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Research Article

Effects of integrated fertilizer application on soil properties and yield of Maize (*Zea mays* L.) on Nitisols in Pawe District, Northwestern Ethiopia

***Seble Getaneh*[1], *Eyayu Molla*[2*], *Dejene Abera*[3]**

[1]Ethiopian Institute of Agricultural Research, Pawe Agricultural Research Center, Pawe, Ethiopia
[2]College of Agriculture and Environmental Sciences, Bahir Dar University, Bahir Dar, Ethiopia
[3]Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center, Melkassa, Ethiopia
***Corresponding author:** eyayuelza@yahoo.com

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Abstract: *In many parts of Ethiopia, the primary challenge limiting crop productivity is the depletion of soil fertility. Despite being one of Ethiopia's primary cereal crops, the yields of maize are currently believed to be low owing to low soil fertility, continuous farming, and poor crop management. A field experiment was carried out on the Nitisols of Pawe Research Station in northwest Ethiopia during the 2020-21 cropping season to evaluate the effects of the integrated application of farmyard manure (FYM) and inorganic nitrogen fertilizer on soil properties and maize yield. The treatments were a factorial combination of four levels of FYM (0, 5, 10, and 15 t ha^{-1}) and four levels of nitrogen (0, 34.5, 69, and 103.5 kg ha^{-1}) in the form of urea. Besides, 46 kg ha^{-1} P_2O_5 fertilizer was applied for all treatments. The experiment was arranged in RCBD with three replications. The result showed that combined applications of FYM and N fertilizer significantly ($p < 0.05$) improved the soil pH, soil organic carbon, cation exchange capacity, and exchangeable calcium. The combined application of 10 t ha^{-1} FYM and 69 kg ha^{-1} N recorded the highest maize grain yield (10,035.8 kg ha^{-1}) and thousand-grain weight (415.97 g), while the interaction of 103.5 kg ha^{-1} N and 15 t ha^{-1} FYM produced the highest biomass yield (25.83 t ha^{-1}). The combined application of 10 t ha^{-1} FYM and 69 kg ha^{-1}N is therefore recommended for economical production (net benefit of 81,258.7 ETB ha^{-1} and acceptable MRR of 497.96%) of maize and soil fertility improvement in the study area and areas with similar agro-ecology.*

Keywords: Farm yard manure, Grain yield, Nitrogen fertilizer, Soil fertility
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1. Introduction

Agriculture is the economic pillar of most developing countries (Saraceno, 2003). Low soil fertility, however, is thought to be one of the most significant issues affecting agricultural output in Sub-Saharan Africa (SSA) (Vanlauwe et al., 2015). Ethiopia is among the SSA countries with the highest rates of food insecurity, which is a major problem for many people, particularly those living in drought-prone areas. Despite the potential richness of the nation's land resources and agroecologies, agricultural production is low, and the country frequently faces food shortages and hunger (Mohammed et al., 2021). This is associated with soil fertility decline, which is mainly caused by topsoil erosion, soil acidity, reduced organic matter, macro- and micronutrient depletion, deterioration of soil physical properties, water logging, and the development of salinity in the soil (Zelleke et al., 2010). As a result, in recent years, Ethiopia has experienced an increase in both soil degradation and nutrient depletion (Kebede and Yamoah, 2009), with annual nutrient deficits of -41, -6, and -26 kg ha^{-1} yr^{-1} for N, P, and K, respectively, and a 2–3% decline in productivity (Nigussie and Kissi, 2012). Therefore, increasing agricultural production through the improvement of soil fertility is a key factor in ensuring Ethiopian food security and reducing poverty (Lulseged et al., 2017).

Maize (*Zea mays* L.) is one of the most important crops cultivated worldwide to combat chronic food insecurity (Ashraf et al., 2016). It is one of the most important grains cultivated in Ethiopia, ranking second in terms of area covered and first in terms of total production, following *teff* (*Eragrostis tef*). However, the average production of maize in the country is only about 3.99 t ha^{-1}, which is significantly less than the global average yield of 4.92 t ha^{-1} (CSA, 2019).

According to Amin (2011), inorganic fertilizers are the primary and crucial sources of nutrients for the cultivation of maize (*Zea mays* L.), the promotion of optimal yield, and the enhancement of nutritional quality. These chemical fertilizers are usually applied to improve nutrient deficiency and increase crop productivity in Ethiopia. However, the primary obstacles to their adoption are their high price, their inaccessibility to small-holder farmers, and the lack of recommendations tailored to specific sites with little attention to the types of soils, climate, and crops (Lulseged et al., 2017). For instance, the average national rate of urea and DAP (di-ammonium phosphate) fertilizer application was 43 kg and 65 kg/ha, respectively. These are significantly less than the recommended rates of 100 kg urea and 150 kg DAP/ha (Lulseged et al., 2017). In addition, the ability to maintain soil fertility over the long term is hampered by inorganic fertilizers in continuous cropping systems (Zaman-Allah et al., 2007). On the other hand, organic amendments alone cannot replenish the depleted nutrients due to their slow and inadequate nutrient release, and they need to be applied in large quantities to meet the nutrient requirements of crops (Chapagain and Gurung, 2010; Jinwei. and Lianren, 2011; Ejigu et al., 2021). As a result, using organic fertilizers like compost and farmyard manure (FYM) in place of inorganic fertilizers alone won't be sufficient to maintain the demand for agricultural productivity (Efthimiadou et al., 2010). These demonstrated that agricultural yield cannot be sustained by using only mineral or organic fertilizers (Shah et al., 2009). Thus, the best way to maintain soil fertility and crop productivity is to combine inorganic fertilizers with organic fertilizers—such as FYM, green manure, compost, crop residues, and other organic sources—and use them more effectively (Mengistu and Mekonnen, 2012; Osman and Abera, 2015; Ejigu et al., 2021).

In the study area, Pawe District maize is an essential food item and one of the community's primary sources of calories. Nevertheless, the production and productivity of maize crops in the study area remained very low, primarily due to low soil fertility brought on by frequent cropping, crop residue removal, inadequate fertilizer supplies, and severe soil erosion. Even if farmers have a belief in the use of chemical fertilizers to boost agricultural productivity, there are still gaps in getting the full benefits of fertilizer application. Besides, farmers in the study area do not have adequate practice and knowledge of the importance of FYM and the integrated application of organic and inorganic fertilizers to overcome the problems associated with soil fertility. Furthermore, no research has been conducted in the study area on how integrated nutrient management affects soil fertility and total maize production. Therefore, this study was initiated to investigate the effect of integrated application of FYM and mineral N fertilizer on soil properties, yield, and yield components of maize in the Nitisols of Pawe district, Northwestern Ethiopia.

2. Materials and Methods

2.1 Description of the study area

The experiment was conducted in the research station of the Pawe Agricultural Research Center (PARC) in Pawe district, northwestern Ethiopia (Figure 1). Geographically, the study area is located between 11°8'0" to 11°26'0" N and 36°18'0" to 36°42'30" E. The altitude varies between 1000 and 1200 masl, having a gently undulating to undulating plain with an average slope of 5% (Abbute, 1998).

Following the Ethiopian traditional agro-climatic zonation, Pawe District is located in a *Wet Kolla* (hot humid) climate zone. It has a unimodal rainfall pattern, with an extended rainy season from March to September. Based on thirty-year (1990–2020) climatic data recorded from the PARC meteorology station, the average annual precipitation of the area was 1641 mm, with a mean annual maximum and minimum temperature of 37 and 16 °C, respectively (Figure 2).

The geology of Pawe District consists of metaconglomerate and quartzite from the Precambrian basement complex (Esayas, 2003). The major soil types of the district are Nitisols, Vertisols, and Luvisols (Dieci and Viezzoli, 1992). The experiment was conducted on the Nitisols at the research site. The major crops cultivated in the study area and its surroundings include maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), soybean (*Glycine max*), haricot bean (*Phaseolus vulgaris*), sesame (*Sisamum indicum*), and groundnut (*Arachis hypogaea*).

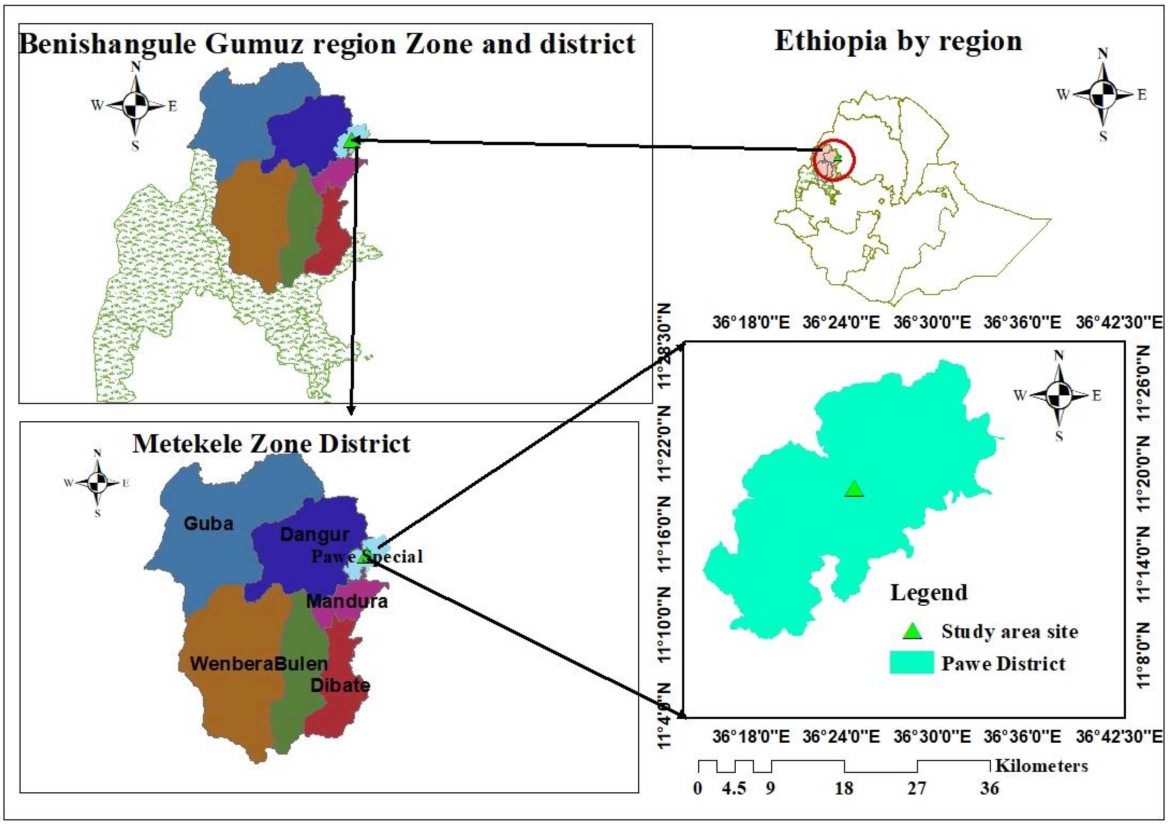

Figure 1: Location map of the study area

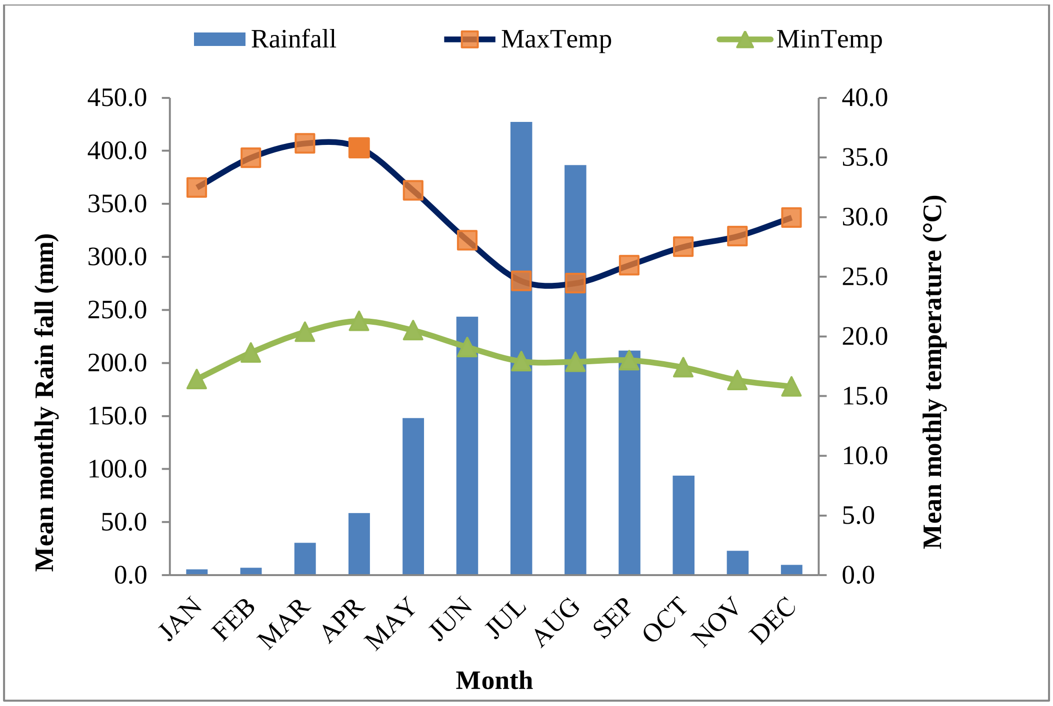

Figure 2: Mean monthly rainfall and minimum and maximum temperature of the study area based on three decades (1990–2020) of records at the PARC meteorology station (unpublished data)

2.2 Experimental treatments, design and procedures

The experiment consisted of a factorial combination of four levels of nitrogen (in the form of urea) (0, 34.5, 69, and 103.5 kg ha^{-1}), of which 69 kg ha^{-1} N was recommended by PARC for the area, and four levels of FYM (0, 5, 10, and 15 tons ha^{-1}), where 10 tons ha^{-1} was the recommended rate. The experiment was laid out in a randomized complete block design (RCBD) with three replications. The gross plot area was 3m x 3.75 m, and the net plot area was 3m x 2.25 m. The path between experimental plots and blocks was separated by 1 m and 2 m, respectively.

The experimental site was ploughed by a tractor to a depth of 22 cm and then leveled for plot preparation. An improved maize variety (BH-546) was used as a test crop. The crop was planted in rows with inter- and intra-spacing of 0.75m and 0.3m, respectively. Urea and TSP fertilizers were used as the sources of N and P, respectively. Nitrogen fertilizer was applied in two equal splits, half at planting and half after 35 days of plant sowing. All phosphorus fertilizer (46% P_2O_5) was applied at sowing. A full dose of well-matured FYM was applied three weeks before sowing. The FYM was prepared from cattle dung, where it was stored to decompose for eleven months before it was used for this experiment. All cultural practices, such as weeding and hoeing, were applied uniformly to all treatment plots.

2.3 Soil ad farmyard manure analysis

Following the standard soil sampling procedures, representative composite soil samples were collected from all plots at a depth of 0–20 cm before planting and after crop harvest using an Edelman auger. The soil samples were air-dried, mixed well, grounded, and passed through a 2 mm sieve for the analysis of most of the soil properties, but some parts of the soil samples were passed through a 0.5 mm sieve for total nitrogen and organic carbon analysis.

Soil texture was analyzed by the Bouyoucos hydrometer method (Day, 1965). Bulk density (BD) was determined by a core sample method (Blake, 1965). Soil pH was determined in 1:2.5 soil-to-water ratio suspensions using a glass electrode attached to a digital pH meter (Peech 1965). Soil organic carbon (OC) was determined following the modified method of Walkley and Black (1934). Total nitrogen (TN) was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorous was extracted following the $NaHCO_3$ extraction method (Olsen et al., 1954). Exchangeable bases (Ca, Mg, K, and Na) were determined after extracting the soil samples with ammonium acetate (1N

NH_4OAc) at pH 7.0. Exchangeable Na and K were analyzed by a flame photometer, while Ca and Mg were analyzed by an atomic absorption spectrophotometer (AAS) (Van Reeuwijk, 2002). The cation exchange capacity (CEC) of the soil was determined titrimetrically by the distillation of ammonium that was displaced by sodium from the NaCl solution (Chapman, 1965). Similarly, the nutrient composition of FYM that was prepared from cattle dung was determined from composite FYM samples after being air-dried, crushed, and screened through a 2 mm sieve for laboratory analysis. Both the soil and FYM were analyzed at the PARC soil laboratory following standard laboratory procedures.

2.4 Agronomic data collection

Days to tasseling and silking were recorded as days from the date of sowing to the time when 50% of the plants protruded tassels and silk, respectively. Maize physiological maturity was recorded when 90% of the plant`s black layer at the seed base was observed. Plant height (cm) was determined by measuring the height from the ground level up to the base of a tassel of five randomly selected plants, and the average height was used. Lodging was measured at harvest by dividing the number of lodged plants by the number of harvested plants. The number of cobs per plant was counted from five randomly selected representative plants, and the average value was used. Ear length (cm) was recorded from five randomly selected ears by measuring the point where the cob attached the stem to the tip of the cob and averaging it. Ear diameter (cm) was measured from the diameter of five randomly selected representative cobs by using a caliper, and the mean value was recorded. Aboveground dry biomass yield (t ha^{-1}) was determined by weighing the whole aboveground plant parts from the net plot area after complete sun-drying for seven days. Thousand-grain weight (g) was determined by weighing 1000 grains of maize with the analytical balance from the bulk grain yield of the net plot area and was adjusted to 12.5% moisture level using the formula indicated by [1]. Grain yield (kg ha^{-1}) was measured using a sensitive balance adjusted to 12.5% moisture and converted to hectares.

$$\text{Adjusted yield} = \frac{\text{Actual yield} * (100 - \text{M})}{100 - \text{D}} \quad [1]$$

Where, M is the measured moisture content in grain and D is the designated moisture content (12.5%)

Harvest index (%) was calculated by dividing grain yield by the total aboveground dry biomass yield following the formula [2] below.

$$\text{Harvest idex (\%)} = \left(\frac{\text{Grain yield}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Aboveground biological yield}\left(\frac{\text{kg}}{\text{ha}}\right)}\right) * 100 \quad [2]$$

2.5 Data analysis

All the agronomic and soil data were analyzed using a two-way analysis of variance (ANOVA) with statistical analysis software (SAS, 2014) 9.4 version. All significant treatment means were compared using the least significant difference (LSD) test at a 5% probability level.

2.6 Partial budget analysis

A partial budget analysis was done to investigate the economic feasibility of the treatments. Partial budget dominance and marginal rate of return analyses were done based on the formula developed by CIMMYT (1988).

Adjusted grain yield was the average yield (AY), which was down-scaled by 10% to reflect the difference between the experimental plot yield and the yield of farmers expected from the same treatment.

$$\text{Adjusted grain yield (AGY)} = \text{AY} - (\text{AY} * 0.1) \quad [3]$$

Gross field benefit (GFB) was computed by multiplying the field/farm gate price of the crop at the time of harvesting with the adjusted yield.

$$\text{GFB} = \text{AGY} * \text{Farm gate price} \quad [4]$$

Total variable costs (TVC) are costs that vary with the treatment. Purchase and transport costs of N and FYM, as well as labor wages for the application of FYM were considered variable costs. The prices of these variable costs and maize grain were determined through a market survey at the harvesting time.

Net financial benefit (NFB) was calculated by subtracting the total costs that vary from gross field benefits for each treatment.

$$\text{NFB} = \text{GFB} - \text{total variable cost} \quad [5]$$

The marginal rate of return (MRR) was calculated by dividing the change in net benefit by a change in the total variable cost of the treatments. When more than two treatments give an MRR above 100%, the treatment with a higher net income was selected as indicated by CIMMYT (1988).

3. Results ad Discussion

3.1 Soil properties of the experimental site before planting

The soil properties before planting are summarized in Table 1. The soil analysis result showed that the textural class of the experimental plots was clay with a low bulk density. The soil pH was moderately acidic, with low TN and AvP, very low OC, and high CEC. This shows that the soil at the experimental site was deficient in basic nutrients. However, the CEC value was high, which could be associated with the high clay content (47%), which increases the negative surface charges (CEC) for the retention of cations and nutrients (Elias, 2016).

3.2 Evaluation of the chemical quality of farmyard manure

The farmyard manure was slightly alkaline, with 5.42% OC, 0.82% TN, and 0.51% TP, with a C: N ratio of 6.61 indicating that it was well decomposed (Table 2). As per Hazelton and Murphy (2007), organic matter with a C: N ratio of less than 10 is expected to decompose quickly. On the other hand, if the C: N ratio is greater than 20, it is more likely that nitrogen will lock up during the organic matter decomposition process, reducing the amount of N that is available for the crop.

Table 1: Soil physicochemical characteristics of the experimental site before treatment application

Soil Parameters	Value	Rating	References
BD (gcm^{-3})	1.25	Low	Hazelton and Murphy (2007)
Sand (%)	44	-	
Silt (%)	9	-	
Clay (%)	47	-	
Soil textural class		Clay(C)	Hazelton and Murphy (2007)
pH (H_2O)	5.32	Moderately acidic	Landon (2014)
OC (%)	1.90	Very low	Landon (2014)
TN (%)	0.139	Low	Landon (2014)
AvP (mg kg^{-1})	12.53	optimum	Landon (2014)
CEC ($Cmol_c$ kg^{-1})	27	High	Hazelton and Murphy (2007)
Exc. Ca ($Cmol_c$ kg^{-1})	12.39	High	FAO (2006)
Exc. Mg ($Cmol_c$ kg^{-1})	2.67	Medium	FAO (2006)
Exc. K ($Cmol_c$ kg^{-1})	0.52	Medium	FAO (2006)
Exc. Na ($Cmol_c$ kg^{-1})	0.195	Low	FAO (2006)

BD = Bulk density, pH = Power of hydrogen, OC = Organic carbon, TN = Total nitrogen, AvP = Available phosphorus, CEC = Cation exchange capacity, Exc. Ca = Exchangeable calcium, Exc. Mg = Exchangeable magnesium, Exc. K = Exchangeable potassium, Exc. Na = Exchangeable sodium

Table 2: Chemical properties of farmyard manure

FYM Property	Value
pH 1:2.5 (H_2O)	7.53
Organic carbon (OC)	5.42%
Total nitrogen (TN)	0.82%
Available phosphorus	176.98 mg/kg^{-1}
Carbon: Nitrogen (C:N ratio)	6.61 mg/kg^{-1}
Cation exchange capacity (CEC)	52.01 $cmol_c$ kg^{-1}
Exchangeable calcium	23.6 $cmol_c$ kg^{-1}
Exchangeable magnesium	8.64 $cmol_c$ kg^{-1}
Exchangeable potassium	7.98 $cmol_c$ kg^{-1}
Exchangeable sodium	0.77 $cmol_c$ kg^{-1}

3.3 Effects of farmyard manure and nitrogen rates on soil properties after harvesting

3.3.1 Bulk density

Bulk density (BD) was significantly (P ≤ 0.01) affected by the sole application of FYM. Nevertheless, neither the application of N fertilizer alone nor the combination of N fertilizer and FYM had any effect on it. The lowest BD (1.18 gcm^{-3}) was recorded from the addition of 15-ton ha^{-1} FYM, while the highest (1.25 gcm^{-3}) was from the control (Tables 3 and 4). An increase in soil organic matter, mainly FYM, which encourages soil aggregation, may be the cause of the soil's lowest BD. The findings were consistent with those of Agegnehu et al. (2016), who observed a noteworthy decrease in soil BD following the harvest of barley crops in plots treated with organic fertilizer. The benefits of organic additions including compost, manures, and biochar on raising soil organic matter, porosity, and accessible water content and thereby reducing soil bulk density were also documented by Widowati et al. (2020) and Ejigu et al. (2021). However, as per the ratings of Hazelton and Murphy (2007), all treatments showed low BD.

3.3.2 Soil pH

Both the combined and individual applications of FYM and N fertilizers had a significant (P ≤ 0.05) effect on the soil pH. When 15 tons of FYM and 34.5 kg of ha^{-1} N fertilizer were added, the soil pH reached its highest value of 5.51. However, the applications of 103.5 kg ha^{-1} mineral N fertilizer alone, which were statistically comparable to the control treatments, as well as the individual mineral fertilizers of 34.5 and 69 kg ha^{-1} N, led to a lower soil pH (5.28) (Table 4). The level of pH was rated as strongly acidic in most of the treated plots and the control, despite the fact that there was a significant difference (P < 0.05) in soil pH between treatments and the control. The exceptions were the plots treated with 34.5 kg ha^{-1} nitrogen and 15 t ha^{-1} FYM, which were rated as moderately acidic (Landon, 2014). This might be associated with the nitrogen fertilizer, i.e., urea, which releases hydrogen ions (H^+) and decreases soil pH through the nitrification process. The result was in line with Iqbal et al. (2022), who reported a decline in soil pH after the sole application of urea, which resulted from accelerated nitrification and soil acidification. However, they reported that there was a significant increase in plots treated with integrated organic and inorganic N fertilizer and organic fertilizer alone in rice-cultivated fields. Schroder and colleagues (2011) also documented a reduction in soil pH in treatments that received a single mineral N fertilizer. This was explained by the acidic nature of urea applications, which can release significant amounts of H^+ ions into the soil through nitrification. Similarly, Adane et al. (2020) reported the improvement of soil pH from acidic to neutral conditions after the application of FYM in acidic soils for food barley crops. According to Liu et al. (2011), the application of organic manure will increase soil pH, whereas the highest application of chemical fertilizers, like too much NPK fertilizer, could lower the pH of the soil.

Table 3: Main effects of FYM and N fertilizer rates on soil properties after harvesting maize

FYM (t ha-1)	BD (gcm^{-3})	TN (%)	AvP (mg kg^{-1})	Exc. K ($cmol_c$ kg^{-1})	Exc. Mg (cmolc kg^{-1})
0	1.25^{a}	0.14^{c}	17.03^{c}	0.43^{d}	2.55^{c}
5	1.23^{ab}	0.16^{b}	19.54^{b}	0.58^{b}	2.83^{b}
10	1.21^{b}	0.17^{ab}	20.27^{a}	0.69^{b}	2.94^{ab}
15	1.18^{c}	0.18^{a}	20.81^{a}	0.73^{a}	3.01^{a}
LSD (0.05)	0.032**	0.005**	0.68**	0.041**	0.110**
N (kg ha^{-1})					
0	1.22	0.15^{b}	19.74^{a}	0.63	2.90
34.5	1.22	0.16^{ab}	19.68^{a}	0.61	2.84
69	1.20	0.16^{ab}	19.47^{a}	0.61	2.81
103.5	1.22	0.17^{a}	18.76^{b}	0.57	2.78
LSD (0.05)	NS	0.005**	0.68*	NS	NS
SE±	0.006	0.001	0.011	0.007	0.019
CV%	3.19	3.83	4.17	8.12	4.60

BD = Bulk density; TN = Total nitrogen; AvP = Available phosphorus; Exc. K = Exchangeable potassium; Exc. Mg = Exchangeable Magnesium; ** Significant at P < 0.01, * significant at P < 0.05, NS = no significant difference

3.3.3 Soil organic carbon (OC)

The analysis showed a significant difference ($P \leq 0.05$) in OC in plots treated with the applications of FYM and N fertilizer individually and in combination. The highest soil OC (2.74%) was recorded from plots treated with the combined application of 69 kg ha^{-1} N and 15 tons ha^{-1} FYM. However, the lowest soil OC (1.94%) was found in the control (Table 4). Although there was a significant difference, according to Landon (2014), OC was rated as low in the treated plots and very low in the control. This result might be associated with the decomposition and mineralization of FYM by soil microorganisms. In agreement with the results of this study, Hammad et al. (2020) reported the highest level of soil OC from the combined application of compost and chemical fertilizer, while the lowest was recorded from solely chemical fertilizer-treated plots. Babu and Reddy (2000) and Tana and Woldesenbet (2017) also reported a significant increase in soil OC after the combined application of organic and inorganic fertilizers on rice fields and food barley crops, respectively. However, there was no significant change in soil OC when inorganic fertilizers were applied alone to either crop.

3.3.4 Total nitrogen (TN)

The sole application of FYM and N fertilizers significantly affected ($P \leq 0.01$) soil TN. Accordingly, the highest soil N (0.18%) was recorded from the addition of 15 tons ha^{-1} FYM, while the lowest (0.14%) was from the control (Table 3). An increment in soil N after crop harvest resulted from the addition of organic N contributed by FYM. However, the interaction effect of both factors did not show a significant ($P > 0.05$) difference (Table 4). The findings were consistent with Thamaraiselvi et al. (2012), who reported increased soil TN and available P after the application of FYM. Khan et al. (2010) also reported the synergistic effects of organic manures with inorganic fertilizers, which usually accumulate more TN in soils.

Concerning the effect of inorganic (N) fertilizer rates, the highest soil residual TN (0.17%) was recorded at the rate of 103.5 kg ha^{-1} N fertilizer, while the lowest TN (0.15%) was recorded from the control plots (Table 3). According to Landon (2014), all nitrogen fertilizer and FYM-treated plots had an optimum level of TN, but it was rated as low in the untreated plots. On the other hand, the lower TN recorded in mineral (N) fertilizer-treated plots than FYM-treated plots could be associated with the faster rate of inorganic nitrogen fertilizer solubility and their availability to the crop in the soil solution. The result was in line with Mitiku (2014) and Singh et al. (2001), who reported lower TN in soils treated with inorganic fertilizer alone because nutrients from this source were readily available and directly used by plants.

3.3.5 Available phosphorus (P)

The analysis of variance showed that soil available P was significantly affected ($P \leq 0.01$ and $P \leq 0.05$) by the sole application of FYM and N fertilizers, respectively (Table 3). However, no significant difference ($P > 0.05$) was found in the interaction effect of both factors (Table 4). After crop harvest, the value of available P in all treatments was higher than the value of available P before planting. The reasons for this increase could be the residual effect from the application of the recommended 46 kg ha^{-1} P_2O_5 fertilizer during planting for all plots, as well as the direct addition of N and P from the decomposition of the FYM added to the soil. The improvement of soil pH in treated plots could also play a significant role in increasing available phosphorus by reducing its fixation by Al and Fe cations.

The highest available P (20.81 mg kg^{-1}) was recorded from plots treated with 15 t ha^{-1} FYM, while the lowest (17.03 mg kg^{-1}) was obtained from the control plots (Table 3). Although there was a significant difference between treated and control plots, the amount of available P was in the range of high to very high in all plots based on the ratings of Landon (2014). The increase in available P in FYM-treated plots might be attributed to an increased P content of the FYM used in this study (Table 2). This showed that the application of FYM brought an increase in soil pH, which in turn reduced P fixation in acidic soils. In line with this result, Mann et al. (2006) reported enhanced P availability in the soil after the addition of organic manures in acidic soils. Similarly, Thamaraiselvi et al. (2012) reported the highest concentration of available P from the combined application of 15 t ha^{-1} FYM and 100 kg ha^{-1} P_2O_5 after harvesting lowland rice from rain-fed agriculture.

Concerning the effect of inorganic (N) fertilizer rates, the highest available P (19.74 mg kg^{-1}) was recorded from the control plot, while the lowest available P (18.76 mg kg^{-1}) was recorded at the rate of 103.5 kg ha^{-1} N fertilizer alone (Table 3). When the N fertilizer rate increases, the vegetative growth of maize also increases, which consequently increases the uptake of more essential nutrients from the soil by the maize plant. Alternatively, the soil's acidity might increase in the highest mineral N fertilizer, which might result in P fixation and a decrease in the amount of available nutrients. The study was in agreement with the findings of Admas et al. (2015) and Hepperly et al. (2009), who reported the importance of higher chemical fertilizer input to get higher crop productivity. However, overconfidence in mineral fertilizers is associated with a decline in some soil properties and crop yields over time and causes soil degradation.

3.3.6 *Exchangeable calcium (Ca^{+2})*

The sole application of FYM and in combination with N fertilizer significantly (p ≤0.01) affected the content of exchangeable Ca^{+2}, but not for exchangeable Mg^{2+} and Na^{+}. The maximum soil Ca (13.15 $cmol_c$ kg^{-1}) was recorded from the sole application of 15 ton ha^{-1} FYM and the lower (12.15 $cmol_c$ kg^{-1}) from the sole application of 69 kg ha^{-1} N fertilizer (Table 4). However, according to FAO (2006), the amount of Ca^{2+} in all treated and control plots were rated as high. The outcome was consistent with the findings of Ejigu et al. (2021), who reported that the interaction effect of organic and inorganic fertilizers significantly increased the exchangeable Ca^{2+} in acidic soils. Similarly, Munyabarenzi (2014) reported an increase in exchangeable Ca^{2+} in plots treated with organic fertilizer alone compared to inorganic fertilizer and control treatments after the harvesting of the maize crop.

3.3.7 *Exchangeable potassium (K^{+})*

The analysis of the results showed that exchangeable potassium was significantly ($P \leq 0.01$) affected by the main effects of FYM alone but not by the sole application of nitrogen or by the interaction effects of both factors. However, the exchangeable Mg^{2+} and Na^{+} did not show a significant difference between the individual application of FYM and/or nitrogen fertilizer rates (Tables 3 and 4).

The highest exchangeable K^{+} (0.728 cmolc kg^{-1}) was recorded from the addition rate of 15 ton ha^{-1} FYM, while the lowest (0.428 cmolc kg^{-1}) was recorded from the control plots (no FYM) (Table 3). In general, the amount of exchangeable K^{+} at the experimental site was in the range of optimum to high in all treated plots and optimum in the control plots (FAO, 2006). The result was in line with Redda and Kebede (2015) and Han et al. (2016), who reported an increase in major exchangeable cations, as well as potassium, nitrogen, and phosphorus, after the application of a large amount of organic manure that was attributable to their high content of nutrients.

3.3.8 *Exchangeable magnesium (Mg^{2+})*

Exchangeable Mg^{2+} was significantly ($P \leq 0.01$) affected only by the main effect of FYM but not by the sole application of N fertilizer or in combination with FYM (Table 3). Numerically, the highest soil Mg (3.01 $cmol_c$ kg^{-1}) was recorded from the addition of 15 ton ha^{-1} FYM, which was statistically at par with the result of 2.94 $cmol_c$ kg^{-1} recorded from the application of 10 ton ha^{-1} FYM, while the lowest soil Mg^{2+} (2.55 $cmol_c$ kg^{-1}) was recorded from the 0 t ha^{-1} FYM (Table 3).

According to FAO (2006), the soil at the experimental site after the treatment application showed a moderate level of magnesium, while the highest application of FYM showed a high level of magnesium. The result was in line with that of McClintock and Diop (2005), who reported that compost application increased the organic matter content, exchangeable bases (Ca, Mg, and K), and CEC of the soil. Wondimu (2011) also reported that the soil of Ethiopia contains a medium amount of Ca and Mg and a high amount of K.

3.3.9 *Exchangeable sodium (Na^{+})*

Exchangeable Na^{+} didn`t show a significant difference ($P > 0.05$) between the interaction effect and the main effect of organic (FYM) and inorganic (N) fertilizer rate applications. However, there was a numerical difference between treatments (Table 4). As per the ratings of FAO (2006), the amount of exchangeable Na^{+1} was low in all treated plots and the control group. In agreement with the results of this study, Qian et al. (2005) found that repeated application of swine manure for 5-7 years did not significantly increase extractable Na in the soil. Ejigu et al. (2021) also reported that the interaction effect of organic and inorganic fertilizer rates didn't show a significant difference in the exchangeable Na^+ content of the soil after harvest**.**

3.3.10 Cation exchange capacity of the soil

Following crop harvest, there were statistically significant ($P \leq 0.05$) changes in the CEC of the soil between plots treated with individual FYM fertilizers and those treated with an integrated N and FYM fertilizer. The application of 34.5 kg ha^{-1} N and 15 tons ha^{-1} FYM jointly produced the highest CEC (31.00 cmolc kg^{-1}), followed by 69 kg ha^{-1} N and 15 tons ha^{-1} FYM, while the control plots had the lowest (26.29 cmolc kg^{-1}) (Table 4).

According to Hazelton and Murphy (2007) ratings, all plots had a high CEC value, despite the fact that there was a substantial difference between the treatment and the control plots. A high CEC could indicate that more nutrients were retained in the soil, which would have slowed their release and reduced their mobility. The application of organic farmyard manure was the primary factor in the rise in negative surface charges, which may be linked to the increase in CEC. In conformity with this result, Redda and Kebede (2017) reported a significant increase in CEC due to the main effect of FYM and the interaction effect of FYM with inorganic fertilizers in the rice crop-cultivated farmlands of Tselemti District, northwestern Ethiopia. Similarly, Agegnehu et al. (2014) reported that when the proper amount of inorganic and organic fertilizer was applied, the soil became more fertile and had greater levels of organic matter and CEC content.

Table 4: The interaction effect of N and FYM fertilizer rates on selected soil properties after harvesting of maize

Nitrogen (kg ha^{-1})	FYM (t ha^{-1})	BD (gcm^{-3})	pH (H_2O)	OC (%)	TN (%)	Av.P (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})	Exchangeable cations (cmol$_c$ kg^{-1})			
								Ca^{+2}	Mg^{+2}	K^{+1}	Na^{+1}
0	0	1.26	5.30^{g}	1.94^{h}	0.133	17.47	26.29^{g}	12.30^{gh}	2.65	0.50	0.193
	5	1.21	5.35^{ef}	2.38^{f}	0.150	19.86	29.02^{c-e}	12.88^{b-e}	2.88	0.54	0.20
	10	1.21	5.44^{c}	2.49^{c-f}	0.157	20.61	29.43^{b-e}	13.01^{a-c}	2.99	0.69	0.196
	15	1.20	5.47^{ab}	2.55^{b-d}	0.163	21.02	30.00^{b}	13.15^{a}	3.08	0.77	0.201
34.5	0	1.25	5.30^{g}	2.07^{g}	0.140	16.96	27.04^{g}	12.20^{h}	2.56	0.45	0.193
	5	1.25	5.36^{e}	2.46^{d-f}	0.157	19.79	28.20^{f}	12.91^{a-e}	2.81	0.57	0.207
	10	1.22	5.44^{c}	2.45^{d-f}	0.167	20.81	29.47^{b-e}	12.96^{a-d}	2.96	0.68	0.207
	15	1.18	5.51^{a}	2.73^{a}	0.173	21.15	31.00^{a}	13.13^{a}	3.01	0.72	0.21
69	0	1.25	5.29^{g}	2.13^{g}	0.143	16.86	27.03^{g}	12.15^{h}	2.52	0.41	0.196
	5	1.20	5.33^{f}	2.53^{b-e}	0.157	19.50	28.90^{d-f}	12.94^{a-d}	2.81	0.60	0.200
	10	1.20	5.47^{b}	2.69^{a}	0.177	20.24	29.72^{bc}	13.10^{ab}	2.91	0.70	0.200
	15	1.15	5.49^{ab}	2.74^{a}	0.180	21.29	30.90^{a}	13.13^{a}	2.99	0.72	0.201
103.5	0	1.25	5.28^{g}	2.12^{g}	0.153	16.82	27.03^{g}	12.39^{gh}	2.47	0.35	0.193
	5	1.25	5.33^{f}	2.40^{f}	0.160	19.02	28.75^{ef}	12.51^{gf}	2.82	0.58	0.196
	10	1.20	5.41^{d}	2.61^{a-c}	0.163	19.43	29.48^{b-e}	12.76^{ed}	2.89	0.67	0.203
	15	1.17	5.42^{cd}	2.66^{ab}	0.183	19.77	29.56^{b-d}	12.84^{c-e}	2.93	0.70	0.203
LSD (P = 0.05)		NS	0.026**	0.13*	NS	NS	0.758*	0.24**	NS	NS	NS
SE±		0.006	0.0022	0.011	0.001	0.0112	0.066	0.021	0.019	0.007	0.0009
CV (%)		3.19	0.284	3.18	4.06	4.17	1.575	1.143	4.60	8.122	1.567

BD = Bulk density; pH = power of hydrogen; OC = Organic carbon; TN = Total nitrogen; AvP = Available phosphorus and CEC = Cation exchange capacity; Ca = Calcium; Mg = Magnesium; K = Potassium; Na= Sodium; ** Significant at P<0.01, * significant at P<0.05, NS = no significant difference

3.4 Effect of nitrogen and farm yard manure on phenological and growth parameters of maize

3.4.1 Days to 50% of tasselling and silking

The 50% tasselling and silking of the maize crop were significantly affected ($P \leq 0.05$) by the main and interaction effects of FYM and N fertilizers. The dual application of 103.5 kg ha^{-1} N and 15 t ha^{-1} FYM resulted in the longest days at 50% tasselling (62.0) and silking (67.0). However, the shortest days of tasseling (55.67) and silking (59.00) were recorded from the untreated plots (Table 5). The delay in tasselling and silking in the higher N fertilizer rates and FYM-treated plots could be attributed to the slow and timely release of essential nutrients from FYM throughout the growing season that promotes plants` photosynthesis and vegetative growth. These findings were in line with Basir et al. (2016), who reported a delayed date of silking and tasselling due to the gradual mineralization of nutrients from a FYM.

3.4.2 Days to 90% maturity

The interaction effects as well as the main effect of N and FYM fertilizers had a significant effect ($P \leq 0.05$) on maize maturity. The two combined treatments (69 kg ha^{-1} N + 15-tons ha^{-1} FYM and 103.5 kg ha^{-1} N + 15 t ha^{-1} FYM) had the longest days (133.67) to reach 90% maturity. On the other hand, the shortest (128.00) days were recorded for the control treatment (Table 5). This demonstrates how fertilizers containing FYM and N cause an increase in the days to physiological maturity. The delayed crop maturity in the high FYM and combined nutrient treatments may be associated with the gradual discharge of nutrients from the FYM, the crop's higher root growth, and the potential need for extended periods of time to use adequate nutrients and moisture resulting from the high soil BD or compaction. According to Basir et al. (2016), the application of mineral N and FYM delayed leaf senescence, sustained leaf photosynthesis during the active crop growth stage, and extended the duration of vegetative growth on the wheat crop. Similarly, Ali et al. (2013) and Matsi et al. (2003) suggested that delayed physiological maturity in FYM-treated plots may have been caused by the slow release of N from FYM, which is in line with our findings.

3.4.3 Plant height

The main effects of FYM and mineral N fertilizer rates and their interaction effects showed a significantly higher ($P \leq 0.01$) difference in maize plant heights. As a result, the treatment combination of 103.5 kg ha^{-1} N and 15 t ha^{-1} produced the tallest plant height (258.13 cm), while the control group produced the smallest plant height (199.53 cm) (Table 5). The increase in plant height might be associated with the integrated application of FYM and nitrogen fertilizer, which improves the physical, chemical, and biological properties of the soil. This leads to improvements in root growth and development and, thereby, the uptake of nutrients and water from greater soil volume, resulting in better plant growth (Achieng et al. 2010). The result was in agreement with Akinnifesi et al. (2007), who reported an increase in plant height after the application of organic and inorganic fertilizers to maize crops. In the same vein, Yigermal et al. (2019) observed a noticeably higher plant height following the application of 150 kg ha^{-1} N along with 10 t ha^{-1} FYM to the maize crop.

3.4.4 Lodging percentage

There was a significant difference ($P \leq 0.05$) in the lodging percentage between the main effects of FYM and N fertilizer rates and their interaction effects. The lowest lodging percentage (6.67%) was recorded at 69 kg ha^{-1} N combined with 10 t ha^{-1} FYM. On the other hand, the control plots had the greatest lodging proportion (33.33%) (Table 5). The thin and spindly stems were the cause of the increased lodging percentage in the treatments with lower rates of fertilizer.

According to Brady and Weil (2002), plants that are deficient in N develop thin and spindly stems, which are susceptible to lodging mainly by wind and heavy rain storms. Moreover, N-deficient plants have poor root systems, which reduce their anchorage capacity. Similar to the shortage of fertilizer, too much N fertilizer causes excessive vegetative growth that exposes top-heavy plants prone to lodging during heavy rain or wind periods. Contradicting this result, Selassie (2015) also reported a reduced lodging percentage of maize on Alfisols in north-western Ethiopia with the increased application of N fertilizer rates.

3.5 Effects of nitrogen and farmyard manure on yield and yield component of maize

3.5.1 Number of cobs per plant

The number of cobs per plant was significantly (P ≤ 0.01) affected by the interaction and the main effects of FYM and mineral N fertilizer rates. The maximum number of cobs per plant (1.22) was recorded from a combination of 103.5 kg ha^{-1} N and 10 t FYM ha^{-1}. However, the minimum number of cobs per plant (1.0) was obtained from the control (Table 6). This outcome was consistent with that of Wang et al. (2020), who reported a significantly increased maize cob per unit area after the application of organic manure combined with mineral fertilizer.

3.5.2 Ear length

The interaction and the main impacts of FYM and N fertilizer rates had a significant (P ≤ 0.05) effect on the ear length of maize. The interaction effects of 10 t ha^{-1} FYM and 69 kg ha^{-1} N produced the longest ear length (22.63 cm). However, the minimum ear length (16.80 cm) was recorded from the control plots (Table 6). The result indicated that an adequate supply of nutrients from both organic and inorganic sources during vegetative growth is necessary for proper ear length development in maize plants. The outcome was consistent with the findings of Chapagain and Gurung (2010), who observed vigorous plant growth, increased ear length, cob length, and grain yield in the maize crop following the application of FYM along with 50% of the recommended rate of urea fertilizer. In a similar study, Ahmad et al. (2018) reported a significant increase in ear length with increased rates of N and P fertilizer application from different sources.

Table 5: The interaction effects of nitrogen and farmyard manure fertilizers on maize phenological characteristics

Nitrogen (kg ha^{-1})	FYM (t ha^{-1})	Day to 50% tasseling	Day to 50% silking	Day to 90% maturity	Plant height (cm)	Lodging (%)
0	0	55.67^{h}	59.0^{g}	128.00^{h}	199.53^{g}	33.33^{a}
	5	57.67^{g}	61.67^{f}	129.33^{g}	210.00^{f}	26.67^{a-c}
	10	59.67^{de}	63.33^{de}	130.67^{ef}	224.07^{e}	24.00^{d-f}
	15	59.67^{de}	64.00^{cd}	131.67^{cd}	224.13^{e}	18.67^{b-d}
34.5	0	58.0^{g}	61.67^{f}	130.13^{f}	222.53^{d}	30.67^{ab}
	5	59.0^{ef}	62.67^{e}	130.33^{f}	234.73^{cd}	26.67^{a-c}
	10	60.0^{cd}	65.00^{b}	132.33^{bc}	234.87^{cd}	16.33^{ef}
	15	60.67^{bc}	65.33^{b}	132.35^{bc}	239.27^{bc}	12.00^{fg}
69	0	58.33^{fg}	63.00^{e}	131.33^{de}	234.60^{cd}	18.67^{d-f}
	5	59.67^{de}	64.67^{bc}	132.00^{b-d}	240.93^{bc}	21.33^{c-e}
	10	61.33^{ab}	66.33^{a}	132.67^{b}	253.33^{a}	6.67^{g}
	15	61.67^{a}	66.67^{a}	133.67^{a}	254.93^{a}	11.33^{fg}
103.5	0	59.33^{de}	63.33^{de}	130.67^{ef}	240.07^{bc}	18.67^{d-f}
	5	59.67^{de}	64.67^{bc}	132.00^{b-d}	241.87^{b}	13.33^{fg}
	10	61.33^{ab}	66.67^{a}	132.68^{b}	254.93^{a}	14.65^{ef}
	15	62.0^{a}	67.00^{a}	133.67^{a}	258.13^{a}	14.67^{ef}
LSD (p=0.05)		0.80*	0.73 *	0.99*	6.86**	7.61*
SE±		0.07	0.063	0.085	0.59	0.66
CV (%)		0.8	0.68	0.45	1.75	23.76

LSD = Least Significant Difference at 5% level; CV = Coefficient of Variation; SE = Standard error; ** highly significant at p<0.01, * significant at P < 0.05, NS = no significant difference

3.5.3 Ear diameter

Ear diameter was significantly (P ≤ 0.01) affected by the interaction and the main effects of FYM and N fertilizer rates. The highest ear diameter of maize (4.98 cm) was recorded from the interaction effects of 69 kg ha^{-1} N and 10 t ha^{-1} FYM. On the other hand, the control plots had the lowest ear diameter (3.35 cm) (Table 6). These results were consistent with those of Baharvand et al. (2014), who found that applying organic manure and mineral fertilizer together resulted in a considerably larger ear diameter. Similarly, Badu (2014) showed that the utilization of both FYM and inorganic (N) fertilizer together provides an adequate supply of vital nutrients, which improves cell activity, cell multiplication, enlargement, and ear diameter in the maize crop

3.5.4 Aboveground biomass yield

The aboveground biomass yield of maize was significantly (P $\leq$ 0.05) affected by the interaction as well as the main effects of FYM and mineral N fertilizer rates. The combination of 103.5 kg ha^{-1} N and 15 t ha^{-1} FYM produced the highest aboveground biomass yield (25.83 t ha^{-1}). But the control plots had the lowest aboveground biomass yield (15.17 t ha^{-1}) (Table 6). The overall improvement of the plant's vegetative development brought about by the combined application of organic and inorganic fertilizers may lead to a rise in biomass production. The outcome was consistent with that of Achieng et al. (2010), who demonstrated that the combination application of organic and mineral fertilizers increased grain and straw yield. In a related investigation, Dilshad et al. (2010), from a two-year study, also showed that the application of 50% NPK (60–45–30 kg ha$^{−1}$) with 50% FYM (10 t ha$^{−1}$) produced the highest biological yield of the maize crop.

3.5.5 Thousand grain weight

The interaction effect and the main effects of FYM and N fertilizer rates both significantly (P $\leq$ 0.01) affected the thousand grain weight. The highest thousand grain weight (415.97 g) was recorded from the application of 69 kg ha^{-1} N with 10 t ha^{-1} FYM and the lowest (299.47 g) from the control plots (Table 6). The result was corroborated by Achieng et al. (2010), who reported an increase in grain weight in maize crops due to the balanced supply of nutrients from both urea and FYM throughout the grain filling and development period. The bigger ear size provided sufficient space for the development of an individual grain, leading to a higher thousand-grain weight at a sufficient supply of N and FYM fertilizer (Gurmu and Mintesnot, 2020).

Table 6: Interaction effects of N and FYM rates on yield and yield parameter

Nitrogen (kg ha^{-1})	FYM (t ha^{-1})	Cob per plant	Ear length (cm)	Ear diameter (cm)	AGBY (t ha^{-1})	TGW (g)	GY (kg ha^{-1})	HI (%)
	0	1.00^{g}	16.80^{h}	3.35^{h}	15.17^{g}	299.47^{k}	4534.1^{h}	29.56^{h}
	5	1.08^{f}	18.60^{g}	4.16^{g}	16.80^{f}	319.67^{j}	5200.0^{gh}	30.96^{f-h}
0	10	1.09^{ef}	19.73^{ef}	4.33^{eg}	18.62^{e}	329.73^{ij}	5950.6^{fg}	31.95^{e-h}
	15	1.14^{cd}	20.27^{c-f}	4.35^{eg}	20.19^{d}	363.67^{ef}	6150.6^{ef}	30.49^{gh}
	0	1.10^{ef}	19.60^{fg}	4.21f^{g}	19.22^{e}	339.13^{i}	6148.1^{ef}	31.99^{e-h}
	5	1.11^{ef}	19.73^{ef}	4.46^{de}	20.19^{d}	345.40^{hg}	6587.7^{d-f}	32.62^{d-g}
34.5	10	1.19^{ab}	21.27^{bc}	4.75^{bc}	21.35^{c}	379.43^{c-e}	6918.5^{c-e}	32.40^{d-g}
	15	1.12^{de}	20.73^{b-e}	4.50^{de}	22.01^{bc}	379.93^{c-e}	7348.1^{b-d}	33.31^{d-g}
	0	1.11^{ef}	20.00^{df}	4.53^{de}	21.72^{bc}	342.90^{hi}	6804.9^{c-e}	31.30^{f-h}
69	5	1.19^{ab}	20.67^{b-e}	4.64^{cd}	22.43^{b}	368.10^{de}	7876.5^{b}	35.11^{b-d}
	10	1.21^{a}	22.63^{a}	4.98^{a}	25.20^{a}	415.97^{a}	10035.8^{a}	39.52^{a}
	15	1.21^{a}	21.47^{b}	4.87^{ab}	25.72^{a}	395.57^{b}	9501.2^{a}	36.95^{ab}
	0	1.17^{bc}	20.97^{b-d}	4.41^{ef}	21.79^{bc}	351.20^{fg}	7571.4^{bc}	34.72^{b-e}
103.5	5	1.19^{ab}	20.73^{b-e}	4.43^{e}	22.54^{b}	341.90^{hi}	7567.9^{bc}	33.89^{c-f}
	10	1.22^{a}	21.53^{b}	4.76^{bc}	25.59^{a}	383.27^{b-d}	9476.5^{a}	37.00^{ab}
	15	1.21^{a}	21.67^{ab}	4.87^{ab}	25.83^{a}	390.80^{bc}	9401.0^{a}	36.40^{bc}
LSD (0.05)		0.033**	1.02*	0.204**	0.86*	15.83**	787.87**	2.99*
SE±		0.0024	0.088	0.018	0.075	1.37	68.19	0.26
CV (%)		1.72	2.99	2.74	6.46	2.64	6.46	5.33

AGBY = aboveground biomass yield; TGW = Thousand grain weight; GY = Grain yield; HI = Harvest index; ** significant at p<0.01, * significant at P < 0.05, NS = no significant difference

3.5.6 Grain yield

Grain yield was significantly ($P \leq 0.01$) affected by the interaction as well as the main effects of FYM and N fertilizer rates. The highest grain yield of 10,035.8 kg ha^{-1} was recorded from the combined application of 69 kg ha^{-1} N and 10 t ha^{-1} FYM. However, the lowest grain yield (4534.1 kg ha^{-1}) was recorded from the control plots (Table 6). Increased application of N fertilizer and FYM increased the grain yield of maize in this study due to an increase in the fertility level of the soil, sufficient nutrient availability for crops, and a reduced lodging percentage. The results were similar to the findings of Achieng et al. (2010) and Shah et al. (2009), who reported the positive effects of the combined use of organic and chemical fertilizers in increasing soil fertility and grain yield in maize crops compared to either the sole application of urea or FYM.

3.5.7 Harvest index

The major effects of FYM and N fertilizer, as well as the interaction between the two, significantly ($P < 0.05$) affected the harvest index. The highest harvest index (39.52%) was recorded from the combined application of 69 kg ha^{-1} N and 10 t ha^{-1} FYM, while the lowest (29.56%) was recorded from the control plots (Table 6). The harvest index increases, but the biomass has in many cases been slight; hence, the rise in harvest index might be due to reduced investment in non-harvested organs and a higher grain yield from biomass ranches. The result was in line with Shah et al. (2009), who reported a significant effect of the organic and inorganic sources of fertilizers on the harvest index of the maize crop.

3.6 Partial budget analysis

The outcomes of the economic analysis, which was conducted using a partial budget analysis approach, are shown in Table 7. Investment was not significantly affected by treatments that yielded lower net financial benefits (NFBs).These treatments are referred to as dominant, and the partial budget analysis removed them and assigned a "D." Since the prices of other agronomic techniques were very comparable for all treatments, all expenses were computed without taking that into account. However, a partial budget analysis was conducted using the following data: FYM (400 ETB per ton) estimated from dung (to be used as fuel wood), the official price of urea as a source of N (15.09 ETB per kg), and the farm gate price at which farmers sold maize on the local market during harvesting season (10 ETB kg^{-1}). In addition, average FYM transport and application costs (250 ETB per ton) and mineral N fertilizer transport and application costs (split application) (250 ETB per 100 kg) were used during the 2020 cropping season.

The grain yield of maize was adjusted downward by 10% to reflect the real farmer`s expected yield as a production management condition. In this study, a 100% marginal rate of return (MRR) was considered the minimum acceptable rate of return for farmers' recommendations (CIMMYT, 1988). When 69 kg ha^{-1} N and 10 tons ha^{-1} FYM were applied, the partial budget analysis result showed a maximum net benefit of 81,258.7 ETB ha^{-1} with an acceptable MRR (497.96%) (Table 7). Hence, the treatment produced 40,451.8 ETB ha^{-1} more compared to no input used. Nevertheless, the single applications of 34.5 kg ha^{-1} N fertilizer were the cause of the highest MRR (951.28%), with NFB 53,951.15 ETB and 13,144.25 ETB difference over income as compared to the control treatment (Table 7).

According to the economic analysis of CIMMYT (1988), the treatment recommendation is not necessarily based on the highest marginal rate of return but on the lowest cost, the highest net benefit, and the highest grain yield. Therefore, for maize production in the study area, the application of 69 kg ha^{-1} N along with 10 t ha^{-1} FYM was the most recommended and economically feasible. This resulted in a net benefit of 81,258.7 ETB ha^{-1} with an acceptable MRR of 497.96%. The result was in line with Jinwei and Lianren (2011) and Lingaraju et al. (2010), who found that a combined application of organic manure and inorganic fertilizer produced a high net benefit income and cost-benefit ratio compared with the sole application of either organic or inorganic fertilizer on the maize crop.

Table 7: Partial budget analysis of the combined effect of nitrogen and farm yard manure fertilizer rates on grain yield of maize

N (kg ha^{-1})	FYM (t ha^{-1})	AGY (kg ha^{-1})	GFB (ETB)	VCN (ETB)	VCFYM (ETB)	TVC (ETB)	NFB (ETB)	MRR (%)
0	0	4080.69	40806.9	0	0	0	40806.90	-
34.5	0	5533.29	55332.9	1381.75	0	1381.75	53951.15	951.28
69	0	6124.41	61244.1	2563.50	0	2563.50	58680.60	400.21
0	5	4680.00	46800.0	0	3250	3250.00	43550.00	D
103.5	0	6814.26	68142.6	3745.25	0	3745.25	64397.35	483.75
34.5	5	5928.93	59289.3	1381.75	3250	4631.75	54657.55	D
69	5	7088.85	70888.5	2563.50	3250	5813.50	65075.00	32.76
0	10	5355.54	53555.4	0	6500	6500.00	47055.40	D
103.5	5	6811.11	68111.1	3745.25	3250	6995.25	61115.85	D
34.5	10	6226.65	62266.5	1381.75	6500	7881.75	54384.75	D
69	10	9032.22	90322.2	2563.50	6500	9063.50	81258.70	497.96
0	15	5535.54	55355.4	0	9750	9750.00	45605.40	D
103.5	10	8528.85	85288.5	3745.25	6500	10245.25	75043.25	D
34.5	15	6613.29	66132.9	1381.75	9750	11131.75	55001.15	D
69	15	8551.08	85510.8	2563.50	9750	12313.50	73197.30	D
103.5	15	8460.90	84609.0	3745.25	9750	13495.25	71113.75	D

AGY = Adjusted grain yield, GFB = Gross field benefits, VCN = Variable cost of nitrogen, VCFYM = Variable cost of farmyard manure, TVC = Total variable cost, NFB = Net financial benefits, MRR = Marginal rate of return, D = dominated

4. Conclusion

The present study showed that the integrated application of FYM and N fertilizers significantly improved the soil pH, OC, and CEC. Similarly, the sole application of FYM considerably improved soil pH, OC, total N, available P, CEC, and exchangeable K and decreased soil BD. The overall result demonstrated that the combined applications of 34.5 kg ha^{-1} N and 15 t ha^{-1} FYM, 69 kg ha^{-1} N and 10 t ha^{-1} FYM, and 69 kg ha^{-1} N and 15 t ha^{-1} FYM, and the sole applications of 10 and 15 t ha^{-1} FYM with a blanket application of P (20 kg ha^{-1}) fertilizers improved soil physicochemical properties. Similarly, the combined application of 69 kg ha^{-1} N and 10 t ha^{-1} FYM, 69 kg ha^{-1} N and 15 t ha^{-1} FYM, 103.5 kg ha^{-1} N and 10 t ha^{-1} FYM, and 103.5 kg ha^{-1} N and 15 t ha^{-1} FYM improved maize yield and yield components. This could have been caused by the application of organic and inorganic fertilizers, which increased soil fertility and supplied the maize crop with essential nutrients. Nonetheless, the combined application of 10 t ha^{-1} FYM and 69 kg ha^{-1} N was economically feasible, enhanced soil characteristics, and increased grain yield with an acceptable marginal rate of return. Therefore, this treatment combination could be recommended for maize production in the Nitisols of the study area. However, additional research is required to ascertain the precise integration rate of FYM and mineral fertilizer as well as to look into the long-term residual effects of FYM and mineral fertilizers among different soils and agro-ecologies.

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Data availability

The data used and/or analyzed are available from the first author on reasonable request.

Conflict of interest

The authors disclosed no potential conflicts of interest.

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