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Research Article

Enhancing maize yield in Ethiopia a meta-analysis

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Abstract

Accurate nitrogen (N) fertilization and optimum plant density increase crop yields. In this study, I report the effects of N fertilization rate and plant density on maize yield in a meta-analysis, by using observations from 15 studies conducted in Ethiopia since the 2000s for possible refinement of N fertilizer and plant density recommendations. I assessed the response of maize to different N rates ha^{-1} compared to the control using the yield response approach. Application of N fertilizer significantly increased maize yields by 31.5% - 65.9% compared to control. plant density increased maize yields by 42% - 72.4% compared to the control. The interaction effect of the N rate increased maize yields by 27.6% - 95.9%, with Plant density, 58.7% - 152% on loam soil, compared to control yield. The interaction effect of Plant density with soil type increased maize yields by 47% - 108% on loam soil.

In conclusion, the grain yield of maize increased with increasing N rate and plant density up to the optimum. Therefore, it's possible to recommend using a high N rate with both low and medium plant density (< 45,000 plants ha^{-1}) and (45,000 to 65,000plants ha^{-1}) to harvest high grain yield.

Introduction

Planting population and fertilizer nutrients are two of the most critical agronomic methods used to enhance the yield of maize and the use of plant nutrients [1]. Nitrogen, which increased vegetative growth, development, and seed yield is considered a fundamental nutrient for maize crops [2]. To attain a higher kernel yield application of a large amount of nitrogen is very important [3]. Even though the use of chemical fertilizer is one of the most important methods to improve the yield of maize, overuse of N fertilizer causes a reduction in maize yield and NUE [4].

Maize kernel yield can be increased by increasing the planting population and applying optimum nitrogen utilization which was essential agronomic practice, so optimizing fertilizer management throughout the maize growth period reduces N-input and increase kernel yield [5]. Factors that determine the yield output of maize in Ethiopia were: declining productivity of the soil, poor management practice, scarcity of agronomic inputs, lacking technological invention, and seed quality problems, mostly limiting the yield of maize significantly [6,7]. The fertilizer recommendation and plant population in Ethiopia were determined based on the environmental condition suitable for maize production. But the N needs and planting population was not well determined [7].

At present, the single crop fertilizer advice for all crops was common in Ethiopia. It depends on the general plant-specific guideline, that is single advice for all crops 100 kg DAP and 100 kg Urea. Such type of advice often disappoints to concern alterations in resource endowment, hence frightening farmers from fertilizer utilization. Additionally, the blanket advice of fertilizers and sustainable utilization will deplete nutrients in the soil. So, both yields and returns cannot be continued by applying an unfair fertilizer, as the practice outcomes in

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accelerating shortages of other nutrients in the soil. Then, the lack of one or more plant nutrients can lower the yield of a crop considerably [8].

Nutrient and planting density highly alter the maize crop yield, because maize has no tillering ability to regulate the number of plants [1]. Both low and excessive density decreases the yield, hence yield increases by enhancing plant population to the optimum for maize crop genotype produced in a given maize production environment and agronomic practices [9]. The plant population density responds better than the N rate in all maize agronomic attributes. Plant density mostly affects yield components like ear length and both Stover and maize kernel. But most maize agronomic attributes were not affected by the nitrogen level. According to Jiang, by using the combination of the highest plant population and nitrogen level, the highest kernel yield was produced [10]. Thus, the combined application of higher plant density and optimum fertilizer rate produced better kernel yield and were initiated to be most reasonably beneficial. In Ethiopia, the amount of fertilizer utilized is exceptionally low conjointly, and the yield obtained is additionally very low [8].

Maize could be a vital high-yielding crop grown over the world [11]. Maize production depends on the correct agronomic practice and the right application of production inputs like fertilizer and improved seeds to sustain the environment and production. Plant density and spacing of rows are the finest management practice that had important considerations during optimizing kernel and Stover [12]. In every production method, there is a plant density that manipulates the utilization of accessible supplies, letting the manifestation of achievable maize yield in a given ecosystem. The Stover and kernel yield of maize was mainly affected by plant density [7]. Nitrogen is considered a major plant nutrient for maize, which increased vegetative development and kernel profit. The use of optimum N is essential to attain higher kernel yields [3], thus, the purpose of this meta-analysis is to discuss an overview of the plant density and N rate which determine the target maize Stover and economic yield, to describe the consequences of plant density and N rate on yield description and distinguish the variations of plant attributes that had supported to enhance maize adaptation to elevated crop density and optimum N rate due to achieving the following objective: 1) To identify the best crop density. 2) To identify the right N rate.

Materials and methods

Data selection and database

The data used in this meta-analysis were gathered from the scores of scientific research trials on maize yield response to nitrogen fertilizer, and plant density conducted in Ethiopia. We explored relevant peer-reviewed publications from 2000 to 2020 in international journals using Google Scholar, Science Direct, and Web of Science. The studies linked to N rate, plant density, and their combinations were searched with keywords ''maize grain yield, nitrogen application rate, soil texture, rainfed, seasonal rainfall, maize varieties, temperature, OC and Ethiopia.'' Data in figure form were digitized using the Getdata v2.22 software (http://getdata-graph-digitizer.com/).

To attain the indicated aims, we narrowed the explore items by choosing studies that encounter the following criteria: (i) the attention had to be on nitrogen rate from chemical fertilizer, (ii) studies reported on plant density per hectare or it may be given by the distance between plant and row, (iii) analyses stated on at least one of the application of N rate and plant density, (iv) findings provided sample size for treatments and, lastly, (v) data that had been used in numerous publications were analyzed only once.

This method chose 15 studies that contain 244 applicable observations for the meta-analysis. It includes 15 findings with 244 observations for N, 14 findings with 225 observations for plant density, and 14 findings with 210 observations for their interactions. The observations were invented from Ethiopia. 93% of the observations were from interactions and 100% of observations were from N rate (Table 1). We made a database with four components, nitrogen rate (NR), plant density, other factors, and their interactions.

To explore the factors possibly determining the effect of N fertilization on maize yield, a categorical analysis was then conducted. We selected seven possible factors to refer to N rates, agronomies (plant density and maize variety), soil properties (soil organic carbon SOC, texture, and pH), and climates (mean annual precipitation (MAP)).

Categorization and explanation

The N rate was categorized into three: Low N rate (< 30 kg ha^{-1}), medium (30 - 100 kg ha^{-1}), and high N rate (> 100 kg ha^{-1}) [13]. The mean value of low N rate was 18kg ha^{-1}, for medium (67kg ha^{-1}) and high N rate (124kg ha^{-1}). Plant density was classified into three categories: "low plant density (< 45,000 plants ha^{-1}), medium plant density (45,000 - 65,000 plants ha^{-1}), and high plant density (> 65,000 plants ha^{-1})". The mean plant density for low, medium and high density was 43884, 52,933, and 70,085 plants ha^{-1}, respectively. The maize varieties used in this meta-analysis were different, BH-140, BH-540, BH-546, and BH-660. The SOC used was classified into three categories: low (0.6 - 1%), Medium (1 - 1.8%), and high (1.8 - 3%) SOC [14]. MAP was categorized into three categories: low (<600mm), medium (600-1000mm), and high (> 1000mm) MAP [13]. No data was observed under low rainfall areas for maize production in Ethiopia. The MAT (mean annual temperature) is too narrow in my studies, therefore, I could not consider it in my work.

The soil texture was classified into three groups. It was categorized based on its percentage of clay content. Sandy soil was soil that contains (<20% clay) while loam soil contains (20 – 32% clay) and clay soil was soil that contains (> 32% clay content) [15]. There was no data for maize production in soil category 1(< 20% clay content) in Ethiopia under this study. Soil pH used was classified into three categories: acidic (< 6.5), neutral (6.5 - 7.3), and alkaline (> 7.3) [14].

To evaluate the effects of all factors, the data were additionally classified into two pairwise comparisons for treatment and control within each study. control is data from experiments without any N fertilizer.

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Table 1: Designated findings for the meta-analysis, screening details on publication, plant density pH, SOC, MAP, maize variety, soil type and N rates in Ethiopia.

References	Density (plants ha^{-1})	pH	SOC (%)	MAP (mm)	Maize Variety	Soil type	N rates (kg ha^{-1})
[9]	33,333, 44,444, 66666	5.01	0.88	1598	BH-546	clay	23, 46, 69, 92, 115
[6]	44,444	5.05	/	1431	/	clay	46, 69, 92, 115
(Tolera A. et al. 2019)	44,444	5.4	2.53	1279	/	loam	55, 110
[28]	53,333	6.6	0.77	971	/	loam	30, 60, 90, 120
[32]	44,444			720	/	/	3.6, 64, 67.6
[33]	47,619	/	/	/	/	clay	30, 60, 90, 200
[8]	44,444	5.8	1.43	1243	BH-546	clay	46, 92, 138, 176, 222
[34]	53,333	/	/	1750	/	clay	23, 46, 69, 92
(Geremew Taye, 2015)	44,444	5.04	3.05	1400	BH-660	loam	16, 50, 104, 200.5
[35]	53,333	7.42	2.3	877	/	loam	16.8, 34, 52.6, 64
[36]	53,333	7.7	1.24	961.2	BH-140	loam	23, 46, 69, 92, 115
[25]	53,333	/	/	/	/	/	86.6,89.9,91.1,90.4, 90.6
[37]	/	/	0.64	1000	/	loam	23, 46, 69, 97.5,130
[38]	41,666	6.5	1.72	1085	BH-540	clay	30, 60, 90
[39]	53,333	6.27	2.64	1559	BH-140	clay	75, 116.5

Meta-analysis

The natural log of the response ratio (ln) was employed to quantify the effect of N fertilization on maize yield using the following equation [16]:

$$LnRR = \ln (Y_t/Y_c) \text{ .... (Formula 1)}$$

where Y_t and Y_c represent the mean yield in treatments (N fertilization) and controls (zero N input), respectively, for a given group (i.e., N rate, plant density, maize varieties, soil SOC, annual precipitation). The grouped effect size was unweighted.

The average effect size for each categorical variable was calculated with bias-corrected 95% confidence intervals generated by the bootstrapping procedure in SPSS software by using 4999 repetitions. The effect of N fertilization on maize yield was considered significant if the 95% CI did not overlap with zero. Means of categorical variables were considered significant if their 95% confidence intervals did not overlap each other. The results were back-transformed and reported as the percentage change of yield of the treatment relative to the control. A positive percentage change indicated that N fertilization increased yield.

The maximum yield gain was obtained under the higher N rate (> 100 kg ha^{-1}), with 65.9% higher than control (zero N input), followed by medium N rate (30-100 kg ha^{-1}, 52.6%) and lower N rate (<30 kg ha^{-1}, 31.5%) (Figure 1a).

The highest yield gain was generated under medium plant density (45,000-65000 plants ha^{-1}), with 72.5% higher than control, followed by lower plant density (<45000 plants ha^{-1}, 42.1%) and higher plant density (> 65,000plants ha^{-1}, 37.7%) (Figure 1b).

The highest maize yield gain was produced by (BH-660) maize variety that scored 108.2% higher than the control and significant to (BH-546). BH-140 maize variety was 90.1% higher than the control treatment and significantly different from BH-546. It was followed by BH-540 which was 86.5%, and BH-546 was 36.3% higher than the control, respectively (Figure 1c).

The largest yield gain occurred on moderate SOC (1 - 1.8%) with 72.85% higher yield, followed by lower SOC (0.6 - 1%). The lower SOC (0.6-1%) was 68.2% higher than the control yield (Figure 1d).

The largest yield gain was generated on moderate alkaline soil (pH 7.4 - 8.4) with a 57.5% higher yield than control, followed by neutral soil (pH 6.6 - 7.3) and acidic soil (pH 3 - 6.5) that produced 48.4% and 48.1% higher yield than the control, respectively (Figure 1e).

The greater yield gain was observed on loam soil, with a 90.5% higher yield than control, which was significantly higher than clay soil (67.2%) (Figure 1f).

There are similar yield gains in the high rainfall region (MAP > 1000mm) and in the medium rainfall region (MAP 600-1000mm), with 55.7% and 55.1% higher yields than control, respectively (Figure 1g).

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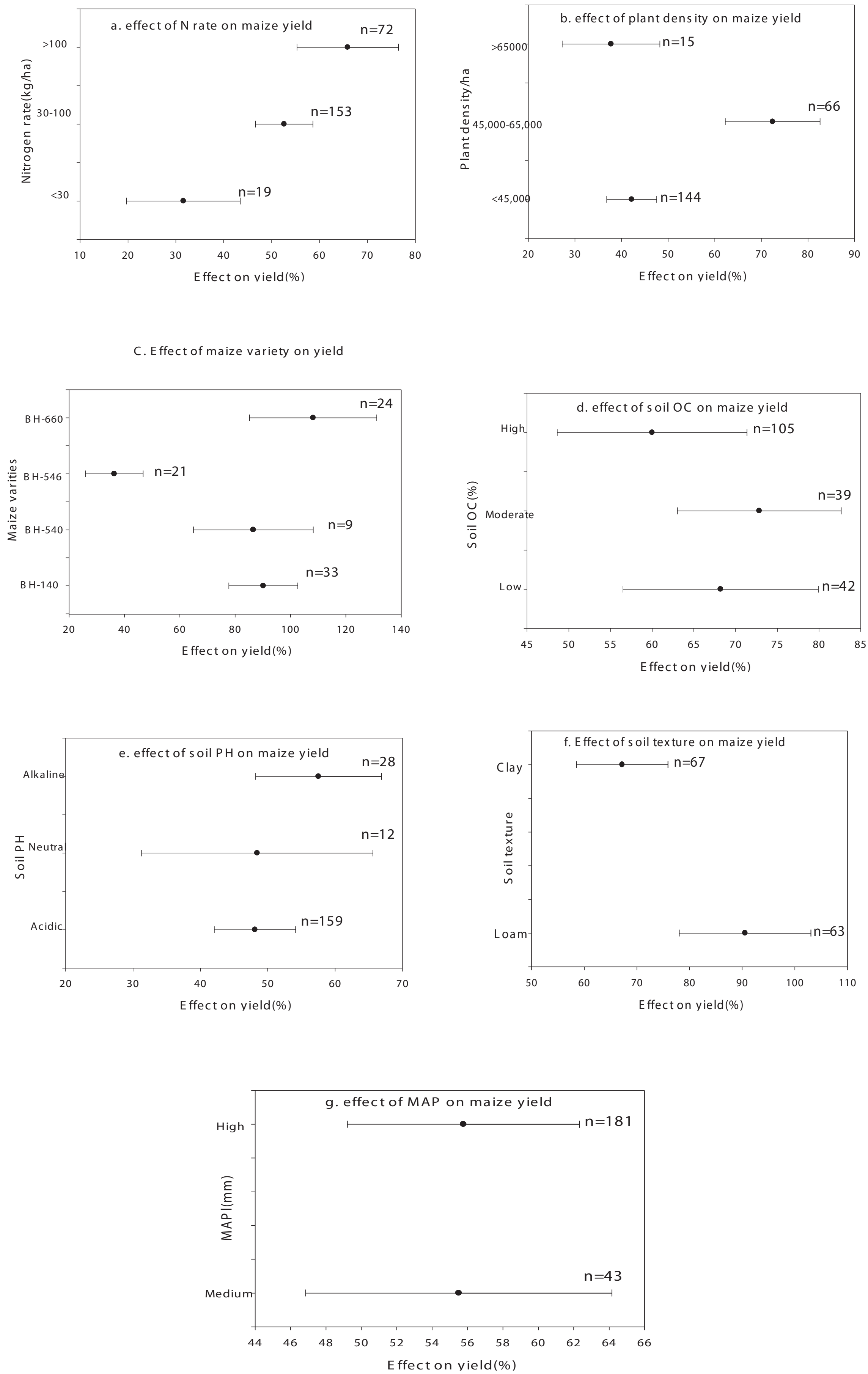

Figure 1: Maize yield response to N, density, maize variety, OC, pH, soil texture and rainfall.

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Appropriate N rate

The highest yield gain under loam soil type-N rate interaction was 152.1% higher than the control and shows a significant difference in this soil type under a high N rate (> 100kg ha^{-1}), followed by a medium N rate (30 - 100kg ha^{-1}), 75.6%, and low N rate (<30kg ha^{-1}) 58.7%, higher than the control yield respectively (Figure 2a).

The highest yield gain under clay soil type-N rate interaction was 78.6% higher than the control under a higher N rate, followed by a medium N rate, 74.9% higher than the control. The higher and medium N rates interactions with clay soil type were statistically higher than the low N rate. The low N rate was 11.3% higher than the control yield (Figure 2a).

The maize yield response to medium mean annual precipitation(MAP) (600-1000mm), under the higher N rate (> 100kg ha^{-1}) was 71.7% higher than the control and significantly different from the low N rate (<30kg ha^{-1}), followed by medium N rate (30-100kg ha^{-1}), 59.4%, significantly different from low N rate (<30kg ha^{-1}) and the yield response of low N rate (<30kg ha^{-1}) was 28.28% higher than the control yield (Figure 2b).

The highest maize yield response to high MAP (> 1000mm) was scored under the higher N rate (> 100kg ha^{-1}), It was significantly different from the low N rate (<30kg ha^{-1}) and 65.5% higher than the control yield, followed by, medium N rate (30-100kg ha^{-1}). It was 51.3% higher than the control and the low N rate (<30kg ha^{-1}), which also scored 43.6% higher than the control yield (Figure 2b).

Appropriate plant density

The yield response to plant density-loam soil type interaction under low plant density (<45,000plants ha^{-1}) was 108.2% higher than the control and shows a significant difference from medium (45000 - 65,000) plant density. Medium plant density (45000 - 65,000), was 47.5% higher than the control under this soil type (Figure 2c).

The highest yield response under the plant density-clay soil type interaction observed under medium plant density (45,000 -65,000plants ha^{-1}) was 85.2% higher than the control and significantly different from both lower and higher plant density. Low plant density (<45,000plants ha^{-1}) was 52.4% higher than the control and the higher plant density (> 65,000plants ha^{-1}) was 34.5% higher than control (Figure 2c).

The maize yield response to medium MAP (600 - 1000mm) was scored under the lower plant density (< 45,000plants ha^{-1}), which was 90.1% higher than the control, followed by medium plant density (45,000 - 65,000plants ha^{-1}), 54.64%, higher than the control yield respectively and there was no data for high plant density with low rainfall interaction (Figure 2d).

The highest maize yield response to high MAP (> 1000mm) was scored under the medium plant density (45,000 - 65,000plants ha^{-1}), 151.7% higher than the control yield, which was significantly different from both low and high plant density. It was followed by low plant density (< 45,000plants ha^{-1}), and 42.2% higher than the control yield (Figure 2d).

Interactive effects between N rate and plant density

Under a low N rate, the yield gain in medium plant density (27.6%) was slightly higher than in low plant density (22.6%). While under both medium and high N rates, yield gains in medium plant density (74.9% and 95.9%) were greatly higher than low plant density (37.5% and 52.3%). It suggests that higher yield gain tends to be generated with a higher N rate combined with higher plant density (Figure 2e).

Discussion

Nitrogen is needed for the optimum yield of cereal crops [17-19]. Maize is the greatest productive cereal crop in Ethiopia. However, its present productivity is less than its potential productivity, and the N rate is one of the most factors limiting maize productivity [6]. Without increased soil fertility, increases in crop yields would have been impossible in Ethiopia. As seen from the yield result, the highest maize yield in Ethiopia was observed under the higher N rate (> 100kg ha^{-1}) which was 65.9% higher than the control and significantly increased maize yield than other N rates. It was followed by a medium N rate (30 - 100kg ha^{-1}) which was significantly higher than the lower N rate (<30kg ha^{-1}) and 52.6% higher than the control. The lower N rate (<30kg ha^{-1}), was 31.5% higher than the control yield (Figure 1a). Increasing the N application rate which is a key element for maize yield is an important way to attain high grain yield [5]. In another way, over-fertilization increases grain yield, however, it has a negative effect on the environment, reducing N efficiency (NUE), and increasing costs. To realize the aim of sustainable agriculture, refining the fertilizer application, particularly with higher N efficiency, is one of the essential strategies [5,17].

Response of maize yield to plant density

The highest maize yield response was observed under medium plant density (45,000 - 65000plants ha^{-1}) which was 72.4% higher than the control treatment and significantly different from both higher plant density (> 65,000plants ha^{-1}) and lower plant density (< 45,000plants ha^{-1}), followed by lower plant density (< 45000plants ha^{-1}), 42.1% and higher plant density (> 65,000plants ha^{-1}), 37.7% higher grain yield than the control respectively (Figure 1b). As the result indicates there was a high yield difference which was in agreement with [20]. Even though as plant density increases, yield also increases, when plant density exceeds the optimum level, grain yield tends to decline due to competition for nutrients, space, and water [10], and also increased plant density increases the susceptibility of the crop to lodging and disease [21].

Response of yield to maize variety

The maize yield productivity could be enhanced by producing a new variety with high yielding performance, under suitable conditions and use of the optimum quantity of nutrients at a right time [19]. Maize grain yield increases with enhancing plant population only up to the optimum, however recently there was various types of maize that can tolerate high plant population not only with a high N rate but also with a low N rate [22]. Maize varieties respond to nitrogen rate and plant density by changing in grain yield and phenological period that reflects different responses [23].

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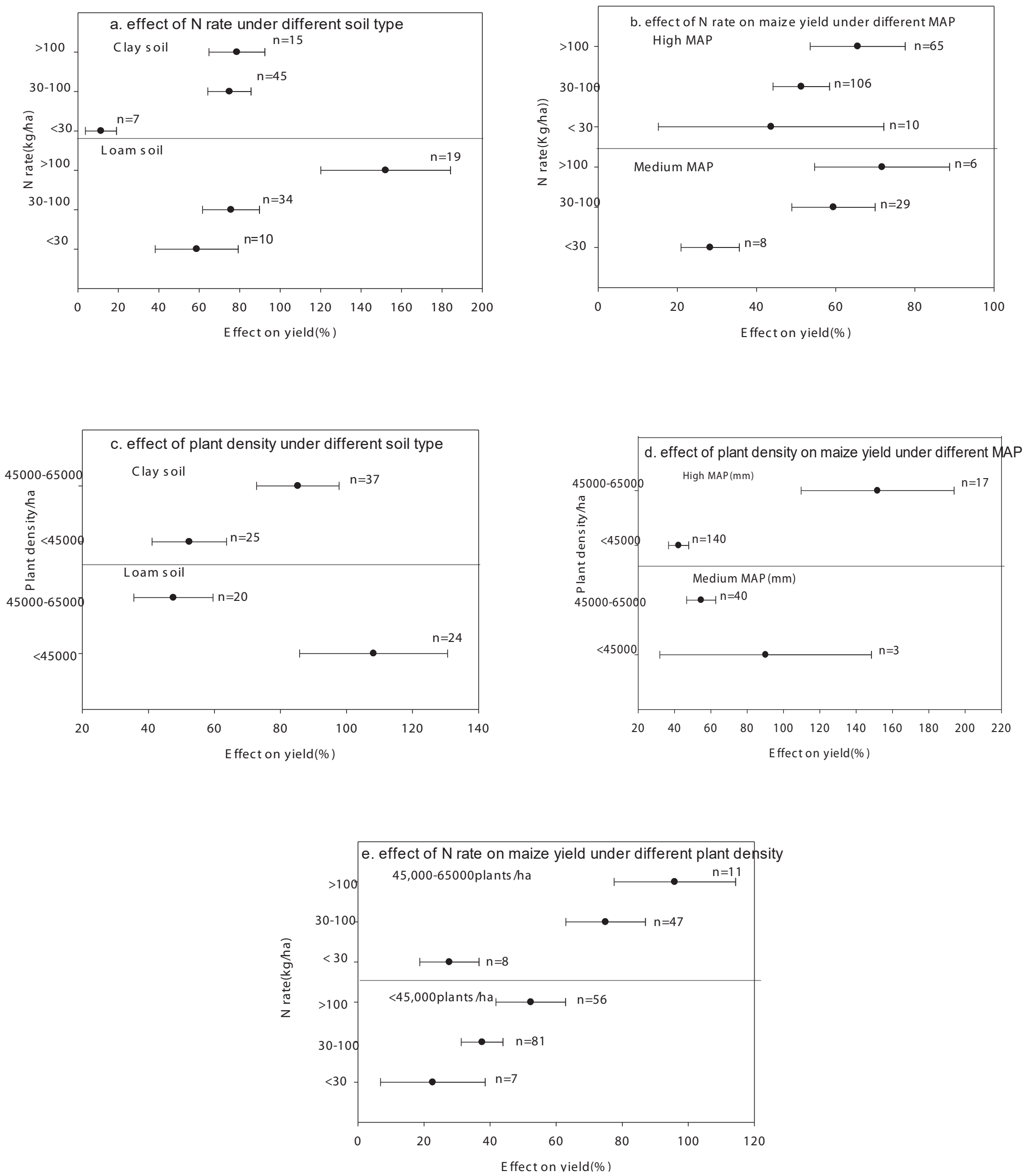

Figure 2: Maize yield response to the interaction of N rates, soil types, rainfall and plant density.

The highest maize yield response was produced by (BH-660) scored 108.2% higher than the control and significant to (BH-546). (BH-140 and BH-540) maize variety is also significantly different from (BH-546). They were 90.1%, 86.5%, and 36.3% higher than the control respectively (Figure 1c).

Investigating the NUE of maize hybrids aids to know the rate of N used in relation to crop N requests. Therefore, for sustainable maize production, the identification of varieties with better N efficiency has a great role for smallholders [24,25]. It also reduces the expense to buy fertilizer and releasing it into the environment and causes pollution.

Response of maize yield to N rate under different soil organic carbon

Soil organic carbon modifies the structure of the soil and makes a conducive environment for plant roots and increases crop yield [26]. The highest maize yield response to OC in Ethiopia was scored under moderate soil organic carbon (1 - 1.8%). It was 72.8% higher than the control. The higher and lower SOC Scored 60% and 68.2% higher yields than the control (Figure 1d).

Maize yield response to pH in Ethiopia

The highest maize yield response to soil pH under alkaline soil (7.4 - 8.4), scored higher yield which was 57.5% higher than the control, followed by neutral soil with a pH value of (6.6 - 7.3), 48.4% higher than the control, and acidic soil pH (4.5 - 6.5) produced 48.1% higher grain yield than the control (Figure 1e).

Maize yield response to soil texture in Ethiopia

Soil fertility is reduced by natural and human-making factors from time to time, which is a severe problem for crop production. Thus, this problem can be solved by the utilization

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of balanced recommended fertilizer levels depending on soil and crop variety [27]. The N fertilizer rate recommendation for crops depends on crop variety and soil fertility [28], thus, N fertilization improves maize grain yield by enhancing the number of ears, total grain, and enhancing mean ear weight [28]. In this meta-analysis results, the highest maize yield response to soil type was observed under loam soil, which was 90.5% higher than the control and significantly different from clay soil. Clay soil is 47.2% higher than the control (Figure 1f).

Maize yield response to precipitation in Ethiopia

Crops are sensitive to shortage of water, especially during their critical period which was statistically affected by the variability of rainfall [29]. The maize yield response to rainfall was almost the same under both high rainfall areas, which was 55.7% higher than the control and 55.5% under medium rainfall areas. There was no difference between the two areas in maize yield (Figure 1g). However, maize is sensitive to shortage of water during its critical period) [30] and in high MAP areas, N is lost by leaching and run- off which has a great influence on the N rate i.e., the applied N is not absorbed by the crop because of the leaching effect in this area [6]. It is possible to increase and stabilize maize yield by utilizing irrigation when a water deficit occurs.

The interaction affects nitrogen, plant density, soil, and climates

There is a positive yield response to nitrogen level and plant population (Figures 1a and b). The maize yield was enhanced considerably as the N rate increased up to the optimum level, and as plant density increases the yield increases with it. But the optimum N rate and plant population were not well determined in Ethiopia. This result agrees with [31], that maize kernel yield is enhanced by increasing both N level and crop population. Plant population and nitrogen are the greatest prominent factors for corn production as it has no tillering ability to fine-tune available area and its high receptiveness to available nutrients. Therefore, enhancing these factors to the optimum levels considerably enhances the kernel yield [31]. As the result indicates, low plant density (< 45,000plants ha^{-1}), gives a higher yield under a high N rate (> 100kg ha^{-1}) which was considerably dissimilar to a low N rate. Medium plant density (45,000 - 65,000plants ha^{-1}) also produces higher yield under high N rate (> 100kg ha^{-1}) (Figure 2e). This indicates that the yield of maize increased with the N rate and to achieve a higher yield, improving the application of N fertilizer is essential.

The response of plant density and N rate under different soil types

As the result indicates, low plant density (45,000plants ha^{-1}) gives a higher yield under a high N rate (> 100kg ha^{-1}) on loam soil, and the medium plant density (45,000 - 65,000plants ha^{-1}) also gives a higher yield under high N rate (> 100kg ha^{-1}) on clay soil. Therefore, as the given result indicates, it's recommended to use a high N rate for both low and medium plant density in both soil categories (Figure 2a, c, and e).

The response of plant density and N rate under different precipitation

The low plant density (<45,000plants ha^{-1}) gives a higher yield with a high N rate (> 100kg ha^{-1}) under medium MAP (600-1000mm) due to competition for water, whereas the medium plant density (45,000-65,000plants ha^{-1}) gives higher yield with high N rate (> 100kg ha^{-1}) under high MAP areas (> 1000mm). Therefore, it's better to use low plant density with a high N rate (> 100kg ha^{-1}) under medium MAP (600 - 1000mm) due to competition for water, and medium plant density (45,000 - 65,000plants ha^{-1}) with a high N rate (> 100kg ha^{-1}) under high MAP areas because plant nutrients probably lost by leaching and surface runoff (Figure 2b, d, and e).

Maize is an important food and animal feed, especially in Ethiopia where maize provides about one-third of the country's caloric intake. However, the low yield seriously restricts the sustainable development of the corn industry in the country. To obtain higher maize yields, it is necessary to increase nitrogen fertilizer application. However, there are huge variations in the nitrogen fertilizer effect in the Ethiopian region, and the supply of nitrogen fertilizer is also seriously insufficient, so the rational application of nitrogen fertilizer and the search for suitable organic fertilizer sources are important issues at present.

The yield of maize was improved by altering plant density and nitrogen level due to the mobile nature of N. Hence, by modifying these two factors the maize yield can be enhanced significantly. The grain yield of maize increased with increasing N rate and plant density up to the optimum. Therefore, it's possible to recommend using medium plant density with a high N rate in the clay soil category to harvest high grain yield. In the other cases it's better to use low plant density with a high N rate (> 100kg ha^{-1}) under medium rainfall (600-1000mm) due to competition for water, and medium plant density (45,000 - 65,000plants ha^{-1}) with high N rate (> 100kg ha^{-1}) under high rainfall areas because plant nutrients probably lost by leaching and surface runoff based on the result indicated.

Conclusion and recommendation

Nitrogen is the most reducing plant nutrient in all soil types in the smallholder parts of Ethiopia, because of the combination of naturally low soil nutrient content and crop nutrient removal. Thus, the highest economic yield response and economic profits are anticipated after the fertilizer is sewn into the soil for crop production. As the result indicates, the crop response depends on the amount of N fertilizer used, plant density, soil type, soil organic carbon, and agro-ecological conditions (MAP). This study confirmed that maize yield response to nitrogen utilization was commonly positive but, different N utilization levels, plant density, soil organic carbon, total rainfall received, soil type, and maize variety scored various results. The positive responses emphasize the position of N as a plant nutrient in maize production systems, plant density, and other related factors.

The yield of maize was improved by altering plant density and nitrogen level due to the mobile nature of N. Hence, by

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