop. Generally, the number of days to 50% silking increased by increasing nitrogen dose up to 69 kg ha^{-1}. In these, three study areas it was observed that luxury use of nitrogen increased days to silking in maize plants. Amanullah [27] reported that maize crop took 57 days for 50% silking when nitrogen fertilizer was applied at the rate of 180 kg ha^{-1} in three splits.

Days to 90% physiological maturity: Days to 90% physiological maturity, the data along with the comparison of means are presented in Table 4, indicated that the time and rate of nitrogen application had a significant effect on days to physiological maturity. Accordingly, minimum (117 at Yeki, 151.7 at Menit Goldia and 156.2 at Adiyyo Kaka) days to 90% of physiological maturity were recorded for the control plots. The crop matured earlier at the control treatment and when nitrogen fertilizers were applied at lower rate. Whereas, the maximum days (85.58, 1105.3 and 108.9) to 90% physiological maturity were recorded from the application of (N3) 69 kg N ha^{-1} in split as1/4 at planting+2/4 at knee height and ¼ tasseling, respectively for Yeki, Menit Goldia and Adiyyo Kaka districts.

The process of physiological maturity was delayed by the time and rate of nitrogen application and their combinations as compared to the control. Days to maturity were delayed significantly with the high levels of 46 and 69 kg N ha^{-1}. The comparison of means of nitrogen application time effect on days to maturity showed that nitrogen splits as T4 delayed maturity as compared to the T3 and T5. Overall, the mean days to maturity were indicated that maize crop took more days to physiological maturity when nitrogen was applied at 69 kg ha^{-1}. The changes in the nitrogen application timing and increase in nitrogen fertilizer rate might have enhanced the rate of photosynthesis which resulted in the leaf longevity and delayed tasseling, silking and maturity stage of the crop in maize [28]. These results are similar to those reported by Hammad [29]. Application of nitrogen at later stages of crop delayed crop days to maturity. Similarly, days to maturity of the crop was increased linearly by increasing nitrogen dose up to 300 kg ha^{-1}. Akbar [30] found that maize crop took more days to maturity when the crop was subjected to 200 kg N ha^{-1}.

These results are in line with nitrogen application time and rate effects on days to tasseling and silking. The prolonged stages of days to maturity due to rates and time of nitrogen application were reported who showed that higher nutrient availability and favorable soil conditions due to nitrogen fertilizer could be a possible reason for delayed phenology in nitrogen treated plots. Namvar [31] reported that increasing in nitrogen rates significantly delays the duration of the vegetative and reproductive period what is a proof of the lengthening of the time to maturity.

Growth attributes: Analysis of variance revealed significant ($p<0.05$) differences among the interaction of time and rates of nitrogen application with respect to plant height, and gear length of maize plant in all the study areas (Table 3).

Plant height: Plant height in an important yield attributed characters in maize as more green area will be more photosynthetic activity and more may be shared to grain yield. Data regarding plant height varied significantly to nitrogen levels, application timing and their interactions. Mean data indicated that taller plants (274.8, 289.1 and 293.0 cm) were observed in plots received 69 kg N ha^{-1} applied in split as 25% at plant and 75% at knee height growth stage. However, statistically no significant differences were revealed on plant height among nitrogen rates of 23 kg N ha^{-1}, 46 kg N ha^{-1} and 69 kg N ha^{-1} for most time of applications in all the study locations. Whereas, dwarf plants (216.4, 227.7 and 195.6 cm) was observed on the control treatments for all Yeki, Menit Goldia and Adiyyokaka districts. Data auxiliary revealed that control plots attained minimum plant height as compared to treated.

Higher plant height was recorded when nitrogen was applied at the rate of 69 kg ha^{-1}. It was might be due to increase in accumulation of dry matter as a result of more vigorous vegetative growth with the application of N fertilizer. These results are in line with Ali [32] that N enhances the vegetative growth in maize. Increase in the rate of N leads to increase in plant height, and was also recorded by Imran [33] and Wajid [34] who investigated that higher nitrogen level influence plant height. Nitrogen application timing also showed a significant effect on plant height of maize. These results are in line with Amanullah [35] stated that N in four to five splits can increase plant height of maize. Similarly Hammad [36] revealed that nitrogen in three splits can give maximum plant height in maize. Analysis of variance revealed no significant ($p<0.05$) differences among the main effects of nitrogen rates, application timings and their interaction on cob number per plant on maize plant in all Yeki, Menit Goldia and Adiyyokaka districts.

Ear length: Ear lengths were significantly ($P<0.05$) affected by the main effects as well as the interaction effect of time and rates of N application in all districts (Table 5). Application of more nitrogen in three split had the longest ear lengths and the shortest ear length was recorded for plots without nitrogen application. Moreover, the longest ear length (20.3, 28.7 and 26.9 cm) was produced at nitrogen application time as T4 with nitrogen rates 46 kg ha^{-1} for Yeki and 69 kg ha^{-1} at Menit Goldia and Adiyyokaka districts, respectively. The shortest ear length (15.22, 22.00 and 19.49 cm) was recorded from the control treatment.

The result of this research is in agreement with the previous founding reported that the interaction of application time×N rates was significant. The maximum cob length (22.3 cm) was obtained at application of 225 kg N ha^{-1} as T1, and the minimum (16.1 cm) was recorded from control treatment. Cob length generally declined with decreasing of N rates. A significant increase in maize cob length with N application over control.

Yield and yield components: Analysis of variance showed significant ($p<0.05$) difference among the interaction of time and rates of nitrogen fertilizer application with respect to above ground biomass in tonha^{-1}, grain yield and harvesting index of maize in all the study areas (Table 6).

TABLE 5

Effect of Rate and time of nitrogen fertilizer application on 100-grain weight, grain and straw nitrogen contents of maize

TNA	RNA	Above Ground Biomass in t/ha			Grain Yield t/ha			Harvesting index %		
		Yeki	M. Goldia	A. Kaka	Yeki	M. Goldia	A. Kaka	Yeki	M. Goldia	A. Kaka
0	0	4.83^{a}	6.94^{a}	4.37^{a}	1.50^{a}	2.30^{a}	1.43^{a}	31.33^{a}	33.09^{a}	33.00^{a}
1	1	7.53^{ab}	10.54^{abc}	6.81^{bc}	2.95^{bc}	4.25^{abc}	2.630^{b}	39.33^{bcd}	39.96^{abc}	39.00^{abc}
1	2	10.10^{de}	15.46^{de}	10.26^{d}	4.30^{de}	6.66^{def}	4.12^{c}	39.33^{bcd}	43.15^{bcd}	40.00^{bc}
1	3	11.90^{ef}	16.00^{de}	10.98^{de}	5.10^{efg}	7.03e^{fg}	4.75^{cd}	42.67^{cd}	44.08^{bcd}	43.33^{bcd}
2	1	11.13^{de}	12.07^{bcd}	11.00^{de}	4.54^{ef}	4.70b^{cd}	4.42^{c}	40.67^{bcd}	38.94^{abc}	40.00^{bc}
2	2	14.30^{gh}	14.64^{cde}	12.92^{fg}	7.27^{h}	6.68d^{ef}	6.10^{ef}	50.67^{e}	45.75^{cd}	47.00 ^{def}
2	3	13.94^{fgh}	14.90^{cde}	13.15^{fg}	7.31^{hi}	7.28^{fg}	6.35^{f}	52.67^{e}	49.02^{d}	48.33^{def}
3	1	9.33^{cd}	12.47^{bcde}	7.23^{c}	3.52^{cd}	4.81^{bcd}	2.79^{b}	38.00^{bc}	38.05^{abc}	38.67^{ab}
3	2	12.16^{efg}	14.82^{cde}	11.93^{ef}	5.45^{fg}	5.82^{cdef}	5.36^{de}	44.67^{d}	38.99^{abc}	45.33^{cde}
3	3	14.05^{fgh}	16.60^{e}	12.92^{fg}	5.74^{g}	6.57^{def}	5.40^{de}	42.00^{cd}	39.50^{abc}	42.00^{bcd}
4	1	11.33^{de}	10.59^{abc}	10.93^{de}	4.87^{efg}	4.61^{bcd}	4.70^{cd}	43.00^{cd}	43.47^{bcd}	43.00^{bcd}
4	2	15.93^{h}	15.59^{de}	14.12^{g}	8.80^{ji}	8.04g^{h}	7.38^{g}	55.24^{e}	51.62	52.27^{f}
4	3	16.04^{h}	16.82^{e}	14.20^{g}	8.30^{ij}	8.62^{h}	7.22^{g}	51.74^{e}	51.23^{d}	50.84 ^{ef}
5	1	5.17^{ab}	9.94^{ab}	5.08 ^{a}	1.92^{a}	3.62^{ab}	2.04^{ab}	35.33^{ab}	36.49^{ab}	40.33^{bc}
5	2	6.02^{ab}	11.71^{bcd}	5.31^{ab}	2.18^{ab}	4.31^{abc}	2.12^{ab}	36.00^{ab}	36.88^{ab}	39.33^{abc}
5	3	6.27^{ab}	13.14^{bcde}	5.68a^{bc}	2.18^{ab}	4.92^{bcde}	2.30^{b}	35.67^{ab}	37.49^{abc}	39.33^{abc}
CV%		12.3	11.1	9.6	12.17	12.7	11.7	7.8	6.7	9.1
LSD 5%		2.187	2.45	1.56	1.01	1.19	0.84	5.533	4.7	6.48
Significance		*	**	*	**	**	*	*	*	*

Where, TNA= Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2= 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height , 4= 1/4 at planting + 2/4 at knee height 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling Whereas, RNA= Rate of Nitrogen Application; 1= 23 kg ha^{-1}, 2= 46 kg ha^{-1}, 3= 69 kg ha^{-1} and 0= 0 kg ha^{-1} as absolute control.

TABLE 6

Straw, grain and total nitrogen uptake of maize as influenced by rates and time of nitrogen application

		Straw Nitrogen Uptake kg/ha			Grain Nitrogen Uptake kg/ha			Total Nitrogen Uptake kg/ha		
TNA	**RNA**	**Yeki**	**M. Goldiya**	**A. Kaka**	**Yeki**	**M. Goldiya**	**A. Kaka**	**Yeki**	**M. Goldiya**	**A. Kaka**
TNA	RNA	Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka
0	0	32.88^{a}	43.21^{a}	26.70^{a}	15.34^{a}	21.23^{a}	13.98^{a}	48.2^{a}	64.4^{a}	40.7^{a}
1	1	50.55^{ab}	66.46^{b}	41.63^{bc}	34.54^{abc}	49.00^{bc}	28.78^{c}	85.1a^{bcd}	115.5^{b}	70.4^{bc}
1	2	62.80^{bc}	105.78^{efh}	77.19^{efg}	53.75^{cde}	87.80^{fg}	54.82^{e}	116.6^{cdf}	193.6^{df}	132.0^{e}
1	3	79.34^{cdefg}	104.38^{efh}	71.03^{def}	68.83^{ef}	88.89^{fg}	58.45^{e}	148.2^{efg}	193.3^{def}	129.5^{de}
2	1	68.20^{bcde}	70.95^{bc}	66.38^{de}	53.33^{cde}	48.46^{bc}	46.47^{d}	121.5^{def}	119.4^{bc}	112.9^{d}
2	2	84.64^{efg}	97.99^{defg}	84.80^{gh}	99.50^{gh}	92.26f^{g}	82.77^{fg}	84.1^{gh}	190.3^{def}	167.6^{fg}
2	3	81.74^{cdefg}	95.70^{defg}	80.48^{fgh}	102.39^{ghi}	98.91^{gh}	86.74^{gh}	184.1^{gh}	191.3^{def}	167.2fg
3	1	63.00^{bcd}	85.42^{cd}	47.16^{c}	42.71^{bcd}	61.24^{cd}	34.60^{c}	105.7^{bcde}	146.7^{c}	81.8^{c}
3	2	83.44^{defg}	109.55^{fgh}	79.26^{efg}	4.53^{ef}	79.94^{ef}	73.06^{f}	158.0^{fg}	189.5^{de}	152.3^{f}
3	3	98.82^{g}	110.29^{gh}	85.26^{gh}	78.96^{fg}	88.99^{fg}	72.36^{f}	177.8^{gh}	207.5^{ef}	157.6^{fg}
4	1	73.80^{cdef}	61.16^{b}	63.12^{d}	63.41d^{ef}	49.77^{bc}	49.63^{de}	137.2^{efg}	110.9^{b}	112.7^{d}
4	2	95.09^{g}	100.67^{defg}	93.29^{h}	121.47^{hi}	118.53i	105.33^{i}	216.6^{h}	219.2^{f}	198.6^{h}
4	3	93.51^{fg}	118.49^{h}	78.56^{efg}	125.67^{i}	113.57^{hi}	95.89^{hi}	219.2^{h}	209.3e^{f}	174.4^{g}
5	1	35.77^{a}	54.06^{ab}	30.20^{ab}	20.35^{ab}	40.82^{b}	22.49^{ab}	56.1^{ab}	104.9^{b}	52.7^{ab}
5	2	38.00^{a}	88.87^{de}	37.09^{abc}	25.54^{ab}	58.40^{cd}	28.30^{bc}	63.5^{ab}	147.3^{c}	65.4^{bc}
5	3	42.19^{a}	92.36^{def}	44.90^{c}	27.65^{ab}	67.48^{de}	30.11^{bc}	69.8^{abc}	177.8^{d}	75.0^{c}
CV%		18.2	11.8	12.7	12.5	12.9	11.4	12.9	11	9.4
LSD (5%)		20.55	17.48	13.29	13.09	15.65	10.46	28.08	29.54	18.46
Significance		*	*	*	**	**	*	**	*	**

Where, TNA= Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2= 1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height , 4= 1/4 at planting + 2/4 at knee height + 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling
Whereas, RNA= Rate of Nitrogen Application; 1= 23 kg ha^{-1}, 2= 46 kg ha^{-1}, 3= 69 kg ha^{-1} and 0= 0 kg ha^{-1} as absolute control.

Biomass Yield: Nitrogen applied at the rate of 69 kg ha^{-1} with three split nitrogen application timings 1/4 at planting+2/4 at knee height+1/4 at tasseling resulted maximum biomass yield (16.04-ton ha^{-1}) in Yeki district, followed by nitrogen applied at the rate of 46 kg ha^{-1} which resulted in the production of higher above ground biomass (15.93-ton ha^{-1}) for the same time of nitrogen application. Whereas control treatments (unfertilized plots) and nitrogen applied at the rate of 23 kg N ha^{-1} in split as 25% at sowing+25% at knee height and 50% at tasseling stage resulted minimum above ground biomass yield (4.83 and 5.17 t ha^{-1}), respectively, followed by nitrogen applied at the rate of 46 kg N ha-1 (6.02 ton ha^{-1}), nitrogen applied at the rate of 69 kg N ha^{-1} (6.27 t ha^{-1}) with time 1/4 at planting+1/4 at knee height+2/4 at tasseling and nitrogen applied at the rate of 23 kg N ha^{-1} (7.53 ton ha^{-1}) for nitrogen application timing 50% at planting and 50% at knee height Yeki district.

Regarding nitrogen application time lower above ground biomass yield was recorded in plots fertilized with more nitrogen at tasseling time, while maximum above ground biomass yield was recorded in plots treated with nitrogen 25% at sowing+50% at knee height and 25 at tasseling stage. The result of this study revealed that, combination of rates nitrogen fertilizer application with time of nitrogen application in all districts resulted in significantly higher biomass yield over the control and the blanket recommendation.

Similarly, the analysis of variance indicated a significant ($p<0.05$) difference among the treatments with respect to above ground biomass in t/ha at Menit Goldia district. Accordingly, the highest (16.82 t ha^{-1}) biomass yield was recorded for the application of 69 kg N ha^{-1} with split application of nitrogen fertilizer at a time of 1/4 at sowing+2/4 at knee height and 1/4 at tasseling stage followed by (15.93 t ha^{-1}) for the application of 46 Kg N ha^{-1} interaction with the same time of application. Whereas, the lowest (4.37 t ha^{-1}) biomass yield was obtained from the control treatment. However, statistically no significant differences were observed among the means of control and the application of 23 kg N ha^{-1} for most of time of nitrogen application at Menit Goldia district (Table 6). The recorded variation on biological yield of maize might be attributed by the improved in soil nutrient status due to increased applied rates of nitrogen and optimum availability of nitrogen as a result of split application of fertilizer; thus, improves growth and development of the crop as well as biomass yield. This indicates that split application of the recommended nitrogen fertilizers is important for growth and development as well as improvement of biological yield in maize.

In the same manner nitrogen applied at the rate of 69 kg ha^{-1} with split nitrogen application timing 1/4 at planting+2/4 at knee height+1/4 at tasseling resulted maximum biomass yield (14.2.04 ton ha^{-1}) followed by nitrogen applied at the rate of 46 kg ha^{-1} which resulted in the production of higher above ground biomass (14.12 ton ha^{-1}) for the same time of nitrogen application. Whereas control treatments (unfertilized plots) and nitrogen applied at the rate of 23 kg N ha^{-1} in split as 25% at sowing+25% at knee height and 50% at tasseling stage resulted minimum above ground biomass yield (4.37-ton ha^{-1}), followed by nitrogen applied at the rate of 46 kg N ha^{-1} (5.31-ton ha^{-1}) and nitrogen applied at the rate of 69 kg N ha-1 (5.68 t ha^{-1}) with time 25% at planting+25% at knee height 50% at tasseling Adiyyo Kaka district.

The outcome of this trial was confirmed with the recent finding who determined that a significant effect of nitrogen levels and application timings on biomass yield of maize. He also presented that nitrogen applied at the rate of 160 kg ha^{-1} resulted maximum biomass yield (9593 kg ha^{-1}) whereas 80 kg N ha^{-1} resulted minimum biomass yield (7939 kg ha^{-1}) of maize. Regarding time of nitrogen application lower biological yield (8443 kg ha^{-1}) was recorded in plots fertilized with whole nitrogen at sowing time, while maximum biological yield (9195 kg ha^{-1}) was noticed in plots treated with nitrogen 50% at sowing+50% at 25 days after sowing and generally, treated plots were produced more biological yield than control plots.

Grain yield: Statistical analysis of data showed a significant difference of nitrogen levels, application timings and their interaction on grain yield of maize in all the study area. Accordingly, Nitrogen applied at the rate of 46 kg ha^{-1} with split nitrogen application timings 1/4 at planting+2/4 at knee height+1/4 at tasseling resulted maximum grain yield (8.8 ton ha^{-1}) in Yeki district, followed by (8.30 ton ha^{-1}) resulted from the interaction of nitrogen applied at the rate of 69 kg ha^{-1} with split nitrogen application timings 1/4 at planting+2/4 at knee height+1/4 at tasseling (Table 6). Whereas, the control treatments (unfertilized plots) and nitrogen applied at the rate of 23 kg, 46 kg and 69 kg N ha^{-1} in split as 1/4 at sowing+1/4 at knee height+2/4 at tasseling stage resulted minimum grain yields (1.5 and 1.92 t ha^{-1}), respectively, followed by nitrogen applied at the rate of 46 kg N ha^{-1}(2.18. ton ha^{-1}), nitrogen applied at the rate of 69 kg N ha^{-1} (2.18 t ha^{-1}) with time 1/4 at planting+1/4 at knee height+2/4 at tasseling in Yeki district.

Concerning nitrogen application timings, minimum grain yield was recorded in plots fertilized with more nitrogen at tasseling time, 1/4 at sowing+1/4 at knee height and 2/4 at tasseling stage. While maximum grain yield was recorded in plots treated with more nitrogen was applied at vegetative growth stages most probably, 25% at sowing+50% at knee height and 25 at tasseling stage. The result of this study revealed that, combination of rates nitrogen fertilizer application with time of nitrogen application in Yeki district resulted significantly higher grain yield over the absolute control and the national recommendation.

The variation on mean grain yields of maize for varying rates and timings of nitrogen application in Yeki district might be due to the availability of mare nitrogen for the crops and to be up taken in response to increased rates of nitrogen fertilizer application. Optimum availability of nitrogen in the plant cell increased amount and quality of chlorophylls leading production of more dry matter during the vegetative growth stages and that can be partitioned among the plant parts during dry matter partitioning periods for fruit development and grain filling that determined the amount of yield to be harvested. Similarly, the differences in grain yield among the treatments in response to time of nitrogen application could be resulted from the synchrony of critical nitrogen requirement of maize and accessibility of the nutrients in all the growth stages.

These findings are parallel to that of they observed increase in grain yield by increasing N levels. In case of application timings, nitrogen half at sowing plus half at 25 days interval of sowing gave maximum grain yield. The full dose of nitrogen fertilizers at once is therefore not suggested because it leads to losses as the plant cannot utilize all the fertilizer at once, so to enhance N use efficiency and yield it is advised to use it in splits rather than sole application at the time of planting Saint et al. (2010). Our results are further supported by who observed that nitrogen application of 1/4 at planting+3/4 at knee height considerably increased yield and yield components of maize.

The analysis of variance showed that the main effect of rate of nitrogen application and time of nitrogen application and their interaction was significant ($P \leq 0.05$) on grain yield of maize in Menit Goldia district (Table 6). The highest grain yield (8.62 ton ha^{-1}) was recorded for application of 69 kg N ha^{-1} in three split of 1/4 of the dose at sowing, 2/4 dose at mid-vegetative and 1/4 dose at tasseling stage followed by the combination of 46 kg N ha^{-1} at the same split application of 1/4 of the dose at sowing, 2/4 dose at mid-vegetative and 1/4 dose at tasseling stage (8.04 ton ha-1). On the other hand, the lowest grain yield (2.30 ton ha^{-1}) was obtained from the control (Table 6). However statistically no significant was found between treatment means of the control plots and time of nitrogen application in three split as 1/4 at planting+1/4 at knee height and 2/4 at tasseling growth stages in combination with nitrogen application rate of 23 kg N ha-1 and 46 kg N ha^{-1} at Menit Goldia districts.

Generally, grain yield increased with the increased in the rate of nitrogen across the increased number of split application (Table 6). The highest grain yield at the higher nitrogen rates might have resulted from improved root growth and increased uptake of nutrients and better growth that enhanced yield components and yield. Maize yield increased with increased in the rate of nitrogen application, but no further increase in grain yield when the rate of nitrogen application increased beyond 46 kg N ha^{-1} which could be excess supply of nitrogen favoured more growth of the plant parts which increased the biomass yield rather than grain yield.

Likewise increasing the number of split application from two to three at sowing, knee height and tasseling stage significantly increased grain yield at 46 and 69 kg N ha^{-1} (Table 6). This may be because the plants may have been able to take up balanced amounts of nitrogen throughout the major growth stages due to better synchrony of the demand of the nutrient for uptake by the plant and its availability in the root zone in sufficient amounts. In line with this result, reported that supplying N in two or three applications is a good recommendation to increase N use efficiency in sorghum.

The interaction of nitrogen application timings and nitrogen rates showed significant ($P<0.05$) difference with respect to grain yield of maize in Adiyyo Kaka district (Table 6).In view of that, nitrogen applied at the rate of 46 kg ha^{-1} with three split nitrogen application timings, 1/4 at planting+2/4 at knee height+1/4 at tasseling gave the highest grain yield of maize (7.38 ton ha^{-1}), followed by (7.22 ton ha^{-1}) obtained from the interaction of nitrogen applied at the rate of 69 kg ha^{-1} with split nitrogen application timings 25% at planting+50 at knee height+25% at tasseling (Table 6). While the lowest grain yield (1.5 t ha^{-1}), was recorded from control treatments (unfertilized plots) and followed by nitrogen applied at the rate of 23 kg, 46 kg and 69 kg N ha^{-1} in split as 25% at sowing+25% at knee height and 50% at tasseling stage resulted minimum grain yields (1.92, 2.18 and 2.18 t ha^{-1}), respectively.

With reference to nitrogen application timings, minimum grain yield was recorded in plots fertilized with more nitrogen at anthesis, 25% at sowing+25% at knee height and 50 at tasseling stage. While maximum grain yield was recorded in plots treated with more nitrogen was applied at vegetative grove stages most probably, 25% at sowing+50% at knee height and 25 at tasseling stage. The result of this study revealed that, combination of rates nitrogen fertilizer application with time of nitrogen application in Adiyyo Kaka district resulted significantly higher grain yield over the absolute control and the national recommendation (Table 6). The highest grain yield at the higher nitrogen rates might have resulted from improved root growth and increased uptake of nutrients and better growth that enhanced yield components and yield. This finding inconformity with the previous results reported by Cassman et al., also reported that greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, and split applications of N during the growing season, rather than a single, more application, are known to be effective in increasing N use efficiency. Kidist reported that increasing the rate of nitrogen from 130.5 to 174 kg N ha^{-1} decreased the grain yield by 5.4%. Thus, the optimum grain yield was obtained at 130.5 kg N ha^{-1}.

Harvest index: Harvesting index was significantly ($P<0.05$) affected by nitrogen application timings, rates and their interaction in all the study districts. Accordingly, the minimum values (31.33%, 33.09% and 33.00%) harvesting index was recorded from the control treatments or unfertilized plots of Yeki, Menit Goldia and Adiyyo Kaka districts, respectively (Table 6). Whereas, the maximum harvesting index (55.24%, 51.62% and 52.27%) were obtained for the application of 46 kg N ha^{-1} in split 25% of the dose at planting+50% of the dose at knee height + 25% of the dose tasseling followed by (50.67%, 51.22% and 50.84%) harvesting index from the application of 69 kg N ha^{-1} in split 1/3 at planting+1/3 knee height+1/3 tasseling (T2)at Yeki, 1/4 at planting+2/4 at knee height+1/4 at tasseling at Menit Goldia and 1/4 at planting+2/4 at knee height+1/4 at tasseling at Adiyyo Kaka districts, respectively. However, no significant differences were exhibited between nitrogen application at the rate of 46 kg N ha^{-1} and 69 kg N ha^{-1} regarding to harvest index in all Yeki, Menit Goldia and Adiyyo Kaka, respectively.

Increased nitrogen rates showed significant increased on harvest index of maize. Increasing nitrogen application rates up to 46 kg ha^{-1} increased the value of harvest index by (23.91%, 18.53% and 19.27%) for Yeki, Menit Goldia and Adiyyo Kaka respectively, as compared with the control treatments. Increasing nitrogen from 0 to 46 kg N ha^{-1} increased the harvest index, and the increment was consistent, but no significant difference was observed between 46 kg N/ha and 69 kg N/ha. Harvest index was noticed to be significantly affected by nitrogen levels. The increase synthesis of dry matter as a result of photosynthesis and the significant interference of active enzymes due to the use of nitrogen in inert form led to more harvest index in maize. Similarly, stated that whenever, yield and yield components increases, a positive association might be there for harvest index of maize. Optimum harvest index was acquired when more nitrogen was applied.

Hundred-grain weight: Hundred grain weights is an essential yield determining parameter. It expressed the magnitude of grain development for deriving the grain quality and yield per hectare. 100 gain weights maize were significantly ($P<0.05$) influenced by the interaction effects of nitrogen rates and nitrogen application timings in all the study locations (Table 7).

TABLE 7

Apparent recovery, Agronomic and physiological efficiency of Maize as Influenced by Rates and Time of Nitrogen Application

TNA	RNA	Straw Nitrogen Uptake kg/ha			Grain Nitrogen Uptake kg/ha			Total Nitrogen Uptake kg/ha		
		Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka	Yeki	M. Goldiya	A. Kaka
0	0	32.88^{a}	43.21^{a}	26.70^{a}	15.34^{a}	21.23^{a}	13.98^{a}	48.2^{a}	64.4^{a}	40.7^{a}
1	1	50.55^{ab}	66.46^{b}	41.63^{bc}	34.54^{abc}	49.00^{bc}	28.78^{bc}	85.1^{abcd}	115.5^{b}	70.4^{bc}
1	2	62.80^{bc}	105.78^{efgh}	77.19^{efg}	53.75^{cde}	87.80^{fg}	54.82^{de}	116.6^{cdef}	193.6^{def}	132.0^{e}
1	3	79.34^{cdefg}	104.38^{efgh}	71.03^{def}	68.83^{ef}	88.89^{fg}	58.45^{e}	148.2^{efg}	193.3^{def}	129.5^{de}
2	1	68.20^{bcde}	70.95^{bc}	66.38^{de}	53.33^{cde}	48.46^{bc}	46.47^{d}	121.5^{def}	119.4^{bc}	112.9^{d}
2	2	84.64^{efg}	97.99d^{efg}	84.80^{gh}	99.50g^{h}	92.26^{fg}	82.77^{fg}	84.1^{gh}	190.3^{def}	167.6^{fg}
2	3	81.74^{cdefg}	95.70d^{efg}	80.48^{fgh}	102.39^{ghi}	98.91^{gh}	86.74^{gh}	184.1^{gh}	191.3^{def}	167.2^{fg}
3	1	63.00^{bcd}	85.42^{cd}	47.16^{c}	42.71^{bcd}	61.24^{cd}	34.60^{c}	105.7^{bcde}	146.7^{c}	81.8^{c}
3	2	83.44^{defg}	109.55^{fgh}	79.26^{efg}	4.53^{ef}	79.94^{ef}	73.06^{f}	158.0^{fg}	189.5^{de}	152.3^{f}
3	3	98.82^{g}	110.29^{gh}	85.26^{gh}	78.96^{fg}	88.99^{fg}	72.36^{f}	177.8^{gh}	207.5^{ef}	157.6^{fg}
4	1	73.80^{cdef}	61.16^{b}	63.12^{d}	63.41^{def}	49.77^{bc}	49.63^{de}	137.2^{efg}	110.9^{b}	112.7^{d}
4	2	95.09^{g}	100.67^{defg}	93.29^{h}	121.47^{hi}	118.53^{i}	105.33^{i}	216.6^{h}	219.2^{f}	198.6^{h}
4	3	93.51^{fg}	118.49^{h}	78.56^{efg}	125.67i	113.57^{hi}	95.89^{hi}	219.2^{h}	209.3^{ef}	174.4^{g}
5	1	35.77^{a}	54.06^{ab}	30.20^{ab}	20.35ab	40.82^{b}	22.49^{ab}	56.1^{ab}	104.9^{b}	52.7^{ab}
5	2	38.00^{a}	88.87^{de}	37.09^{abc}	25.54^{ab}	58.40^{cd}	28.30^{bc}	63.5^{ab}	147.3^{c}	65.4^{bc}
5	3	42.19^{a}	92.36^{def}	44.90^{c}	27.65^{ab}	67.48^{de}	30.11^{bc}	69.8^{abc}	177.8^{d}	75.0^{c}
CV%		18.2	11.8	12.7	12.5	12.9	11.4	12.9	11	9.4
LSD (5%)		20.55	17.48	13.29	13.09	15.65	10.46	28.08	29.54	18.46
Significance		*	*	*	**	**	*	**	*	**

Where, TNA=Time of Nitrogen Application; 1=1/2 at planting + 1/2 at knee height, 2=1/3 at planting + 1/3 at knee height + 1/3 at near tasseling, 3= 1/3at planting + 2/3 at knee height , 4= 1/4 at planting + 2/4 at knee height + 1/4 at tasseling, and 5= 1/4 at planting + 1/4 at knee height + 2/4 at near tasseling.
Whereas, RNA= Rate of Nitrogen Application; 1= 23 kg ha^{-1}, 2= 46 kg ha^{-1}, 3= 69 kg ha^{-1} and 0= 0 kg ha^{-1} as absolute control.

The highest 100 grain weights 25.82, 28.22 and 26.89 g, respectively were recorded in Yeki, Menit Goldia and Adiyyokaka districts from the application of 46 kg N ha^{-1} interacted with the application timings in three splits 1/4 at sowing+2/4 at mid vegetative growth stages/ knee height+1/4 at tasseling stages. However, application of nitrogen fertilizer at rates of 46 kg and 69 kg N ha^{-1} for all timings of application except, T5, (1/4 at sowing+1/4 at knee height+2/4 at tasseling stages) was not significant. The minimum 100 grain weights, 17.10, 15.65 and 15.98 g, respectively, were recorded in Yeki, Menit Goldia and Adiyyokaka districts for the control treatments. But, statistically application of nitrogen 23 kg N ha^{-1} for all timings of nitrogen application in all the study location were par with the unfertilized plots or the control treatments (Figure 1).

The increased in nitrogen rate and application nitrogen fertilizer in more than two split resulted increased 100 grain weight in maize. Thus, increased nitrogen rates from 0 to 46 kg ha^{-1} with split application (1/4 of the dose at sowing+2/4 of the dose at mid vegetative growth stages/ knee height+1/4 of the dose at tasseling stage) increased 100 grain weight of maize by 8.72, 12.57 and 10.91 at Yeki, Menit Goldia and Adiokaka, respectively. The variations in 100 grain weight among the treatments might be due to availability of nitrogen throughout the growth periods of maize crop which supplied the required nutrient for fruit and grain development during grain filling periods.

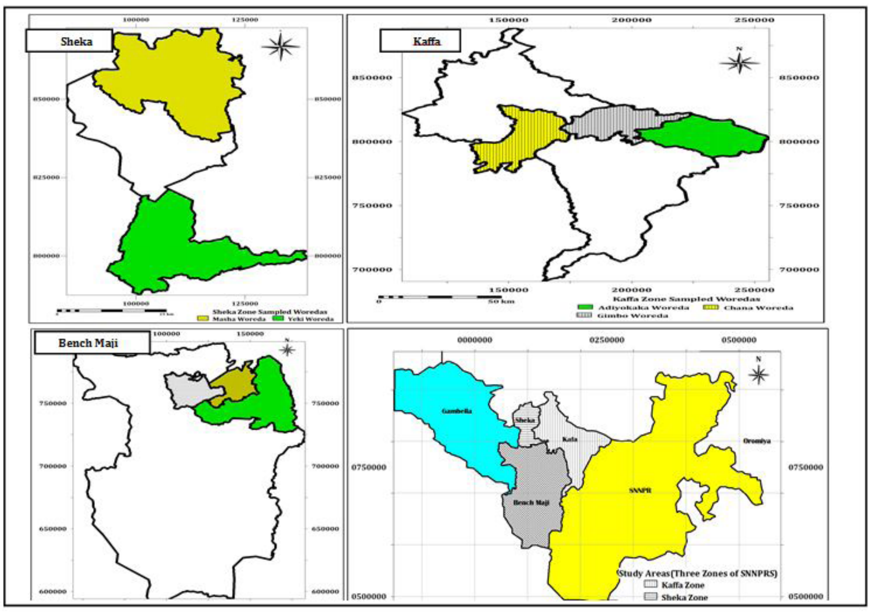

Figure 1) *Location map of the research area*

The results of this research were in agreement with the previous founding of who revealed that maximum 100 grain weight (24.5 g) was noticed in plots fertilized with (160 kg N ha^{-1}). While minimum 100-grains weight (22.5 g) was recorded in plots received 80 kg N ha^{-1}. In application timings higher 100 grain weight (24.7 g) was recorded in plots to which nitrogen was applied 1/2 as AT1 and 1/2 as AT2, while lower hundred grain weight (23.4 g) was noted in plots to which whole N was applied at sowing time. Furthermore, it is evident from the planned mean data that rest experimental units produced higher thousand grains weight (23.8 g) when compared to control (215 g).

Similarly, heaviest grains may be due to the utilization of nitrogen at the proportion, which resulted in bold and robust (healthy) seed size. The effect of phosphorous levels showed that maximum grains weight of (44.9) g were recorded in plots treated with (150, 100) as compared to lower doses. It may be due to greater contribution of N & P by producing healthy grains well filled grains and bigger grains while minimum grains weight was obtained at lower levels (0, 0) N:P kg·ha^{-1}.

Maize grain and straw nitrogen contents: The grain and straw nitrogen contents were significantly ($p \leq 0.05$) influenced by the main effect of nitrogen rates, time of applications and their interactions (Table 7). Therefore, maximum nitrogen concentration in grain (14.60, 13.85 and 14.58) and (12.66, 13.73 and 13.52) in straw yield of maize were recorded for the application of higher dose of nitrogen 46 kg N ha^{-1} in split (1/4 of the dose at sowing+2/4 of the dose at mid vegetative growth stages/ knee height+1/4 of the dose at tasseling stage), respectively at Yeki, Menit Goldia and Adiyyokaka districts. The minimum nitrogen concentration both in grain and straw (10.85:9.88, 9.57:9.42 and 9.82:9.07) were obtained from the control treatment for Yeki, Menit Goldia and Adiyyokaka districts, respectively.

The result of this experiment revealed that higher grain and straw nitrogen content were noticed when more nitrogen was applied in three split keeping that quarter of the dose at sowing, half at knee height and quarter at tasseling stages in all the study locations. Increased nitrogen concentration both in grain and straw in response to increased rates of nitrogen might be due to accessibility of the nutrient in all growth stages of the crop which intern increased uptake and reduces loss of nitrogen either by leaching and volatilization resulted from single or two split applications. The highest (14.60) grain and (13.52) straw nitrogen contents were recorded at the highest level of nitrogen (69 kg N ha^{-1}) application, implying a positive response of the crop to nitrogen fertilizer application. On the other hand, the low grain (1.53%) and straw (0.28%) nitrogen contents were recorded from unfertilized plots. Hence, the maximum grain and straw nitrogen contents exceeded the minimum grain and the straw nitrogen contents by about 29.87 and 60.78% respectively.

This result implies a positive response of grain and straw nitrogen concentration to the increased nitrogen level, and is consistent with the results decrease in grain nitrogen content of wheat with decreased levels of nitrogen application. It appears that the availability of nitrogen in the grain filling stage of maize increased grain protein content. Application of nitrogen in split doses increased grain protein content by 1.55%. Furthermore, nitrogen application is the most important environmental factor affecting protein content and composition.

Straw, grain and total nitrogen up take: The straw, grain and total nitrogen uptake is depicted on Table 8 for three districts, respectively. Accordingly straw nitrogen uptake was significantly ($p<0.05$) affected by interaction effects of different rate and time of nitrogen application in three districts.

Straw nitrogen uptake: The highest straw nitrogen up take 98.82, 118.49 and 93.29 kg was obtained from application of 69 kg/ha applied in two spits (1/3 at planting and 2/3 at knee height) in Yeki, Menit Goldia and Adiyokaka districts, respectively. The lowest straw nitrogen up takes 32.88, 43.21 and 15. 34 kg/ha was recorded from control treatment in Yeki , Menit Goldia and Adiyokaka districts, respectively which is statistically non-significant with application of three level of nitrogen (23, 46 and 69 kg/ha) applied full doses near tasseling in Yeki Woreda . The higher in straw nitrogen up take from application of higher doses (69 kg/ha) in splits (1/3 at planting and 2/3 at knee height) may be due to maize require high amounts of nitrogen during vegetative stages. This study is in line with the recent study by Nanno, 2017 who reported high straw nitrogen up take with increasing rate of nitrogen fertilizer of wheat with split application.

Grain nitrogen uptake: Grain nitrogen uptake was highly significant ($P<0.01$) in Yeki and Menit Goldia districts and significantly ($P<0.05$) influenced in Adiyokaka districts with interaction effect of different rate of nitrogen fertilizer and time of nitrogen application (Table 8). The highest grain nitrogen up take was obtained from application of 69 kg /ha applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Yeki districts and 118.53 and 105.33 kg/ha was obtained from application of 46 kg/ha of nitrogen fertilizer applied in three splits (1/4 planting+2/4/ knee height+1/4 near tasseling) in Menit Goldia and Adiyokaka districts, respectively. The lowest grain nitrogen up 15.34, 21.23 and 13.98 kg/ha were obtained from control treatments in Yeki, Menit Goldia and Adiyokaka districts respectively.

TABLE 8

Partial budget analysis of maize yield as influenced by nitrogen fertilizer rates and time of application at Yeki, Menit Goldia and Adiyokaka Districts

NR*TN	Yeki	Menit	Adiyokaka	Yeki	Menit	Adiyokaka	Yeki	Menit	Adiyokaka	Yeki	Menit	Adiyokaka	Yeki	Menit	Adiyokaka
	AGY	AGY	AGY	GR	GR	GR	TVC	TVC	TVC	NR	NR	NR	20.55	20.55	20.55
	t/ ha	t/ha	t/ ha	ETB/ ha	ETB/ ha	ETB/ ha	ETB/ ha	ETB/ ha	ETB/ ha	ETB/ ha	ETB/ha	ETB/ha	20.55	20.55	20.55
0,0	1.49	2.28	1.43	8195	12523.5	7786.35	-	-	-	8195	12523.5	7786.35	-	-	-
1,1	2.92	4.21	2.63	16060	23141.25	14320.35	922.5	884.05	934	15137.5	22257.2	13386.35	D	D	D
1,2	4.26	6.59	4.12	23430	36263.7	22433.4	1445	1368.1	1468	21985	34895.6	20965.4	D	D	D
1,3	5.05	6.96	4.75	27775	38278.35	25863.75	1967.5	1852.15	2002	25807.5	36426.2	23861.75	D	D	D
2,1	4.49	4.65	4.42	24695	25591.5	24066.9	1122.5	1084.05	1134	23572.5	24507.45	22932.9	D	D	D
2,2	7.2	6.61	6.1	39600	36372.6	33214.5	1645	1568.1	1668	37955	3480450	31546.5	D	D	D
2,3	7.24	7.21	6.35	39820	39639.6	34575.75	2167.5	2052.15	2202	37652.5	37587.45	32373.75	D	D	D
3,1	3.48	4.76	2.79	19140	26190.45	15191.55	922.5	884.05	934	18217.5	25306.4	14257.55	D	1514.71	692.85
3,2	5.4	5.76	5.36	29700	31689.9	29185.2	1445	1368.1	1468	28255	30321.8	27717.2	1921.05	D	975.96
3,3	5.68	6.5	5.4	31240	35773.65	29403	1967.5	1852.15	2002	29272.5	33921.5	27401	D	D	D
4,1	4.82	4.56	4.7	26510	25101.45	25591.5	1122.5	1084.05	1134	25387.5	24017.4	24457.5	1533.63		1470.11
4.2	8.71	7.96	7.38	47905	43777.8	40184.1	1645	1568.1	1668	46260	42209.7	38516.1	3994.74	3657.33	2632.7
4,3	8.22	8.53	7.22	45210	46935.9	39312.9	2167.5	2052.15	2202	43042.5	44883.75	37110.9	D	552.43	D
5,1	1.9	3.58	2.04	10450	19710.9	11107.8	1122.5	1084.05	1134	9327.5	18626.85	9973.8	D	D	D
5,2	2.16	4.27	2.12	11880	23467.95	11543.4	1645	1568.1	1668	10235	21899.85	9875.4	D	D	D
5,3	2.16	4.87	2.3	11880	26789.4	12523.5	2167.5	2052.15	2202	9712.5	24737.25	10321.5	D	D	D

Where, NR= Rate of nitrogen, NT= Time of N application, AGY= Adjusted grain yield, GR= Gross return, TVC=total variable cost, NR= Net return, MRR= Marginal rate of return, D= Dominated treatments.

The higher grain nitrogen up take may be attributed to the higher doses of nitrogen application in three splits contributes for the translocation of nitrogen from straw to grain during the growing periods. The study was in agreement with the study of Malinga et al., 011 who reported increase in grain nitrogen uptake in wheat with split application of nitrogen fertilizer in other countries.

Total nitrogen uptake: Total nitrogen uptake is highly significant (P<0.01) in Yeki and Adiyokaka districts as affected by the interaction effect of different rate of nitrogen application and time of application and significantly (P 0.05) affected by interaction effect of different rate of nitrogen application and time of application in Menit Goldia district.

The Highest total nitrogen uptake 219.2 kg/ha was obtained from application higher doses (69 kg/ha) of nitrogen fertilizer application applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Yeki districts were as the highest total nitrogen uptake 219.2 and 198.6 kg/ha was obtained from application of 46 kg/ha of nitrogen fertilizer applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Menit Goldia and Adiyokaka districts respectively. The lowest total nitrogen up takes 48.2, 64.4 and 40.7 kg/ha were obtained from control treatments in all study area.

The higher in total nitrogen up take may be attributed due the higher available nitrogen the higher nitrogen taken up by crops and split application of nitrogen fertilizer reduces nitrogen loss through leaching and volatilization so that plant can absorb higher concentration. The higher in total nitrogen up take of maize from higher doses of nitrogen with three split application of nitrogen fertilizer.

Apparent recovery, agronomic and physiological efficiency of maize

Apparent Recovery: Apparent nitrogen recovery is a measure of the ability of the crop to take out N from the soil. The main effect of N rate and timing of application as well as the interaction effect of these two factors highly significantly (P<0.05) affected apparent nitrogen recovery (Table 9). Apparent nitrogen recovery by the maize plants generally decreased with the increase in the rate of nitrogen application in Yeki experimental site On the other hand, the result did not show any consistency at M. Goldiya and A. Kaka experimental sites.

The highest amount of apparent nitrogen recovery (3.86 and 3.84 at rate of 23 kg N ha^{-1} in response to split applications of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling and split applications of 1/3 dose at planting+2/3 dose at knee height at Yeki and Menit Goldia sites respectively and 3.43 at rate of 46 kg N ha^{-1} in response to split applications of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling at Adiyokaka site) was obtained. Whereas the lowest apparent nitrogen recovery (0.31, 1.73 and 0.49) at Yeki, Menit Goldia and Adiyokaka respectively was recorded at 69 kg N ha^{-1} in split applications of 1/4 dose at planting+1/4 dose at knee height+2/4 dose at near tasseling.

This indicates that Maize plants recovered less amounts of nitrogen from the soil as rate of application went beyond 46 kg N ha^{-1}. Supporting the results of this study, Zafar [37] stated that about 50% of applied N remains unavailable to a crop due to a combination of leaching, fixation and volatilization. The results obtained in this study confirm the observations of Lopez-Bellido [11] that recovery of N applied, which is determined based on measurements of N uptake in the aerial plant biomass, is highly affected by timing of N application.

Agronomic and physiological efficiency: Both agronomic and physiological efficiency were significantly (P<0.05) affected by N rate, timing of application, and by the interaction effect of the two factors. Agronomic efficiency is the amount of additional yield produced for each additional kg of fertilizer applied [38].

The highest agronomic efficiency (15.25 and 12.49) was obtained at Yeki and M.Goldia sites respectively from 46 kg ha^{-1} in split applications of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling and 14.23 which is the highest agronomic efficiency for A.Kaka was obtained from 23 kg ha^{-1} of same application time with the two sites. While the lowest (1.08, 3.8 and 1.15) at Yeki, M.Goldia and A.Kaka respectively was recorded at 69 kg N ha^{-1} in split applications of 1/4 dose at planting+1/4 dose at knee height+2/4 dose at near tasseling.

The agronomic efficiency recorded in the response of split application of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling, increased as the rate increased 23 to 46 kg N ha^{-1}. However, nutrient applied beyond 46 kg N ha^{-1}, showed reduction in agronomic efficiency across all split applications (Table 9). This might be due to the effect of loss of nutrients that the maize crop did not take the applied fertilizer and hence, caused low grain yield. Craswell [39] asserted that high agronomic efficiency is obtained if the yield increment per unit N applied is high because of reduced losses and increased uptake of nitrogen.

In all experimental sites, the highest physiological efficiency value was obtained from the lowest N rate of 23 kg N ha^{-1} in the response of split applications of 1/4 dose at planting+1/4 dose at knee height+2/4 dose at near tasseling at Yeki and M.Goldia sites and in the response of split applications of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling at A.Kaka site). The lowest physiological efficiency recorded at the highest nitrogen rate of 69 kg N ha^{-1} at all experimental sites in the response of split applications of 1/4 dose at planting+1/4 dose at knee height+2/4 dose at near tasseling at Yeki and M.Goldia and in the response of split applications of 1/3 dose at planting+2/3 dose at knee height at A.Kaka site. The application of high N rates may result in poor N uptake and low NUE due to excessive N losses. The ratio of grain N yield to the total N yield provides an estimate of efficiency of N translocation from vegetative tissue to grain and indicated that at low N rate the amount of N trans located to the grain was high.

Partial budget analysis of nitrogen fertilizer rate and time of application: The curiosity of producers in using fertilizer is not only boosting yield, but also to make return out of it. Towards maximizing profit, the amount, time of fertilizer applications and costs of fertilizer are key factors. Owing to this fact increasing grain yield can increase farmers profits.

As showed in the Table 10, the partial budget analysis revealed that the highest net benefit of 46260.00, 44883.75 and 38516.7 Birr ha-1, were obtained in the treatment that received 46, 69 and 46 kg N ha-1 in split application of 1/4 at sowing+2/4 at knee height and 1/4 at tasseling stage, respectively for Yeki, Menit Goldia and Adiyyokaka. However, the lowest net benefit 8195, 12523.50 and 7786.35 Birr ha-1 was obtained from control treatment for Yeki, Menit Goldia and Adiyokaka districts, respectively.

The highest marginal rate of return (3994.74, 3657.33 and 2632.70%) were recorded from the plot treated with 46 kg N ha-1 in three split applications (1/4 dose at sowing and 2/4 dose at knee height and 1/4 of the dose at tasseling stage). However, the dominated treatments were abandoned from further economic analysis to differentiate treatments with optimum return to farmer's practice; marginal analysis was performed on non-dominated treatments. For treatment to be considered as advisable to farmers, between 50% and 100% marginal rate of return (MRR) was the minimum acceptable rate of return [26].

Therefore, (3994.74, 3657.33 and 2632.70%) MRR recorded from application of 46 kg N ha-1 in three split 1/4 dose at sowing and 2/4 dose at knee height and 1/4 of the dose at tasseling stage) with highest net benefit and MRR is profitable and recommended for farmers in Yeki, Menit Goldia and Adiokaka districts and others similar agro-ecological conditions.

CONCLUSION

In conclusion, grain yield, harvesting index, 100-grain weight, nitrogen uptake and agronomic efficiency were influenced by the interaction of rates and application time of nitrogen fertilizer. Nitrogen applied at the rate of 46 kg ha^{-1} at Yeki, 69 kg ha^{-1} at Menit Goldia and 46 kg ha^{-1} at Adiyokaka with split nitrogen application timings 1/4 at planting+2/4 at knee height+1/4 at tasseling, resulted maximum grain yield (8.8-ton ha^{-1}, 8.62-ton ha^{-1} and 7.38-ton ha^{-1}), respectively. On the other hand, the highest 100-grain weights 25.82, 28.22 and 26.89 g, respectively were recorded in Yeki, Menit Goldia and Adiyyokaka districts for the application of 46 kg N ha^{-1} interacted with nitrogen application timings in three splits 1/4 at sowing+2/4 at mid vegetative growth stage and knee height+1/4 at tasseling stages.

Grain and straw nitrogen contents, uptake, apparent recovery and nitrogen use efficiencies were significantly influenced by varying rates and nitrogen application timings in all the study districts. As a result maximum nitrogen concentration in grain (14.60, 13.85 and 14.58) and (12.66, 13.73 and 13.52) in straw yield of maize were recorded for the application of higher dose of nitrogen 46 kg N ha^{-1} in split (1/4 of the dose at sowing+2/4 of the dose at mid vegetative growth stages/ knee height+1/4 of the dose at tasseling stage), respectively at Yeki, Menit Goldia and Adiyyokaka districts. Correspondingly, the highest straw nitrogen up take 98.82, 118.49 and 93.29 kg was obtained for the application of 69 kg/ha applied in two spits (1/3 at planting and 2/3 at knee height) in Yeki, Menit Goldia and Adiyokaka districts and the highest grain nitrogen up take was obtained from application of 69 kg /ha applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Yeki districts and 118.53 and 105.33 kg/ha was obtained from application of 46 kg/ha of nitrogen fertilizer applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Menit Goldia and Adiyokaka districts. The highest total nitrogen uptake 219.2 kg/ha was obtained from application higher doses (69 kg/ha) of nitrogen fertilizer application applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Yeki districts were as the highest total nitrogen uptake 219.2 and 198.6 kg/ha was obtained from application of 46 kg/ha of nitrogen fertilizer applied in three splits (1/4 planting+2/4 knee height+1/4 near tasseling) in Menit Goldia and Adiyokaka districts, respectively.

On the other hand, the highest agronomic efficiency (15.25 and 12.49 kg grain yield kg^{-1} N) was obtained at Yeki and M.Goldia sites, respectively from 46 kg ha^{-1} in split applications of 1/4 dose at planting+2/4 dose at knee height+1/4 dose at tasseling and 14.23 kg grain yield kg^{-1} N which is the highest agronomic efficiency for A.Kaka was obtained from 23 kg ha^{-1} of same application time as Yeki and M.Goldia sites.

The partial budget analysis revealed that the highest net benefit of 46260.00, 44883.75 and 38516.7 Birr ha^{-1} were obtained in the treatment that received 46, 69 and 46 kg N ha^{-1} in split application of 1/4 at sowing+2/4 at knee height and 1/4 at tasseling stage, with MRR of (3994.74, 3657.33 and 2632.70%) respectively for Yeki, Menit Goldia and Adiyyokaka. Therefore, 3994.74, 3657.33 and 2632.70% MRR recorded from application of 46 kg N ha^{-1} in three split 1/4 dose at sowing and 2/4 dose at knee height and 1/4 of the dose at tasseling stage with highest net benefit and MRR is profitable and recommended for farmers in Yeki, Menit Goldia and Adiyyokaka districts and others similar agro-ecological conditions.

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