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Determination of Appropriate Time of Nitrogen Fertilizer Application for Maize in the Central Highlands of Ethiopia

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ABSTRACT
Excessive nitrogen fertilization and improper management can cause a decrease in NUE in the maize cropping system. Most nitrogen fertilizers are applied when the corn is 4-5 weeks after planting. However, recent studies have shown that modern hybrids take up high amounts of nitrogen at the flowering stage. This suggests that a nitrogen fertilization strategy that starts at the beginning of vegetative growth and later in the flowering phase is needed to maximize the yield of hybrid maize in upland. The study was conducted in 2018-2019 in Liban, Jawi, and Toke Kutaye Districts in the West Showa Zone of the Central Highlands of Ethiopia. The research design used a randomized block design with the one-time treatment of fertilizer application consisting of six levels, namely 1/3 at planting + 1/3 at 4-5 weeks after an emergency (WAE) + 1/3 at 70-80 days after planting (DAP); 1/3 part at planting + 2/3 part at 4-5 WAE; 2/3 share at 4-5 WAE + 1/3 at 70-80 DAP; 1/4 at planting + 1/2 at 4-5 WAE + 1/4 at 70-80 DAP; 1/2 at 4-5 WAE + 1/2 at 70-80 DAP; and full at 4-5 WAE). Nitrogen fertilization on2/3part at 4-5 WAE + 1/3 part at 70-80 DAP significantly affected plant height, cob length, grain yield, and biomass yield, but it did not influence root and stem lodging. When the data were combined over the two years, the treatment of 2/3part N application at 4-5 WAE (knee height) + 1/3 part at 70-80 DAP (before tasseling) resulted in the highest grain yield with a yield advantage of 1,598 kg/ha and gave maximum net benefit over the typically used full application at 4-5 WAE (knee height). This fertilizer management strategy could be advised for the Liban Jawi, Toke Kutaye areas, and other similar agro-ecosystem environments.

Keywords: Growth characters; Lodging; Productivity; Timing of N Application

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INTRODUCTION

In Ethiopia, maize consumption will continue to increase in 2021. This increase in consumption is offset by maize production, which has continued to increase over the years in the main maize-producing areas of Ethiopia. The Central Statistics Agency of Ethiopia shows that corn production is 2.53 million hectares of land with a total production of about 10.55 MT with an average national yield of 4.18 $t.ha^{-1}$ (CSA 2021). This result is lower than the international standard (5.75 $t.ha^{-1}$) (FAOstat 2017). Total national corn production in the 2017-2018 planting season was 8.4 million tons from 2.13 million hectares with average productivity of 3.94 $t.ha^{-1}$ (CSA 2018). This yield is very low compared to developed countries, with an average of 6.7 $t.ha^{-1}$. One of the factors that affect production is soil fertility. The decrease in soil fertility causes low crop yields (Boudjabi and Chenchouni 2022). Efforts to overcome this are through efficient and environmentally friendly agriculture. Habitat productivity and soil fertility are related to nutrient content and soil organic matter (Cai et al. 2019). Fertilization should be considered to maintain soil fertility (Bouallala et al. 2020; Boudjabi and Chenchouni 2021).

Corn cultivation in high and medium altitudes with high rainfall can experience high nitrogen losses through leaching and denitrification, leaving nutrients unavailable during critical stages of plant growth. Excessive rainfall after planting often results in loss of N through denitrification and leaching. Based on the research results of Hess et al. (2020) that the intensification of rainfall increases nitrate leaching from cropping systems, and increases nitrate leaching from systems without treatment. Nitrogen leaching is one of the most important pathways for nitrogen loss from cropping systems (Grant et al. 2019). In addition, leached N is an economic loss for farmers, where N fertilizer is often one of the highest direct production costs (Zheng et al. 2020). Nitrogen leaching can reduce the efficiency of nitrogen use and cause corn production to decrease (Abdalla et al. 2019).

The nitrogen requirement of maize at the beginning of planting is 20-30% of the total and 70-80% is needed at the next level of demand (Clark et al. 2020). The

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application of nitrogen to maize is based on historical dogma suggesting that N removed from the field in grain should be replaced (ie, 1% grain N concentration; 10 kg N Mg grain^{-1}). The nitrogen in the stover residue was also considered to need to be replaced (that is, 1% N stover concentration i.e. 50% of the total biomass; 10 kg N stover Mg^{-1}) (Franzluebbers 2018). However, soil type also affects the need for nitrogen fertilization (Rutan and Steinke 2018). Delayed application of nitrogen can inhibit growth and decrease yield potential (Morris et al. 2018). Corn nitrogen uptake does not accelerate until V6 to V8 (Nigon et al. 2020). However, weather, planting date, and fertilization application strategies can affect the ability to develop maize plants to absorb nitrogen (Wang et al. 2018). Fertilization strategies by determining the amount of applied nitrogen, application time, soil permeability, and rainfall in the area can be carried out to reduce nitrogen leaching losses (De Notaris et al. 2018). The application of nitrogen at the right time can promote optimal absorption and the efficiency of increasing N recovery by about 58–70% will further increase grain yields (Rutan and Steinke 2019). This research's novelty is combining nitrogen application time, namely at the beginning of planting and in the flowering phase. This study aimed to determine the appropriate timing of nitrogen fertilizer application for higher yields and profitability of upland maize in the study area.

MATERIALS AND METHODS

The field experiments were conducted in two locations at Liban Jawi and Toke kutaye districts in the West Showa Zone, central high land of Ethiopia during the 2018 and 2019 cropping seasons. Toke kutaye experimental site was geographically located at 8.969167° N and 37.57056° E and altitude of 2272 m.a.s.l were received a mean annual rainfall of 1128 mm with minimum and maximum temperatures of 11°c and 26°c, respectively. Liban Jawi was geographically located at 8.98444° N and to 37.72528°E with an altitude of 2381 m.a.s.l. Liban Jawi has an average annual rainfall of 1128 mm with a minimum temperature of 13 °C and a maximum of 30 °C. The soil in this study had a pH of 5.91 with a groundwater suspension of 1:2.5).

The study used a completely randomized design with one factor, namely the time of nitrogen fertilization with six levels, namely: third at planting + third at 4-5 WAE + third at 70-80 DAP; third at planting + 2/3 at 4-5 WAE; 2/3 at 4-5 WAE + 1/3 at 70-80 DAP; 1/4 001at planting + 1/2 at 4-5 WAE + 1/4 at 70-80 DAP; 1/2 at 4-5 WAE + 1/2 at 70-80 DAP; and full at 4-5 WAE. The variety used was the Jibat variety which was grown at a rate of 25 kg.ha^{-1}. Experimental plot measuring 4.5 x 5 m (22.5 m2), with 6 rows with a spacing of 0.75 m and a length of 5 m. The distance between plot and replication was 0.5 m and 1 m, respectively. Soil management is carried out by reading and leveling the soil. Basic fertilization using Triple superphosphate fertilizer 69 kg per hectare. Meanwhile, nitrogen fertilizer with urea was applied according to the treatment of this study. After two weeks after planting, the plants were thinned. Weeding by hand was carried out three times. When the leaves, stems, and cobs have dried completely from the net area, harvesting is done manually in mid-December 2018 (fourth innermost middle row).

Before planting, a composite soil sample was obtained from the experimental field at 0-20 cm depth. The soil texture, available P, pH, SOC, and CEC were all assessed after the sample was air-dried and processed to pass a 2 mm sieve. The SOC and N were determined using a 1 mm sieve. The Bouyoucos hydrometer method was used to examine the texture of the soil (Day 1965). Olsen et al. (1954) described a technique for extracting available P with a sodium bicarbonate solution). The pH of the soil was assessed using a pH meter potentiometrically in a 1:2.5 soil: water mixture and organic carbon were determined using the Walkley and Black wet oxidation method. The Ammonium Acetate technique was used to determine Cation Exchange Capacity (CEC).

The observational variables of plant height (m), cob height (cm), root fall, stem fall, above ground, and seed yield were collected from five plants selected at random from each plot, excluding boundaries, to collect characters that contribute to yields and yields such as plant height (m), cob height (cm), root fall, stem fall, above the ground, and grain yield. The research data were analyzed using the SAS statistical software's general linear model (GLM) technique. If the effect is real, then further test is carried out with the Tukey test with 95% confidence.

RESULTS AND DISCUSSION

Physical and chemical properties of the soil before planting

Composite soil samples (0-20 cm depth) were taken diagonally from five locations in each replication and tested for selected physicochemical parameters. According to the findings, the experimental site had Nitisol soil, the clay component predominating in texture. The research soil contained 21.5% sand, 19.5% silt, and 19.5% clay (Table 1). Based on the triangle, the soil texture class at the research site is determined to be clay. A high clay concentration indicates that the soil has high water and nutrient retention capabilities. Based on the study's results, the soil organic matter in the research area was 2.88% and was classified as low (Table 1). The organic matter content of 2-3 percent is low (Hong et al. 2019). The content of organic matter is low, and the absorption of plant nutrients will be low. This is due to organic matter as a basic measure of fertility status, water holding capacity, nutrient release, and soil structure. The addition of organic fertilizers regularly is very important because the application of organic fertilizers can increase the organic matter content of the soil (Luo et al. 2022).

The testing site's soil response (pH) was 5.29, which Liu et al. (2021) classified as mildly acidic, with neutral soil ranging from 6.73 to 7.3. According to Yang et al. (2021), most crops and productive soils favor pH ranges between 4 and 8. As a result, the pH of the experimental soil was within the product range. Kang et al. (2021) considered 0.25 percent of total nitrogen in the soil to be high.

The soil samples were found to have a low level of total N (0.17 percent) according to this classification (Table 1), indicating that the nutrient is a limiting factor for optimal crop growth. Because maize is a nitrogen-hungry crop, N shortage significantly impacts its yield potential (Žurovec et al. 2021). The soil samples were found to have a low level of total N (0.17 percent) according to this classification (Table 1), indicating that the nutrient is a limiting factor for optimal crop growth. Because maize is a nitrogen-hungry crop, N shortage has a significant impact on its yield potential (Scarlett et al. 2021).

The cation exchange capacity (CEC) of soil reveals the type of clay mineral present in the soil and its ability to hold nutrients against leaching. Topsoils with a CEC of more than 40 cmol (+) kg^{-1} are classified as very high, while those with a CEC of 25-40 cmol (+) kg^{-1} are classified as high, according to Bernard et al. (2021). Thus, the soil at the experimental site had a high CEC (29.66cmol (+) kg^{-1} soil) according to this classification (Table 1). The cation exchange capacity (CEC) of soil describes its potential fertility and reveals the soil texture, organic matter content, and prevalent clay mineral types. CEC-rich soils are generally thought to be agriculturally fruitful.

Plant height

The time of nitrogen fertilizer administration had a significant (P 0.001) effect on plant height, according to the combined analysis of variance (Table 2). The highest plant height (240 cm) was observed when nitrogen was applied 2/3 at 4-5 WAE and 1/3 at 70-80 DAP, whereas the lowest plant height (201 cm) was observed when nitrogen was applied 1/3 at planting and 2/3 at 4-5 WAE, which was statistically equivalent to nitrogen application 1/3 at planting, 1/3 at 4-5 WAE, and 1/3 at 70-80 DAP. The results showed that applying nitrogen 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling) enhanced plant height by 9.2% over-applying nitrogen full at 4-5 WAE (knee height), however applying nitrogen 1/3 at planting and 2/3 at 4-5 WAE lowered plant height by 7.8%. (Table 2). This indicated that applying nitrogen fertilizer in two stages, 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling), was more beneficial than the other treatments in boosting plant height. This could be due to nitrogen application at the right moment, enhancing N availability to the plant. This result is consistent with that of Lu et al. (2021), who found that the rate and timing of nitrogen treatment substantially impacted maize plant height. Late nitrogen fertilization during crop flowering may be important to optimize maize agronomic performance (Lago et al. 2021; Redondo-Gómez et al. 2021; Wang et al. 2021).

Cob Length

The timing of nitrogen fertilizer administration had a substantial (P 0.001) effect on cob length, according to the combined analysis of variance (Table-2). When nitrogen was applied 2/3 at 4-5 WAE and 1/3 at 70-80 DAP, the highest cob length (127 cm) was recorded, while the lowest cob length (102 cm) was found when nitrogen was applied 1/3 at planting and 2/3 at 4-5 WAE. Applying nitrogen 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling) increased cob length by 11.8 % over-application of nitrogen all at 4-5 WAE (knee height), whereas applying 1/3 at planting and 2/3 at 4-5 WAE decreased cob length by 8.9 % compared to the application of full at 4-5 WAE (knee height) (Table 3). This might be due to synchronized nutrient demand with plant uptake, supplying more nitrogen to the plant. More nitrogen may be attributed to better vegetative development that increased internodal extension, which increased the cob length. This finding is backed by Grujcic et al. (2021) who found that when nitrogen levels increased, maize plant height and cob length increased.

Above-ground biomass or stover yield

The time of nitrogen fertilizer application had a substantial (P 0.001) impact on biological yield, according to the combined analysis of variance (Table-3). The highest biological yield (18891kg) was obtained when nitrogen was applied 2/3 at 4-5 WAE and 1/3 at 70-80 DAP. During vegetative growth, maize can accumulate luxury nitrogen over what is required for biomass accumulation. While the lowest biological yield (9645kg) was obtained when nitrogen was applied 1/3 at planting and 2/3 at 4-5 WAE, which was statistically equivalent to nitrogen being applied 1/3 at planting, 1/3 at 4-5 WAE, and 1/3 at 70-80 DAP. Application of nitrogen 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling) resulted in 26.7 % more biomass than the treatment with N applied full at 4-5 WAE (knee height), whereas applying nitrogen 1/3 at planting and 2/3 at 4-5 WAE resulted in 43.6 % less biological yield compared with the treatment, which was applied fully at 4-5 WAE (knee height). This could be because nitrogen fertilizer applied at the proper moment promotes vegetative development, which leads to higher biomass yield (Salem et al. 2021). The findings were consistent with those of Wan et al. (2021), who found that applying nitrogen fertilizer at the proper time and in the right amount increased wheat biomass production considerably.

Grain yield

The timing of nitrogen fertilizer application had a substantial (P 0.001) impact on grain yield, according to the combined analysis of variance (Table-3). The highest grain yield (6557kg) was obtained when nitrogen was applied 2/3 at 4-5 WAE and 1/3 at 70-80 DAP, whereas the lowest biological yield (3849kg) was obtained when nitrogen was applied 1/3 at planting and 2/3 at 4-5 WAE, which was statistically equivalent to nitrogen applied 1/3 at planting, 1/3 at 4-5 WAE, and 1/3 at 70-80 DAP. Application of nitrogen 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling) resulted in a 24.4 % yield increment than the treatment with N applied full at 4-5 WAE (knee height), whereas applying nitrogen 1/3 at planting and 2/3 at 4-5 WAE resulted in a 22.4 % yield reduction compared with the treatment, which was applied fully at 4-5 WAE (knee height). This might be because the application of nitrogen fertilizer at the right time could synchronize plant nutrient supply with plant nutrient demand and increase NUE, resulting in increased grain yield. As a result, the findings of Ma et al. (2021), who found that applying nitrogen fertilizer 1/4 at planting and 3/4 at knee height produced the maximum yield for late-maturing cultivars, were in conflict. This conclusion contrasts with Yue et al. (2021), who suggested that half of the total nitrogen demand be applied at sowing and the other half be applied as a top dressing at knee height.

Table 1. Before planting, the physical and chemical properties of Toke Kutaye and Liban Jawwe trial sites

Location	Particle size analysis (%)			pH	SOC (%)	CEC meq/100g	N (%)	P_2O_5 ppm
	Sand	Silt	Clay					
Liban jawwe	61.5	14.5	24	5.08	1.75	24	0.18	5.53
Toke kutaye	56.5	24.5	19	5.49	1.60	35.32	0.16	9.45

Note: SOC stands for organic carbon, TN is for total nitrogen, AVa P stands for total available phosphorus, and CEC stands for cation exchangeable capacity

Table 2. Effect of time of nitrogen fertilizer application on plant height and cob length of maize in 2018 and 2019 cropping season at Liban Jawi and Toke Kutaye districts

Time of nitrogen fertilizer application	Plant height (cm)	Cob length (cm)
1/3 at planting + 1/3 at 4-5 WAE + 1/3 at 70-80 DAP	206[c]	107[d]
1/3 at planting + 2/3 at 4-5 WAE	201[c]	102[e]
2/3 at 4-5 WAE + 1/3 at 70-80 DAP	240[a]	127[a]
1/4 at planting + 1/2 at 4-5 WAE + 1/4 at 70-80 DAP	216[b]	110[cd]
1/2 at 4-5 WAE + 1/2 at 70-80 DAP	220[b]	117[b]
All at 4-5 WAE	218[b]	112[c]

Note: Using the Tukey's test, means followed by different letters in columns are statistically significant at the 5% probability level and DAP stands for days after planting, WAE stands for weeks after emergency.

Table 3. Effect of time of nitrogen fertilizer application on biological yield and grain yield of maize in 2018 and 2019 cropping season at Liban Jawi and Toke Kutaye districts

Time of nitrogen fertilizer application	Biological yield ($kg.ha^{-1}$)	Grain yield ($kg.ha^{-1}$)
1/3 at planting + 1/3 at 4-5 WAE + 1/3 at 70-80 DAP	11089[c]	4146[c]
1/3 at planting + 2/3 at 4-5 WAE	9645[c]	3849[c]
2/3 at 4-5 WAE + 1/3 at 70-80 DAP	18891[a]	6557[a]
1/4 at planting + 1/2 at 4-5 WAE + 1/4 at 70-80 DAP	13345[b]	4766[b]
1/2 at 4-5 WAE + 1/2 at 70-80 DAP	13827[b]	5272[b]
All at 4-5 WAE	13853[b]	4959[b]

Note: Using the Tukey's test, means followed by different letters in columns are statistically significant at the 5% probability level

CONCLUSIONS

Based on the results of this study, it can be stated that a split nitrogen treatment of 2/3 at 4-5 WAE (knee height) and 1/3 at 70-80 DAP (before tasseling) resulted in a higher maize grain production in the study area. To maximize maize yield, a split application of nitrogen fertilizer at the above-specified period could be advised for Liban Jawi, Toke Kutaye, and other similar places

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