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Effects of Integrated Use of Lime and Nitrogen Fertilizer Rate on Maize (*Zea mays* l.) Crop and Its Profitability on Nitisols, Ethiopia

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Abstract: In the highlands of Ethiopia soil acidity is the limiting factor for crop production due to leaching effects of basic cations, nutrient loss by erosion, crop residue removal from farmland and other human induced factors. This study was carried out at Burie *district* to determine the effect of integrated use of lime and nitrogen fertilizer rate on yield and yield components of Maize in acidic nitisols. The treatments include lime (0 and 0.5 t ha^{-1}) and nitrogen fertilizer (0, 100, 200, 300, and 400 kg ha^{-1}). To fulfill the law of minimum, 200 kg ha^{-1} die ammonium phosphate (DAP) which is recommended rate of NPS (19% N, 38% P_2O_5 and 7% S) fertilizer was used uniformly to all plots at the time of planting. The maize variety BH-661 was used as a test crop. The experiment was laid out in a randomized complete block design (RCBD) with ten treatments replicated three times. Yield and yield components of maize were collected and analyzed. The analysis of variance result revealed that, interaction effect of lime and N fertilizer reduced the tasseling period (88 days in the application of 0.5 t ha^{-1} lime with 100 kg ha^{-1} N to 85 days in combined use of 0.5 t ha^{-1} lime with 400 kg ha^{-1} N) and silking period from 91 days to 88 days. Grain yield was highly and positively correlated with AGDB (r=0.996) and HI (r=0.987). Grain yield of maize in the study area was increased from 5,550 kg ha^{-1} to 6,410.20 kg ha^{-1} (adjusted yield). Yield increment was 13.42%. The average maize yield in the region was 3,780 kg ha^{-1} but in the study area the adjusted yield was 6,410.20 kg ha^{-1}. As compared with regional maize yield it was increased by 40.3%. However, yield was highly and negatively correlated with DT (r=-0.957) and DS (r=-0.925). The maximum agronomic use efficiency of (3.76%) was from Treatment 10 (0.5 t ha^{-1} lime with 400 kg ha^{-1} N) than Treatment 7 (0.5 t ha^{-1} lime with 100 kg ha^{-1} N) of (3.16%). Based on the economic analysis, the net benefit value 47,701.04 Ethiopian Birr. Therefore, integrated application of 0.5 t ha^{-1} lime and 300 kg ha^{-1} Nitrogen fertilizer is economically reasonable and recommended to the farmers.

Keywords: Economical, Integrated, Liming, Yield, Optimum, Soil Acidity

1. Introduction

Maize (*Zea mays L.*) is a member of *Gramineae* family, and it was originated in America and first cultivated in the area of Mexico more than 7,000 years ago [1]. In world production, maize is ranked as the third major cereal crop after wheat and rice [2]. It is one of the most important food crops worldwide. It has the highest average yield per hectare and it is grown in most parts of the world over a wide range of environmental conditions [3].

Ethiopia is the fifth largest producer of maize in Africa and smallholder farmers make up 94% of the crop production [4]. Maize is cultivated in a wide range of altitudes, moisture

regimes, soil types, and terrains, mainly by smallholder crop producers. It is mainly produced in southern, western, central, and eastern regions of Ethiopia [5]. But specifically, the mid-altitude, sub-humid agro-ecology (1,000-1,800 m.a.s.l) is the most important maize producing environment in Ethiopia [6]. The popularity of maize in Ethiopia is partly because of its high value as a food crop as well as the growing demand for the straw as animal fodder and source of fuel for rural families [7]. Maize is used as human food (accounting for 62% of all household cereal consumption), as a source of cash income (accounting for about 54% of cash income), as fuel (about 25%), feed for livestock and industrial purposes [8]. Farmers consume maize by preparing different dishes, including bread, *injera*, thick porridge, boiled maize, roasted maize and local beer. Green cobs are also sold in big cities and towns [9]. The smallholder farmers' of Ethiopia owning 97% of the total maize land contribute 95% of the national maize production [10]. On the other hand, commercial farms owning only 3% of land contribute 5% of the total production. In the Amhara region, maize production accounts 519,495.71 ha^{-1} with productivity of 3.78 t ha^{-1}, while in west Gojjam it accounts 212,556.78 ha^{-1} with a productivity of 4.23 t ha^{-1}) [10].

Nitrogen is a key factor in achieving optimum grain yield. On the other hand, grain yield is the main target of crop production. Grain yield of maize is a product of three yields components, *i.e.* the number of ears per unit area, the number of grains per ear and the unit grain weight [11]. Increase or decrease in any one of these components, keeping the size of other components constant, contributes to increase or decrease in grain yield, respectively, and thus any exercise whether agronomic (management) or breeding type (genotype), which increase any of these components, keeping the other components constant, will increase the final grain yield. Devi and Muhammad [12] reported that ears per plant, ear length, number of kernels ear^{-1} and 1000 kernel weight directly influence the grain yield and indirectly affect several other parameters. Any kind of stress, for example a drought stress, during or around the stage at which these components are formed may severely affect grain yield. According to [13] grain yield was increased over control per kg N applied and time of N application in maize has been due to good synchrony if N is applied nearest to the time it is needed by the crop. Nitrogen fertilizer use has played a significant role in increase of crop yield. Yield reduction in maize due to N deficiency is more than of other elements deficiency [14]. Although maize is usually considered as energy food, it contains important quantity of protein.

The percentage of N in maize actually varies according to the supply of nitrogen to the crop (fertilizer plus soil), genetic characteristics of the hybrids, planting rate and weather conditions [15]. Nitrogen fertilizer application is required to optimize maize grain yields and tends to improve physical grain quality in maize by increasing kernel weight and protein concentration [15]. Jiban [16] reported that maximum nitrogenous fertilizer delays the senescence of leaves and increased succulence of plants therefore; physiological maturity was increased with increment in nitrogen level. Likewise, successive increment in nitrogen rate from 0 to 200 kg N ha^{-1} significantly increased maize grain yield [17]. The low productivity of maize is mainly attributed to many factors including frequent occurrence of drought, declining soil fertility [18], poor agronomic practice, and limited use of inputs, poor seed quality, disease, and pests [6]. Among these, declining soil fertility (due to continuous cultivation with low input) is a major limitation to crop production and productivity in smallholder farms in Ethiopia [8].

Agricultural liming material is the most common soil management practices whose addition to agricultural soil in moderate amounts may be beneficial as plant nutrients, minimize soil acidification [19]. The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P and Mo, availability, stimulate microbiological activity in the soil, and improve the physical structure of soil [20]. Although, the Amhara National Regional State (ANRS) especially Burie *district* is a potential area for maize production the productivity is generally low, which is attributed to several factors from thus factor soil erosion which cause leaching of basic cations leads to soil acidity and absence of integrated soil fertility management are mentioned. Thus, identifying effective use of integrated fertility management ways is needed to replenish the soil nutrients and increase grain yield of maize in the study area. Therefore, the objective of the present study was to determine the effects of integrated use of lime and nitrogen fertilizer rate on maize yield and yield components on the Nitisols of Burie area, Northwestern Ethiopia.

2. Materials and Methods

2.1. Research Site Location and Soil

The experiment was conducted in Burie *district*, West Gojjam Zone of Amhara National Regional State (ANRS) during the 2018/2019 main cropping season. The study site is located between latitude of 10°43'0" to 10°47'0" North and longitude of 37°3'0" to 37°6'0" East. It is located in the northwestern part of Ethiopia at a distance of 411 km from Addis Ababa and 148 km southwest of Bahir Dar city. The altitude of the Burie *district* ranges from 2087 to 2,637 m.a.s.l. The soil of the area is characteristically humic Nitisols (BWAO, 2019). In general, soils of the area are well-drained, clay in texture, and strongly acidic Nitisols in soil reaction (BWAO, 2019). The district has a total of 29,629 ha agricultural land from this 42.8% is covered by maize crop in the 2018/2019 crop production year (BWAO, 2019). The mean yield of maize from all varieties was 5.55 tha^{-1} which is low as compared with the production potential of the area. The experimental site was covered by wheat crop during the past cropping seasons. The recommended N and NPS fertilizers in the study area are 200 kg ha^{-1} N and 200 kg ha^{-1} NPS, respectively (BWAO, 2019). According to the Amhara Meteorological Agency report (2020), the mean annual rainfall of the District was 1375.8 mm and the mean

minimum, mean maximum and average air temperature of ten years (2010–2019) data in the study area was 12.31°C, 25.93°C, and 19.12°C (Figure 1). Summary of 10 years (2010-2019) mean annual rainfall and temperature data of study area is presented.
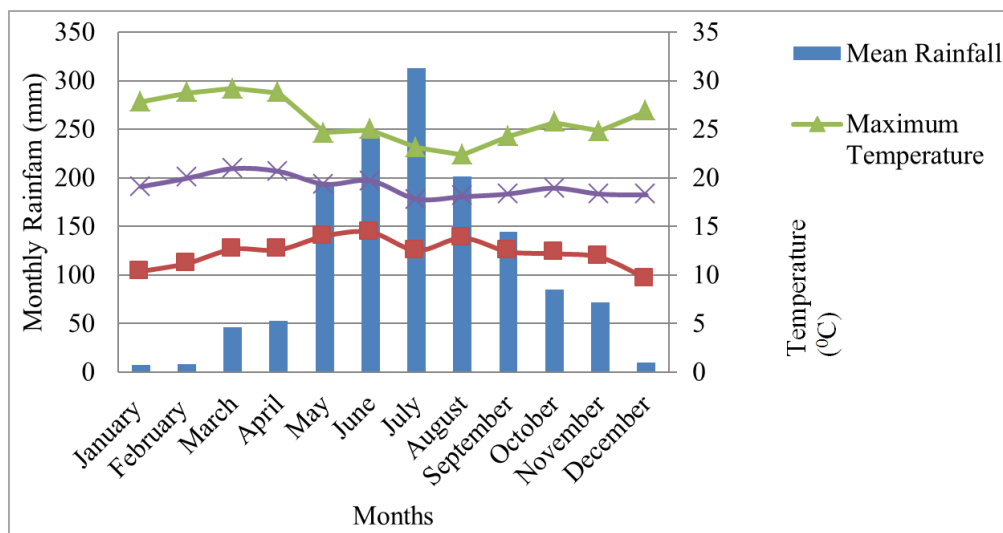

Figure 1. *Monthly rainfall (mm), minimum, maximum and average air temperature (°C) of the study area during 2010-2019.*

2.1.1. Experimental Materials Used

Plant, fertilizer and lime

The maize variety H-661 (Bako Hybrid-661) which is adapted to the agro-ecology and registered at the national level was collected from Amhara Seed Enterprise and used as a test crop. As a feretilizer urea (46% N) at five different levels (0, 100, 200, 300, and 400 kg ha^{-1}) was applied in one dose at knee height sage (Figure 4). This fertilizer was applied by banding at a distance 2 to 3 cm away from the plant and at 20 cm depth and covered immediately with soil. The recommended rate of NPS (19% N, 38% P_2O_5, and 7% S) fertilizer was uniformly applied to all plots at the time of planting.

Liming material in the form of calcium carbonate ($CaCO_3$) passed a 100-mesh was applied. According to Burie district Agricultural Office Manual (2019), there are two ways of lime application. First, during seed sowing (i.e row application) if the lime is a powder, and the secondis broadcasting application for granular type of lime. First, during seed sowing one fourth of the recommended rate of lime ((20 t ha^{-1}) which is 0.5 t ha^{-1} lime was applied using broadcasting application method. Broadcasting application is recommended to apply one or two months before seed sowing (BWAO, 2019). Lime was added as the district agricultural office manual, based on the soil pH of the experimental site. According to BWAO (2019) unpublished mannual, if the pH (H_2O) value of the soil is between 5.14 to 5.32, the recommended lime rate for broadcasting application method was 20 t ha^{-1}. For row application method, 0.5 t ha^{-1} of the recommended rate for broadcasting method was used (BWAO, 2019). Since the soil pH of experimental site was 5.20, the amount of lime rate added during maize sowing was 0.5 t ha^{-1}.

Treatments and experimental design

This experiment was laid out as a randomized complete block design (RCBD) with three replications and ten treatments. A total of 30 experimental plots were designed. Two factors was involved in the study, namely five levels of N (0, 100, 200, 300 and 400 kg ha^{-1} Nitrogen) and two level of lime (0 and 0.5 t ha^{-1}) to have a total of ten (10) treatments that were arranged in 5*2 factorial combinations replicated 3 times.

2.1.2. Application of Treatments and Field Management

The field was leveled and divided into three blocks which were lastly divided into 30 plots. The plots were leveled and ridges were prepared manually. Each gross plot had an area of 3.75 m × 3.5 m (13.125 m^2) and consists of 5 rows of 3.5 m length. The spacing between rows and between plants was 0.75 m and 0.25 m, respectively and the spacing between plots and blocks was 0.5 m and 1 m respectively. The treatments were assigned to each plot randomly.

2.2. Experimental Procedure

2.2.1. Fertilizer Application and Field Activities

The experimental plot was plowing by tractor and oxen. Accordingly, the field was plowed three times, the first plowing, was done in the first of April with disc plough. The second & final plowing was conducted by oxen driven local plow "*Maresha*" at first and last May and seeding or sowing was conducted as per the spacing of the treatment. The experimental field was hand weeded twice at 25 and 45 days after planting to control weeds. A late emerging weed was removed by hoeing to avoid interference with the maize plants for the N applied from NPS source. All other agronomic practices such as fertilization, hoeing, disease, insects and weeds management was as per the recommendation. Finally, maize plants in the central net plot

were harvested.

Figure 2. Field layout and maize planting.

Figure 3. 1ˢᵗ cultivation practice.

2.2.2. Collected data for Yield and Yield Components of Maize

The following phonological, yield and yield components of maize data were collected.

Days to 50% tasseling was recorded when more than 50 percent of the plants produced tassels in each plot. Days to 50% silking was recorded when more than 50 percent of the plants produced silks in each plot.

Days to 90% maturity was recorded as the number of days from emergence to the date on which about 90 percent of the plants in a plot matured (90% plants showed drying of cobs husk).

Plant height (cm): five plants were selected randomly from each net plot. Plant height was measured as the distance from the base of the plant to the height of the first tassel branch and average height was calculated.

Number of leaves per plant: Five plants were randomly selected from three central row of each net plot and counted and their average was worked out (Figure 6).

Number of cob per plant: Five plants were selected randomly and the total numbers of cobs were divided by the total number of plants harvested.

Number of grains per cob: five cobs in each net plot were randomly selected, and then number of grains in each cob were counted and averaged.

Thousands grain weight (g): Two samples of thousand grains had taken at random from each treatment then weighed by digital balance and average was recorded. The 1000 grain weights was weighed after testing seed moisture content by using seed moisture tester instrument at Ethiopia commodity exchange (ECX) office, Burie branch. The final dry weight of 1000 grains was computed using 12.5% as market standard seed moisture content of maize.

Grain yield (kg ha^{-1}): After sun drying, the cobs were threshed manually and yield was recorded on per plot basis, with moisture content 12.5 %, and then converted into kg ha^{-1}.

Above ground dry biomass yield (kg ha^{-1}): Plants from the net plot area were harvested at physiological maturity and weighed after sun drying.

Harvest index: was computed as the ratio of grain yield (GY) to the total above ground Dry-mass (DM) yield. Straw yield: was determined by subtracting grain yield from above ground dry biomass.

Figure 4. Maize at knee stage.

Figure 5. Research site as demonstration.

Figure 6. Silking and tasseling stage of maize.

Figure 7. Grain yield of maize.

2.3.2. Agronomic Use Efficiency

The NPS, nitrogen and lime fertilizer agronomic efficiency was calculated using the procedure described by [21] as Eq. (2):

$$AE\left(\frac{Kg}{kg}\right) = \frac{Gf(kg) - Gu(kg)}{Na(kg)}, \quad (2)$$

where; AE stands for agronomic efficiency, Gf and Gu for grain yield in fertilized and unfertilized plots, respectively, and Na for quantity of lime, urea and NPS fertilizer applied.

3. Results and Discussion

3.1. Effects of Nitrogen Fertilizer and Lime Level on Moropho-Phenological Parameters

Integrated use of lime and N fertilizer significantly (P ≤0.05) affected days to 50% tasselling of maize while significantly (P≤0.01) affected days to 50% silking (Table 1). Similar to days to tasselling, days to silking were delayed with N deficiency. Nitrogen fertilizer and lime interaction had highly significantly (P≤0.01) affected days to 90% maturity. This indicates that increasing the N rate significantly increased the number of days to physiological maturity.

2.3. Data Analysis

The collected data were computed by analysis of variance (ANOVA) using SAS statistical package program version 9.0 (SAS, 2004). All significant treatment means were compared using the least significant difference (LSD) test at 5% probability level. Pearson correlation analysis was used to determine the relationship between yield and yield components of maize.

2.3.1. Economic Analysis

The mean grain data was adjusted down by 90% (to reduce the grain gap between experimental plots and farmers field) partial budget analysis was performed following the CIMMYT partial budget methodology [22]. The gross benefit was calculated as grain yield (kg ha⁻¹) multiplied by field price that farmers receive for the sale of the crop. Total variable cost is the sum of cost that has variable or specific to a treatment against the control. Net benefit was calculated by subtracting total variable cost from the gross benefit. Analysis of marginal rate of return (MRR) was carried out for non- dominated treatments, and MRR were compared to a minimum acceptable rate of return (MARR) of 100% in order to select the optimum treatments to recommend for farmers. A treatment having acceptable MRR and highest NB is said to be economically profitable and will be recommended for farmers [21]. Marginal rate of return was calculated using the procedures described by CIMMYT [21] as Eq. (1):

$$Marginal\ rate\ of\ return\ (MRR) = \left(\frac{change\ in\ net\ benefit}{change\ in\ total\ variable\ cost}\right) * 100 \quad (1)$$

3.1.1. Tasselling Period

The maximum and minimum tasselling period was 88 days from plots treated with 0.5 t ha⁻¹ lime and 100 kg ha⁻¹ N (i.e treatment T7), and 85 days was recorded in 0.5 t ha⁻¹ lime and 400 kg ha⁻¹ N (i.e treatment T10) (Table 1). This might be due the uptake of most of the Ca and N by plants that come from lime and N, respectively. According to [22] reported the significant (P≤0.01) influence of the interaction of lime and potassium on the number of days required for 50% flowering on the soybean crop on acidic soil in Gobu Sayo district, western Ethiopia. According to [19] found synergistic effect of applied lime and inorganic plant nutrient sources and highly influenced phonological parameters of Barely on acid soils of Wolmera district, West Showa, and Ethiopia. The tasseling period slowed as the nitrogen level decreased and the maximum days to 50% tasseling was 91 days that was recorded under 0 kg N ha⁻¹. The fastest 50% tasseling was 85 days recorded in the plot treated with 400 kg N ha⁻¹ (Table 1 and Figure 2). This might be due to the uptake of more N by the maize plant for growth as tasseling time is affected by the amount of N in the soil. Thus, with an increase in N the availability of nutrients in the soil increased. This condition might lead to uniform flowering. Likewise, [24] reported a decrease in days of 50% tasseling from 82.44 to 80.89 days in the maize crop when the N rate was increased from 0 to 115 kg

ha[-1]. Similarly, [26] found earlier days to tasseling in the maize crop treated with increased rates of N. The delaying of flowering date in response to N deficiency has been previously acknowledged by [25, 26]. However, the result of this study disagreed to [27] that reported a consistent increase in days to 50% tasselling due to the prolonging vegetative growth period, when the rate of nitrogen applied increased.

3.1.2. Days of Sillking

As shown in Table 1 the maximum (91 days) and minimum (88 days) DS was recorded in plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N as compared with control DS (94 days). This is in line with [28] showed the significant influence of fertility management on days to silking on maize crop in central plain zone of Uttar Pradesh, India and Ethiopia respectively. Amanullah [29] reported delayed (68 days) of silking was after the application of cattle manure (5 t ha^{-1}) with phosphorus (160 kg P ha^{-1}) and with or without PSB. The analysis

showed that, days to 90% maturity was affected by the interaction effect of lime and N. The shortest (144) days to maturity was recorded from the control and the longest (149) days to 90% maturity was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N. This is due to the availability of N in the soil from urea fertilizer. This might be due to enhancing shoot growth, leave to be green, and maximizes the number of days required to be matured. This might be because of increasing N from urea and Ca^{2+} from lime enhances days to maturity [30]. As the rate of N fertilizer and lime increased days to 90% maturity was increased. Rahman *et al.* [31] reported maximum maturity by combining compost and mineral fertilizer. Abdissa et al. [32] reported that physiological maturity was significantly extended by applications of lime, vermicomposting and chemical P fertilizer on the maize crop in Ebantu *district*, Western highlands of Ethiopia.

***Table 1.** Moropho-phenological parameters as influenced by the interaction effect.*

Interaction effect	Growth parameters				
Lime	Nitrogen fertilizer rate	Treatments	DT (day)	DS (day)	DM (day)
	control	control	92.33[a]	96.33[a]	143.67[e]
control	100 kg ha^{-1}	100 kg ha^{-1}	89[c]	95[b]	146[d]
	200 kg ha^{-1}	200 kg ha^{-1}	88[d]	92[d]	146[d]
	300 kg ha^{-1}	300 kg ha^{-1}	87[e]	91[e]	147.66[b]
	400 kg ha^{-1}	400 kg ha^{-1}	86.33[ef]	90[f]	147.67[b]
0.5 t ha^{-1}	control	0.5 t ha^{-1}	90[b]	94[c]	142.33[f]
	100 kg ha^{-1}	0.5 t ha^{-1} * 100 kg ha^{-1}	88[d]	91[e]	146.66[cd]
	200 kg ha^{-1}	0.5 t ha^{-1} * 200 kg ha^{-1}	87[e]	90[f]	147[cb]
	300 kg ha^{-1}	0.5 t ha^{-1} * 300 kg ha^{-1}	85.66[fg]	88.33[g]	147.66[b]
	400 kg ha^{-1}	0.5 t ha^{-1} * 400 kg ha^{-1}	85[g]	88[g]	149[a]
Mean			87.83	91.56	146.36
LSD			0.7157	0.68	0.95
SE±			0.21	0.252	0.333
CV			0.475	0.43	0.37

Means followed by the same letters in a column are not statically different at p<0.05.

3.2. Effect of Nitrogen Fertilizer and Lime Rate on Vegetative Growth Parameters

As shown in Table 2 plant height of maize was significantly affected by the interaction effect of the two factors (P≤0.05). The ANOVA indicated that there was a significant increasing in the number of leave per plant by the interaction effect of lime and N fertilizers (P≤0.01).

3.2.1. Plant Height

In the combined application, the maximum (352.3 cm) plant height was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} N, and minimum (287 cm) was recorded from plots treated with 0.5 t ha^{-1} with 100 kg ha^{-1} N (Table 2). This might be a synergetic effect of urea and lime. Increased plant height with the increasing rate of lime and mineral fertilizer rate might be due to the addition of Ca^{2+} nutrient and reduce P fixation and, reduce Al^{3+} and H^+ ion from the soil, improve CEC, aeration, root penetration, water storage capacity of the soil [30].

According to [4] found a significant effect of the combined application of organic and inorganic fertilizers on plant height. Likewise, [20] who reported that the integrated application of lime with inorganic fertilizer and compost had a significant effect on Barley plant height.

3.2.2. Number of Leaves Per Plant

As shown in Table 2 the maximum (14.67) NLPP was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the minimum (11.33) mean NLPP was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N. This might be added lime and N in acidic soil improves N and P deficiency of the soil which leads to the greenness of maize plant and to be vegetative as well as increase leaf formation. Based on CIMMYT [20] report higher number of effective tillers of Barley and NPBS due to the synergetic effect of lime, organic and inorganic fertilizers on acidic soils of Wolmera district West Showa.

Table 2. Mean vegetative parameters as influenced by the interaction effect of lime and Nitrogen fertilizer.

Interaction	Growth parameters			
Lime	Nitrogen fertilizer rate	Treatments	PH (cm)	NLPP
	N0	T1	251[g]	9f
L0	N1	T2	264.66[f]	10.33[e]
	N2	T3	276.33[e]	11.33[d]
	N3	T4	319[c]	12.33[c]
	N4	T5	346.33[ba]	13.33[b]
L1	N0	T6	249[g]	10[e]
	N1	T7	287[e]	11.33[d]
	N2	T8	304.33[d]	13[b]
	N3	T9	337.66[b]	14.67[a]
	N4	T10	352.33[a]	14.67[a]
Mean			298.00	12
LSD (0.05)			0.109	0.58
SE±			0.039	0.189
CV			2.14	2.823
P			*	**
R- value			0.983	0.9805

PH=plant height, NLPP=number of leaves per plant, CV= Coefficient of Variation, p=probability level; ** =highly significantly different at p<0.01, * = significantly different at p<0.05. Means followed by the same letter in a column are not significantly different at 5 % probability level by DMRT.

3.3. Effect of Nitrogen Fertilizer and Lime Rate on Yield Components

The interaction of N fertilizer and lime had a significant effect on the number of cobs, TGW, grain yield of maize, AGDB and HI (P≤0.01) as shown in Table 3. The interaction of N fertilizer and lime rate had a significant effect on the number of grains per cobs and STY (P ≤0.05).

3.3.1. Number of Cobs Per Plant

The interaction effect indicated that the maximum (2.93) NCPP was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the minimum (1.96) from plots treated with 0.5 t ha^{-1} lime with 100 kg ha^{-1} N (Table 3). This might be the result of the synergetic effect of N and Ca. The improvement of soil conditions through lime and urea fertilizer might be responsible for better cob production. Kimiti [33] found improved crop yield of Maize after the combined application of lime, manure and mineral fertilizers as compared with the sole application of mineral fertilizers, lime, and manure. However, the result was disagreed to [34] that reported insignificant difference in the number of ears per plant of Maize crop after application of compost with N fertilizer at Khyber Pakhtunkhwa Agricultural University Peshawar Pakistan.

3.3.2. Number of Grains Per Cob

As shown in Table 3 the maximum NGPC (518.1) was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the minimum NGPC (496.5) was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N. This indicates that treatments with higher N fertilizer applied with 0.5 t ha^{-1} lime supported a significantly higher number of grains per cob as compared to the treatments treated with lower fertilizer and lime rates. This high increase in grain number per cob with the increase of N and lime rate might be due to the synergistic effects of Ca and N fertilizers that improved nutrient use efficiencies and normal development

of maize. This result is consistent with [21] who reported that, higher numbers of kernels per spike (51) of barley were obtained with integrated application of 611 kg lime + 5 t compost + 150 kg NPSB + 100 kg KCl +72 kg N ha^{-1} over the control [29]. Similarly, [35] reported a significant increase in the number of grains per spike of wheat by applying or manure and mineral fertilizer in combination as compared to inorganic fertilizer alone.

3.3.3. Thousand Grain Weight

As shown in Table 3 the maximum TGW of maize (417.197 g) was from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the lowest TGW (369.57 g) was recorded from the control plots compared to the sole application of lime TGW (385.49 g). Increased TGW might be due to the synergistic effects of the combined fertilizers for better growth and grain filling of maize. The lowest TGW could be due to shrunken seeds that have small size which contributed to the less grain weight because of nutrient deficiency. [36] reported that increased in TGW due to the synergistic effects of integrated application of lime and inorganic fertilizer that increased growth and grain filling of maize crop in the Angrau, Hyderbad, India. This is in line with [20] reported the highest TSW of barley (44 g) after the application of lime, compost, NPSB, KCl. Similarly, [4] reported that after the application of 5 t ha^{-1} FYM in combination with 75% recommended rate of inorganic NP, the highest TGW of barely was obtained compared with application of 100% recommended rate of inorganic NP. Saidu *et al.* [37] found the highest TGW of wheat grain from the application of 5 t ha^{-1} FYM and 50% inorganic NP, while the lowest TGW was recorded from control.

3.3.4. Grain Yield

Regarding with grain yield the maximum (7,669.88 kg ha^{-1}) was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} N while the minimum grain yield (6062.35 kg ha^{-1})

was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N (Table 3, Figure 7). This might be due to improved soil condition as both Ca and N nutrient was efficiently taken by the plant. This might be due to increased TGW as yield promoting conditions of maize. Since grain yield has strong and positive correlation with lime and nitrogen (r=0.999). According to [20], Barley grain yield of 2,744 kg ha^{-1} that made a significant difference due to the synergistic effect of lime and plant nutrition. Besides, [20] reported significant increase of barley yield over the control after the application of lime and all combinations of fertilizers, either alone or combined.

3.3.5. Above Ground Biomass

As shown in Table 3 the maximum (21,302 kg ha^{-1}) AGDB was recorded from 0.5 t ha^{-1} lime and 400 kg ha^{-1} N, while the minimum (18,370.8 kg ha^{-1}) AGDB was recorded from 0.5 t ha^{-1} lime with 100 kg ha^{-1} N. This enable the maize to respond well to N fertilizer and lime application as a result of its well-developed root system which facilitates absorbtion of the required nutrients for effective dry matter production by the crop and reduction of exchangeable acidity in the soil. The increased AGDB of maize might be an indicator of grain yield improvement as well as straw yield for animal fodder. The increased AGDB yield might be due to the release of unavailable nutrients from highly acidic soil by liming and N fertilizers. This high difference in total AGDB might be due to the synergistic effects of N fertilizer and lime as well as high doses of urea and lime which were well known to increase the vegetative growth of plants, OM, SOC and soil CEC. According to [39, 40] and [20] found that there was significance effect of integrated use of lime and N fertilizer on AGDB of cereals. Likewise, [20] reported that the maximum (11,500 kg ha^{-1}) biomass data was recorded from plots treated with lime, compost, and NPSB and N fertilizer than the control (3,433 kg ha^{-1}). Similarly, [41] reported that total dry matter of maize was higher in treatment combinations of inorganic and organic fertilizers than chemical fertilizers alone. Furthermore, [42] stated that N availability delayed the vegetative and reproductive stages of phenological development and increase biomass production of maize.

3.3.6. Harvest Index

The maximum (36.33%) HI was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} N and the minimum (33%) was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N (Table 3). This could be due to overall improvement of soil conditions by integrated use of lime and N. This indicates that combined use of lime and N fertilizer improve both grain yield and AGDB. From the total AGDB yield 63.67% was straw yield. But HI of 33% revealed that remaining 67% of total AGDB was straw yield. Similarly, [21] who reported that the HI of barley was significantly (P ≤ 0.01) influenced with integrated application of lime and recommended rate of organic and inorganic fertilizers. Likewise, [21] found the highest HI of barley (47%) was obtained with 0.611 t lime ha^{-1}, 5 t compost, 150

kg NPSB, 100 kg KCl and 72 kg N ha^{-1} as compared to other treatments that received less combination of applied lime and fertilizers.

3.3.7. Straw Yield

The interaction effect indicated that, the minimum (9,333 kg ha^{-1}) straw yield was recorded from control plot while the maximum STY was recorded from plots treated with 0.5 t ha^{-1} lime combined with 300 kg ha^{-1} N (13,224 kg ha^{-1}) followed by STY (12,984.67 kg ha^{-1}) obtained from plots treated with the combined use of 0.5 kg ha^{-1} lime and 400 kg ha^{-1} N (Table 3). This might be due to adequate supply of nutrients to the crop helps in the synthesis of carbohydrates, which are required for the formation of protoplasm, thus resulting in higher cell division and cell elongation. Thus, an increase in straw yield might have been on account of overall improvement in the vegetative growth of the plant due to the application of lime in combination with N fertilizer. This is in line with [21] mean straw yield of Barley (6114 kg ha^{-1}) were obtained with 611 kg lime ha^{-1}, 5 t compost, 150 kg NPSB, 100 kg KCl, 72 kg N ha^{-1} as compared to control for straw yield (2115 kg ha^{-1}). This is in line with [43] integrated application of organic, lime and N fertilizer is effective for the growth of maize and improving straw yields.

3.4. Correlation of Maize Yield and Yield Components

As shown in Table 4 interaction effect between lime and N fertilizer showed that grain yield had highly and positively correlated with NGPC (r=0.966) and NLPP (r=0.923) but highly and negatively correlated with DT (r = -0.957) and DS (r = -0.925).

Below is something about bivariate correlation effects of lime and Nitrogen fertilizer.

As shown in Table 4 straw yield was highly and positively correlated with AGDB (r=0.987) and HI (r=0.959), PH (r=0.857), NLPP (r=0.886), DM (r=0.915), NCPP (r=0. 841), TGW (r=0.743) and NGPC (r=0.954). This indicates that the effect of lime and urea fertilizer showed positive increment. When the rate increased the STY increased as well as all the above parameters also increased. But DS (r=-0.887) and DT (r=-0.927) were highly and negatively correlated with STY (Table 4). This could be due to the effect of lime and urea (i.e when the rate increased the STY increased while DS and DT decreased. Similarly, grain yield was highly and positively correlated with AGDB (r=0.996), HI (r=0.987), STY (r=0.977), NGPC (r=0.966), DM (r=0.931), NLPP (r=0.0.923), PH (r=0.909), NCPP (r=0.885) and TGW (r=0.797). This indicate that the effect of lime and urea fertilizer (i.e when the rate increased the GY increased as well as all the above parameters also increased. It was also highly and negatively correlated with DT (r=-0.957) and DS (r=-0.925). This indicate that the effect of lime and urea (i.e when lime and urea fertilizer rate increased the grain yield increased while DT and DS decreased (Table 4). This revealed that grain yield was highly significantly increases with an increase of grain yield per cobs, number of cobs per plant and plant height. In general all of the parameters (growth parameters and yield

components) were positively and significantly correlated with GY except that of DT and DS. This is supported with [44, 45] and [46] grain yield of maize were positively and significantly correlated with yield components.

***Table 3.** Mean yield components of maize as influenced by the interaction effect of lime and Nitrogen fertilizer.*

Interaction effect			Yield parameters						
Lime	N fertilizer rate	Treatments	NCPP	NGPC	TGW (g)	GY (kg ha⁻¹)	AGDB (kg ha⁻¹)	HI (%)	STY (kg ha⁻¹)
L0	N0	T1	1.00[f]	466.33[i]	369.577[f]	3442.47[j]	12959.2[h]	28.33[f]	9333[g]
	N1	T2	1.66[e]	495.13[g]	374.27[f]	5294.73[h]	16904.6[g]	31.67[e]	11494.7[e]
	N2	T3	1.93[d]	506.06[e]	380.56[e]	5766.53[g]	17474.1[f]	32.67[d]	11708.67[e]
	N3	T4	2.60[b]	509.73[d]	386.79[d]	6116.14[e]	18513.5[e]	34.33[c]	12205.33[d]
	N4	T5	2.8b[a]	516.26[b]	393.53[c]	6892.8[c]	19693.8[c]	35[bc]	12799.7[bc]
L1	N0	T6	1.73[ed]	471.13[h]	385.49d[e]	3758.42[i]	13238[h]	26.67[g]	9664[e]
	N1	T7	1.96[d]	496.53[f]	390.097[dc]	6062.35[f]	18370.8[e]	33.0[d]	12306[d]
	N2	T8	2.23[c]	509.6[d]	403.57[b]	6516.03[d]	19165.1[d]	34.33[c]	12645[c]
	N3	T9	2.76[ba]	513.2[c]	415.504[a]	7122.44[b]	20348.1[b]	35.67[ba]	13224[a]
	N4	T10	2.93[a]	518.067[a]	417.197[a]	7669.88[a]	21302.4[a]	36.33[a]	12984.7[ba]
LSD (0.05)			0.2446	1.3538	5.114	49.87	493.75	0.0092	313.17
SE±			0.080	0.645	1.767	59.739	187.193	0.004	114.515
CV			6.59	0.157	0.761	0.495	1.617	1.628	1.542
p			**	*	**	**	**	**	*
R- value			0.966	0.9987	0.9778	0.9997	0.9926	0.981	0.9878

NCPP=number of cobs per plant, NGPC=number of grains per cob, AGDB=above ground dry biomass, GY=grain yield, STY=Straw yield,
TGW=thousand grain weight, HI= harvest index, LSD= Least significance difference, SE± =Standard error;
CV= Coefficient of Variation, p=probability level; ** significantly different at $p<0.05$.
Means followed by the same letters in a column are not significantly different at $p<0.05$.

***Table 4.** Pearson's simple correlation coefficient among yield and yield components of maize.*

Correlations	DT	DS	DM	PH	NLPP	NCPP	NGPC	TGW	GY	AGDB	HI	STY
DTAS	1											
DSILK	.950**	1										
DM	-.853**	-.803**	1									
PH	-.888**	-.889**	.873**	1								
NLPP	-.904**	-.929**	.833**	.925**	1							
NCPP	-.936**	-.901**	.789**	.908**	.890**	1						
NGPC	-.936**	-.863**	.915**	.871**	.868**	.870**	1					
TGW	-.803**	-.887**	.658**	.792**	.905**	.794**	.676**	1				
GY	-.957**	-.925**	.931**	.909**	.923**	.885**	.966**	.797**	1			
AGDB	-.944**	-.906**	.942**	.897**	.912**	.865**	.962**	.779**	.996**	1		
HI	-.890**	-.856**	.961**	.899**	.888**	.821**	.955**	.710**	.987**	.974**	1	
STY	-.927**	-.887**	.915**	.857**	.886**	.841**	.954**	.743**	.977**	.987**	.959**	1
**=Correlation is significant at the 0.01 level (1-tailed).												

HI= harvest index, STY=straw yield, GYPC=Grain yield per cob, GY=Grain yield, AGDB=above ground dry biomass, PH=plant height, NCPP=number of cobs per plant, DM= Date of 90% maturity, DS= Date of 50% silking and DTAS=Date of 50% tasseling.

3.5. Economic Feasibility Analysis of Maize

During the 2018/2019 rainy season the market price of Maize taken at Burie district was 10 Ethiopian Birr per kilogram (ETB kg⁻¹). Field prices for NPS, urea, and lime were taken as 10.40, 12.00 and 1.35 ETB kg⁻¹, respectively (Table 5). The cost of labour for harvesting and bagging were taken at 28 ETB 100 kg⁻¹, the cost of labour for incorporation and transportation of lime was taken at 25 ETB 100 kg⁻¹, the cost of application and transport for fertilizer during planting was 1000 ETB kg⁻¹ considering that 10 laborers can apply fertilizer on a hectare of land in 1 day (daily wage of one laborer is 100 Birr). The same amount of money would be required for side dressing. So it should be 1000 ETB for urea treated plot and daily wage of one labor was 100 ETB.

3.6. Dominances Analysis of Maize

As shown in Table 5 and Table 6 the marginal and dominances analysis of maize in T2, T7, T9 and T8 had greater than 100% in MRR. The maximum net benefit (58,891.47 Ethiopian Birr) with MRR value of (805.24%) was obtained from T9-lime (0.5 t ha⁻¹) + 300 kg ha⁻¹ N) as compared to T8-lime (0.5 t ha⁻¹) + (200 kg ha⁻¹) net benefit (47,701.04 ETB) with MRR (203.59%) (Table 5). This means for T9 on average for each 1 Birr ha⁻¹ invested, the return was 1 birr, plus 8.05 Birr ha⁻¹ in the net benefit which is economically feasible as compared to T8 that showed 1 Birr recovery plus 2.04 Birr ha⁻¹ net benefit. The MRR

analysis of treatment 2, 7, 8 and 9 was more than 100% but T9 is economically feasible to recommend for the farmers. This study suggests that it could be advisable for farmers in the study area to apply integrated lime at 0.5 t ha^{-1} plus 300 kg ha^{-1} nitrogen to enhance maize grain yield and ensuring maximum economic return. This recommendation is also supported by [21] which stated that farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum acceptable rate of return. Based on CIMMYT [20] report integrated use of lime, compost, recommended NPS, KCl and nitrogen fertilizer gave the highest grain yield net benefit and MRR on Barley production. Similarly, [47] reported that higher grain yield and higher net benefit was recorded from higher planting density with higher NPK rate of site specific nutrient management (SSNM).

Table 5. *Dominances analysis of Maize.*

Treatments	TVC (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Dominance
T1	5928.92	25842.43	Non-dominated
T6	6689.272	26356.478	Non-dominated
T2	8599.701	39052.869	Non-dominated
T7	9598.291	44962.859	Non-dominated
T3	9899.129	41999.641	Dominated
T8	10943.23	47701.04	Non-dominated
T4	11281.57	43763.69	Dominated
T9	12332.93	58891.47	Non-dominated
T5	12630.82	51769.03	Dominated
T10	13667.99	55360.93	Dominated

Treatment 3=with 200 kg ha^{-1} N alone, T4=with 300 kg ha^{-1} N alone and T5= with 400 kg ha^{-1} N, treatment 10=with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N were dominated treatments. Hence, these are rejected from further consideration in marginal analysis. Based on this treatment 3, 4, 5 and 10 are rejected because they are dominated by other treatments.

Table 6. *Marginal analysis of Maize.*

Treatments	Grain Yield (kg ha^{-1})	Adjusted yield (-10%) (kg ha^{-1})	Gross return (ETB ha^{-1})	TVC (ETB ha^{-1})	Net benefit (ETB ha^{-1})	MRR (%)
T1	3530.15	3177.135	31771. 35	5928.92	25842.43	----
T6	3671.75	3304.575	33045.75	6689.272	26356.478	67.6
T2	5294.73	4765.257	47652.57	8599.701	39052.869	664.5
T7	6062.35	5456.115	54561.15	9598.291	44962.859	591.8
T3	5766.53	5189.877	51898.77	9899.129	41999.7 D	----
T8	6516.03	5864.427	58644.27	10943.23	47701.04	203.59
T4	6116.14	5504.526	55045.26	11281.57	43763.69 D	----
T9	7122.44	6410.196	64101.96	12332.93	58891.47	805.24
T5	6892.8	6203.52	62035.2	12630.82	51769.03 D	-----
T10	7669.88	6902.892	69028.92	13667.99	55360.93 D	----

D=dominated treatment.

Table 7. *Agronomic use efficiency for maize.*

Treatments	Lime (kg/ha)	N fertilizer (kg ha^{-1})	NPS fertilizer (kg ha^{-1})	Total nutrient added	Grain yield (kg ha^{-1})	AUE
L0N0	--	--	200	200	3530.15	--
L0N1	--	100	200	300	5294.73	5.88
L0N2	--	200	200	400	5766.53	5.59
L0N3	--	300	200	500	6116.14	5.17
L0N4	--	400	200	600	6892.8	5.604
L1N0	500	--	200	700	3671.75	0.202
L1N1	500	100	200	800	6062.35	3.16
L1N2	500	200	200	900	6516.03	3.32
L1N3	500	300	200	1000	7122.44	3.59
L1N4	500	400	200	1100	7669.88	3.76

3.7. Agronomic Use Efficiency

Agronomic use efficiency reflects the direct production impact of an applied fertilizer and relates directly to economic return. The interaction between lime and N fertilizer significantly affected agronomic use efficiency as N fertilizer rate increased but lime rate is constant (Table 7). The highest agronomic use efficiency was obtained from combined use of 400 kg ha^{-1} N fertilizer with 0.5 t ha^{-1} lime than 100 kg ha^{-1} N with 0.5 t ha^{-1} lime.

As shown in Table 7 the nutrient use efficiency (NUE) was good for those plots treated with 100 kg ha^{-1} N and has the highest NUE which is 5.88%. This might be due to the fact N fertilizers were known in releasing nutrients

immediately to the soil and crop which account in yield increase. The maximum (5.88%) AUE was recorded from plots treated with 100 kg ha^{-1} N while the lowest AUE (0.202%) was recorded from plots treated with 0.5 t ha^{-1} lime alone. This confirms that, inorganic fertilizer release nutrients immediately while lime does not release nutrients immediately for maize. The remaining might be lost through erosion, leaching and changed to organic stock. The result was similar with [47] who reported that, the highest agronomic use efficiency (16.14%) of maize was obtained from plots treated with mineral fertilizer only (75 kg ha^{-1} N fertilizer plus 100 kg ha^{-1} NPSZnB fertilizer and lowest NUE (0.04%) was obtained from plots treated with compost only (5000 kg ha^{-1}). Similarly,

[48] reported that low nitrogen use efficiency in cereal production due to denitrification. Plots treated with lime alone or in combination with urea fertilizer were low in their NUE. This is due to the fact that lime is not providing nutrients to the soil and crops immediately. Likewise, [49] found the effect of N fertilizer rate on agronomic use efficiency.

4. Conclusion

The study demonstrates that application of lime and N fertilizer affected yield and yield components of maize. Grain yield is highly correlated with number of cobs per plant (r=0.966). Grain yield of maize was positively and significantly correlated with yield components. The maximum net benefit (58,891.50 ETB) and MRR (805.24%) was obtained from combined use of 0.5 t ha^{-1} lime with 300 kg ha^{-1} N fertilizer. Maize yield was increased by 13.42% from recommended inorganic fertilizer rate in the study area. Integrated application of lime and N fertilizer increased agronomic use efficiency of maize. The optimum rate of lime and N fertilizer for yield increment and maximum economic benefit was resulted by combined application of 0.5 t ha^{-1} lime and 300 kg ha^{-1} N with full recommendation (200 kg ha^{-1}) of NPS. Based on this study it is the recommended rate to the farmers in the study area. The government should supply lime and nitrogen fertilizer. Further study should be done in the residual effect of lime for further growing seasons, with organic and inorganic fertilizers.

Declaration of Interest Statement

The authors declare that they have no competing interests.

Data Availability Statement

The data that support the findings of this study are openly available as the corresponding author's request.

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