Integrated fertilizer application improves soil properties and maize (Zea mays L.) yield on Nitisols in Northwestern Ethiopia

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ABSTRACT

Soil fertility depletion is emerging as a serious challenge causing low crop yields and food insecurity in Ethiopia. An on-farm experiment was conducted in 2017/2018 cropping season to investigate the effects of combined application of compost and mineral fertilizer on selected soil properties and maize yield in North-western Ethiopia. Treatments were factorial combinations of three rates of Urea/NPSB (0/0, 50/50 and 100/100 kg ha$^{-1}$) and three rates of compost (0, 5 and 10 t ha$^{-1}$). The field experiment was arranged in randomized complete block design (RCBD) with three replications. Results showed that combined application of compost and mineral fertilizer significantly (p < 0.05) increased soil pH, organic carbon (OC), total nitrogen (TN), available phosphorus (AP), available sulphur (AS) and cation exchange capacity (CEC) compared to sole mineral fertilizer application and the control. On the other hand, there was significant (p < 0.01) decrease in soil bulk density. Plots amended with 10 t ha$^{-1}$ compost and 100/100 kg ha$^{-1}$ Urea/NPSB provided the highest maize dry biomass (18.62 t ha$^{-1}$) and grain yield (6.07 t ha$^{-1}$). Conversely, the lowest biomass (5.70 t ha$^{-1}$) and grain (1.17 t ha$^{-1}$) yields were obtained from the control. The partial budget analysis also showed that the highest net benefit (32700 Birr ha$^{-1}$) was obtained from combined addition of organic and mineral fertilizer which was significantly higher than applying the highest rate of sole mineral fertilizer (27438 Birr ha$^{-1}$), highest rate of sole compost (9011.3 Birr ha$^{-1}$) and the control (7660 Birr ha$^{-1}$). Therefore, we concluded that integrated fertilizer management improves soil properties and crop yield in the highlands of north-western Ethiopia.

INTRODUCTION

Soil fertility depletion is one of the causal factors that threaten agricultural productivity and food security in Ethiopia like in many Sub-Saharan Africa (SSA) countries (Sanchez, 2002). The soils of the Ethiopian highlands are deficient in most macro/micronutrients and organic matter content (Elias, 2016). In Ethiopia, findings on nutrient balance indicated a depletion rate of 122 kg N ha$^{-1}$ yr$^{-1}$, 13 kg P ha$^{-1}$ yr$^{-1}$ and 82 K kg ha$^{-1}$ yr$^{-1}$ which were rated twice as high as the average nutrient depletion rate for SSA (Haileslassie et al., 2005). Furthermore, the average soil organic carbon balance in the highlands of Ethiopia was -3.7 t ha$^{-1}$ yr$^{-1}$ which steadily decreases through time (Van Beek et al., 2018).

The application of mineral fertilizers like urea (46% N) and diammonium phosphate (DAP: 18% N, 46% P$_2$O$_5$) are the common practices for maintaining soil fertility in Ethiopia (Elias et al., 2019). However, resource poor farmers have been applying low rates of mineral fertilizer due mainly to high cost of fertilizer and lack of soil and crop specific recommendations (Tamene et al., 2017). The national average application rates of 45 kg ha$^{-1}$ DAP and 33 kg ha$^{-1}$ urea for maize is far below the extension recommendation of 150 kg DAP and 100 kg urea ha$^{-1}$ (Elias, 2017). Furthermore, continuous addition of fertilizers containing N and P alone would mainly increase uptake and depletion of secondary nutrients such as sulfur and micronutrients like zinc and boron (Elias, 2016). In recent years, blended fertilizers have been introduced to include sulfur (S), zinc (Zn) and boron (B) in addition to N and P fertilizers (Elias et al., 2019). Nevertheless, continued use of chemical fertilizer is not a sustainable solution as it may cause soil quality deterioration such as increasing of soil acidity, loss of organic matter and depletion of nutrients that are not supplied in the fertilizer formulation (Liu et al., 2010).

The available evidences suggest that the addition of compost plays a vital role in improving soil properties such as increasing soil porosity,

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available water, organic matter, nutrients status, crop yields as well as lowering soil bulk density (Agegnehu et al., 2016; Mengistu et al., 2017). However, small-scale farmers can not afford to add the required amounts of compost due to limited organic resources, competing uses such as animal feed and fuel, labour shortage for preparation and transporting of compost given the bulkiness of compost required for adequate supply of plant nutrients (Abunyewa et al., 2007; Nigussie et al., 2015). Therefore, addition of compost alone as a substitute to inorganic fertilizers is not a sustainable solution to meet the nutrient needs of crops and to optimize crop yields (Fanuel and Gifole, 2013). On the other hand, application of locally available organic inputs such as compost, manures and crop residues combined with mineral fertilizers are considered as the best strategy for improving soil fertility and increasing crop productivity (Agegnehu et al., 2016; Bedada et al., 2014; Vanlauwe et al., 2010). However, adoption of compost application along with mineral fertilizers for improving soil fertility and maize production is poor in the study area. In order to persuade farmers to combined addition of compost and mineral fertilizers, its effect on soil fertility and maize productivity needs to be investigated. Furthermore, soil and crop specific recommendation on combined application of compost and blended mineral fertilizers is lacking. Therefore, this study was designed to investigate the effect of compost and mineral fertilizer application on selected soil properties and maize yields in the highlands of North-western Ethiopia.

2. Materials and methods

2.1. Description of the study area

The study was conducted on farmers’ fields at Mosobo Kebele, Yilmana Densa district, West Gojam Zone of North-Western Ethiopia (Figure 1). Geographically, the area is located at 11° 15’ 49” to 11° 19’ 35” N and 37° 26’ 47” to 37° 29’ 21” E. The altitude ranges from 1500 to 3500 m above sea level falling in a tepid moist to cool highlands agro-ecological zone. The landforms of the area are characterized by undulating to rolling plateaus, scattered moderate hills, dissected side slopes and river gorges (Elias, 2016). Based on a 14 years (2004–2017) climatic data obtained from the National Meteorological Service Agency, the district receives a mean annual rainfall of 1421.3 mm. The main rainy season occurs between June and September (Figure 2). The mean minimum and maximum temperatures of the area are 12.29 and 27.56 °C, respectively.

According to the report (unpublished) of Yilmana Densa District Office of Agriculture, the major land use patterns of the study area comprise cultivated land (57%), forest and bushes (2%), grazing land (33%) and others (8%). The area falls within the highland mixed crop-livestock system with cereals and pulses forming the bulk of the staples. Maize is the dominant cereal along with tef (Eragrostis tef Zucc. Trotter), wheat (Triticum aestivum L.), and barley (Hordeum vulgare) while potato (Solanum tuberosum) and field pea (Pisum sativum) are rotational crops. The area falls within the high potential maize producing belt of the Ethiopian highlands.

The major soil types of the area are Nitisols covering 45% of the soil-landscape followed by Vertisols (30%), and Luvisols (25%). This on-farm experiment was conducted on Luvic Nitisols which is the most dominant soil in the study area. Geologically, basaltic basement complex that over flowed by lava in the Tertiary-Quaternary volcanic rocks, resulted in young soils that are developed over pre-weathered materials (Elias, 2016).

2.2. Experimental treatments and design

The treatments were a factorial combination of three rates of urea/NPSB (0/0, 50/50 and 100/100 kg ha⁻¹) and three rates of compost (0, 5 and 10 t ha⁻¹). The field experiment was arranged in randomized complete block design (RCBD) with three replications. The spacing between blocks, plots, rows and plants were 1.5, 1.0, 0.75 and 0.3 m, respectively. Gross plot size was 3.75m by 2.4m (9 m²) whereas the net plot size was 2.25 m x 0.9 m (2.025m²).

The experimental field was ploughed three times before maize planting which is conventional practice in the area. An improved maize variety (BH-540) promoted by the extension system was used as test crop. As per the treatment, the entire dose of NPSB blend fertilizer (18.1N + 36.1 P₂O₅ + 6.75 + 0.71 B) was applied at sowing. While urea fertilizer was applied in two splits, first half at sowing and the remaining half at tillering stage of maize plants by side-dressing. Well matured compost prepared from locally available materials including crop residues, animal manures, green leaves and ash was used for this field experiment. For compost making, small pit with a volume of 1m³ was dug. Then, the pit was filled with composting materials in five layers as follows. In the first
layer, chopped maize straw was piled up to 20 cm layer. In the second layer, a mixture of wheat and barley straw was added up to 30 cm thickness. The third layer was composed of animal manure piled up to 3 cm thickness on top of which 2 kg ash was spread. Fourth, green materials from leguminous shrubs and trees were added up to 25 cm thickness. The fifth layer contains garden topsoil weighing 3 kg. The materials in the pit were overturned every 21 days to allow air circulation. Composting proceeded for 6 months (from 2 Sep 2016 to 30 Feb 2017). In order to determine the moisture content, compost sample was taken and oven dried at 105 °C for 24 h until it comes to a constant weight. After deducting the moisture content, fresh compost measured on dry weight basis was applied 21 days before sowing. All agronomic practices for maize production were followed as per the extension recommendation.

2.3. Soil and compost sampling and analysis

Composite soil samples at the depth of 0–20 cm were collected before planting and after harvest from each treatment and replication using Edelman auger. Soil samples were air dried and ground to pass through 2 mm sieve for analysis of soil pH, texture, available phosphorus, exchangeable bases, and CEC; while soil samples were passed through 0.5 mm sieve for organic carbon and total nitrogen analysis. In addition, to determine the nutrient composition of compost, composite compost sample was taken, air dried, crushed and screened through 2 mm sieve for laboratory analysis. Then, both the soil and compost samples were analysed at Horticoop soil analysis laboratory following standard laboratory procedures.

Soil texture was analysed using Bouyoucos Hydrometer method (Bouyoucos, 1962). Bulk density was determined using a core sampler (Blake and Hartge, 1986). Soil pH-water was measured potentiometrically with PHS-3E pH meter in the supernatant suspension of 1:2.5 soils to water ratio (Van Reeuwijk, 2002). TN was determined using ammonium acetate (NHOAC) as outlined in Van Reeuwijk (2002). CEC was measured after extracting the soil with 1 M ammonium acetate (NHOAC) as outlined in Van Reeuwijk (2002). Exchangeable Ca, Mg, K, Na and AS were analysed by Meliche-3 method (Mehlich, 1984). CEC was measured after extracting the soil with 1 M ammonium acetate (NHOAC) as outlined in Van Reeuwijk (2002).

2.4. Characteristics of soil and compost before planting

The soil physico-chemical properties and compositions of compost before planting are presented in Table 1 and Table 2. The data showed that the soil is clay loam in texture, strongly acidic, deficient in soil OC, TN, AP and AS but moderate in exchangeable K⁺ and high in exchangeable Ca²⁺ and Mg²⁺. Exchangeable K⁺ content was moderate that suggests application of potassium fertilizers may be required by considering types of crops grown. The higher exchangeable Ca²⁺ and Mg²⁺ of the soil could be attributed to the presence of Ca and Mg rich minerals derived from basaltic parent materials (Elias, 2017). The high content of CEC is consistent with the high levels of clay which has greater surface area for nutrient and cation retention (Elias, 2016). The compost used for the study had a pH of 7.29, OC content of 8.89%, TN of 0.9%, AP content of 290.3 mg kg⁻¹ and AS of 498.2 mg kg⁻¹ (Table 2). The exchangeable Ca²⁺, Mg²⁺, K⁺, Na⁺ and CEC contents of compost were 26.7, 9.6, 8.9 and 0.4 and 38.40 Cmol (c) kg⁻¹, respectively. The result therefore showed the potential of compost application as soil amendment to tackle the low levels of nutrients and organic matter content in the soil.

2.5. Agronomic data collection

Agronomic data collected include plant height, dry biomass, grain and straw yields, and thousand grains weight (TGW). Plant height was recorded by measuring height from the soil surface to the base of the tassel of ten randomly taken maize plants and average value was used. Above ground dry biomass (AGDB) yield was determined by weighing

![Figure 2. Rainfall and temperature distributions (2004-2017) at the study area.](image-url)

Table 1. Selected physico-chemical properties of Nitisols at planting.

| Parameters                  | Values | Rating   | References               |
|-----------------------------|--------|----------|--------------------------|
| Sand (%)                    | 25     | -        |                          |
| Silt (%)                    | 33     | -        |                          |
| Clay (%)                    | 42     | -        |                          |
| Textural Class              | Clay   |          | Weil and Brady (2016)    |
| BD (g cm⁻³)                 | 1.41   | Medium   | Hazleton and Murphy (2007) |
| pH(H₂O)                     | 5.54   | Strongly acidic | Landon (1991a, b)         |
| OC (%)                      | 1.29   | Very low | Landon (1991a, b)         |
| TN (%)                      | 0.12   | Low      | Landon (1991a, b)         |
| AP (mg kg⁻¹)                | 4.10   | Very low | Landon (1991a, b)         |
| AS (mg kg⁻¹)                | 10.90  | Low      | Ethiosis (2016)           |
| Ca (Cmol (c) kg⁻¹)          | 14.54  | High     | FAO (2006)                |
| Mg (Cmol (c) kg⁻¹)          | 5.66   | High     | FAO (2006)                |
| K (Cmol (c) kg⁻¹)           | 0.48   | Medium   | FAO (2006)                |
| Na (Cmol (c) kg⁻¹)          | 0.08   | Very low | FAO (2006)                |
| CEC (Cmol (c) kg⁻¹)         | 29.18  | High     | Hazleton and Murphy (2007) |
the whole above ground plant parts from the net plot area after complete sun-drying for five days. Grain yield was collected from three harvestable rows and measured using sensitive balance by adjusting to 12.5% moisture content and converted to hectare basis. TGW was recorded from the grain samples drawn randomly from the net plot produce of each treatment and the weight were adjusted to 12.5% seed moisture content. Harvest index was calculated by dividing grain yield by the AGDB yield.

2.6. Statistical analysis

The effect of treatments on soil properties and crop parameters were statistically analyzed using two-way analysis of variance (ANOVA) with Statistical Analysis System (SAS) software (SAS (Statistical Analysis System) Institute, 2008). When the ANOVA result showed significant difference among treatments for each parameter, least significant difference (LSD) test at 5% probability level was applied for means separation.

2.7. Economic analysis

Economic analysis was conducted based on the procedure provided by CIMMYT (1988). Total variable costs were estimated by considering the current prices of urea (12.9 BIRR kg⁻¹, 1$ = 29.8 BIRR), NPSB (15.2 BIRR kg⁻¹) and labour cost of compost preparation based on World Food Program work norms of 1100 BIRR and 2200 BIRR for 5 t ha⁻¹ and 10 t ha⁻¹, respectively. The gross benefit was calculated by multiplying maize grain and straw yields with their current prices (6.5 and 0.2 BIRR kg⁻¹, respectively). Net benefits were calculated by subtracting total costs from gross benefit for each treatment. Dominance analysis was done for the net benefits of treatments. The dominated treatments were removed from further economic analysis. Lastly, marginal rate of return (MRR) for the dominant treatments was estimated using the formula below:

\[
\text{MRR} (%) = \frac{\text{Net benefit from superior dominant plot} - \text{Net benefit from inferior dominant plot}}{\text{Total variable cost from superior dominant plot} - \text{Total variable cost from inferior dominant plot}} \times 100
\]

3. Results

3.1. Interaction effects of compost and mineral fertilizer addition on selected soil properties

Results of laboratory analysis of soil samples collected after harvest showed that the addition of compost combined with mineral fertilizer significantly (p < 0.05) affected soil bulk density, pH, OC, TN, AP, AS and CEC of the soil (Table 3). The addition of compost alone or combined with inorganic fertilizer significantly (p < 0.01) decreased soil bulk density compared to sole mineral fertilizer and the control (Table 3). The highest soil bulk density (1.37 g cm⁻³) was recorded from the control plots while the lowest value (1.22 g cm⁻³) was observed in plots treated with 10 t ha⁻¹ compost alone which showed 12.3 and 9.8% decrease compared to the control and sole mineral fertilizer application, respectively.

The application of compost alone or combined with mineral fertilizer significantly (p < 0.05) increased soil pH compared to application of sole mineral fertilizer and the control (Table 3). The highest soil pH (5.68) was obtained from plots amended with 10 t ha⁻¹ compost while the lowest (5.45) was recorded from treatments that received the highest rate of mineral fertilizers (Table 3). This depicts that the addition of compost resulted in consistent increase in soil pH while mineral fertilizers reduced it over the control. The results showed that plots treated with 10 t ha⁻¹ compost along with the full dose of mineral fertilizer resulted in the highest levels of soil OC (1.96%), TN (0.22%), AP (10.90 mg kg⁻¹) and AS (14.15 mg kg⁻¹) (Table 3). The highest content of soil OC was 39 and 35.2% higher than plots which received the full dose of mineral fertilizer and the control treatment, respectively. Furthermore, the highest TN showed 57.1 and 83.3% increase over the full dose of mineral fertilizer.

| Parameter | pH (H₂O) | OC (%) | TN (%) | C:N | AP (mg kg⁻¹) | AS (mg kg⁻¹) | Exchangeable bases (Cmol (+) kg⁻¹) | CEC (Cmol (+) kg⁻¹) |
|-----------|-----------|-------|--------|-----|-------------|-------------|-------------------------------|-------------------|
| Value     | 7.29      | 8.89  | 0.9    | 9.88| 290.3       | 498.2       | 26.7                          | 9.6               |

| Parameter | Ca | Mg | K | Na |
|-----------|----|----|---|----|
| Value     | 26.7 | 9.6 | 8.9 | 0.4 |
| Total     | 38.40 | |

| Table 3. Interaction effects of compost and mineral fertilizers on selected soil properties. |
|---------------------------------|----|----|--------|-----|-------------|-------------|-------------------------------|-------------------|
| Compost (t ha⁻¹) | Urea/NPSB (kg ha⁻¹) | BD (g cm⁻³) | pH (H₂O) | OC (%) | TN (%) | AP (mg kg⁻¹) | AS (mg kg⁻¹) | Exchangeable bases (Cmol (+) kg⁻¹) | CEC (Cmol (+) kg⁻¹) |
|-----------------|---------------------|--------------|-----------|-------|--------|-------------|-------------|-------------------------------|-------------------|
| 0               | 1.37                | 5.52         | 1.45      | 0.10  | 3.92   | 10.82       | 14.10       | 5.40                          | 0.45              |
| 50/50           | 1.35                | 5.48         | 1.45      | 0.12  | 5.08   | 11.32       | 13.90       | 5.35                          | 0.40              |
| 100/100         | 1.34                | 5.45         | 1.41      | 0.13  | 5.79   | 12.13       | 13.85       | 5.32                          | 0.36              |
| 0               | 1.26                | 5.59         | 1.69      | 0.15  | 4.35   | 11.95       | 14.58       | 5.63                          | 0.49              |
| 50/50           | 1.27                | 5.56        | 1.67      | 0.16  | 6.15   | 13.15       | 14.61       | 5.62                          | 0.52              |
| 100/100         | 1.25                | 5.55        | 1.71      | 0.18  | 7.48   | 13.40       | 14.64       | 5.65                          | 0.55              |
| 0               | 1.22                | 5.65        | 1.89      | 0.17  | 5.65   | 13.68       | 14.71       | 5.74                          | 0.64              |
| 50/50           | 1.23                | 5.65        | 1.92      | 0.18  | 9.04   | 13.76       | 14.75       | 5.77                          | 0.63              |
| 100/100         | 1.24                | 5.65        | 1.96      | 0.22  | 10.90  | 14.15       | 14.80       | 5.76                          | 0.65              |
| F value         | 6.74                | 3.17         | 5.08      | 3.44  | 33.49  | 11.58       | 6.34         | 1.45                          | 2.77              |
| P value         | 0.002               | 0.007        | 0.003     | 0.001 | 0.001  | 0.003       | 0.003        | 0.264                         | 0.063             |
| LSD (0.05)      | 0.013               | 0.180        | 0.044     | 0.013 | 0.453   | 0.245       | 0.116        | 0.079                         | 0.066             |
| CV (%)          | 0.62                | 0.19         | 1.43      | 4.90  | 4.04   | 1.35        | 0.46         | 0.80                          | 7.39              |

Means within a column followed by different letters are significantly different at p < 0.05. LSD = least significance difference, CV = coefficient of variation, ns = not significant.
and the control, respectively. Similarly, the highest level of AP was manifested by increase of 88.3 and 178% over the highest rate of mineral fertilizers and the control, respectively. While the highest content of AS results in an increase of 16.7 and 30.8% relative to the highest level of mineral fertilizer and the control plots, respectively.

Data in Table 3 shows that interaction effects of compost and mineral fertilizer did not produce significant ($p > 0.05$) effect on exchangeable Mg, K and Na but significantly ($p < 0.01$) increased the level of exchangeable Ca. The highest exchangeable Ca (14.80 Cmol (kg $^{-1}$) was observed from plots amended with 10 t ha $^{-1}$ compost along with full dose of mineral fertilizers while the lowest exchangeable Ca (13.85 Cmol (kg $^{-1}$) was recorded from plots treated with full dose of mineral fertilizers. The CEC of the soil was significantly ($p < 0.05$) affected by individual and combined application of compost and inorganic fertilizers (Table 3). The highest CEC content (33.07 Cmol (kg $^{-1}$) was obtained from plots that received 10 t ha $^{-1}$ compost and full rate of mineral fertilizers while the lowest CEC (28.96 Cmol (kg $^{-1}$) was recorded from plots treated with sole mineral fertilizers.

### 3.2. Compost and mineral fertilizers interaction effects on yields of maize

The analysis of variance indicated that addition of inorganic fertilizers either alone or combined with compost significantly ($p < 0.05$) increased TGW, SY, AGDB and GY of maize compared to separate addition of either fertilizers (Table 4). The effect of treatments on harvest index was no significant. The highest maize TGW (358.60 g), SY (12.55 t ha $^{-1}$), AGDB (18.62 t ha $^{-1}$) and GY (6.06 t ha $^{-1}$) were obtained from plots treated with 10 t ha $^{-1}$ compost and the highest dose of mineral fertilizers. Moreover, results showed that the highest AGDB and GY of maize obtained from integrated treatments results in an increase of 138.1 and 171.1% and 250.9 and 25.6%, respectively compared to addition of 10 t ha $^{-1}$ compost alone and full dose of mineral fertilizer, respectively. Application of sole mineral fertilizer provided greater maize yield relative to plots treated with sole compost rates and the control. In contrast, lower yield and yield components of maize were produced under the control and addition of 5 and 10 t ha $^{-1}$ compost rates alone compared to application of mineral fertilizers and integrated treatments. The lowest levels of TGW (216.91 g), SY (4.53 t ha $^{-1}$), AGDB yield (5.7 t ha $^{-1}$) and GY (1.17 t ha $^{-1}$) were observed under the control plots (Table 4). This indicates that the addition of sole compost is insufficient to meet the nutrient needs of crops and to achieve the required yield.

### 3.3. Economic analysis

The partial budget analysis showed that the highest net benefit (32700 Birr ha $^{-1}$) was obtained from combined application of 10 t ha $^{-1}$ compost and 100/100 kg urea/NPSB ha $^{-1}$ followed by 5 t ha $^{-1}$ compost and 100/100 kg urea/NPSB ha $^{-1}$ (30017.3) Birr ha $^{-1}$. On the other hand, the lowest net benefit (7659.9 Birr ha $^{-1}$) was obtained from the control plots followed by the addition of 10 t ha $^{-1}$ compost (9011.3) (Table 5). The highest net benefit in response to integrated application of compost and mineral fertilizers could be attributed to the increment of soil nutrients status thereby production of higher maize grain yields.

### 4. Discussion

#### 4.1. Effects of compost and mineral fertilizer application on selected soil properties

The combined application of compost and mineral fertilizer results in improved levels of soil properties. The addition of compost alone or integrated with mineral fertilizer decreased soil bulk density hence improving total porosity, water infiltration and aeration of the soil. Widowati et al. (2020) reported that application of organic amendments such as compost, manures and biochar increased soil organic matter, porosity and available water content, thereby reduced soil bulk density. Similarly, the result was in line with Mengistu et al. (2017) who reported that the lowest soil bulk density (1.24 g cm $^{-3}$) was obtained from plots received vermi-compost combined with mineral fertilizer while the highest (1.28 g cm $^{-3}$) was recorded from the control plots. The result was also in agreement with Gudahde et al. (2015) who found decreased soil bulk density due to integrated addition of organic and inorganic fertilizers.

The addition of compost increased soil pH while sole mineral fertilizers application reduced the level of soil pH. The raise in soil pH by adding compost might be attributed to the high pH of the experimental compost itself (Table 2). The compost also had ash that acts as a liming material. Furthermore, the increase in soil pH under compost treated plots could be related to the release of basic cations such as Ca, Mg, K and Na during the mineralization of compost that can substitute acid cations (H$^+$, Al$^{3+}$, Fe$^{3+}$) from the surfaces of soil colloids (Bedada et al., 2014; Escobar and Hue, 2008). The other mechanism could be release of organic anions like carboxyl, phenolic and hydroxyl substances during decomposition of compost may fix substantial protons (H$^+$), thereby increase the soil pH (Liu and Hue, 2001; Opala et al., 2012). Conversely, the decrease in soil pH from treatments received sole mineral fertilizers may be attributed to acid producing nature of urea application which can release considerable H$^+$ ions to the soil through nitrification (Liu et al., 2010; Schroder et al., 2011). The result was also in line with Agegnehu et al. (2016); Kebede et al. (2019); Liu et al. (2010) who reported that the application of mineral fertilizers decreased soil pH compared to plots treated with organic fertilizers.

### Table 4. Interaction effects of soil amendments on yield components and yield of maize.

| Compost (kg ha $^{-1}$) | Urea/NPSB (kg ha $^{-1}$) | TGW (g) | SY(t ha $^{-1}$) | AGDB (t ha $^{-1}$) | GY (t ha $^{-1}$) | HI (%) |
|------------------------|-------------------------|---------|----------------|-------------------|----------------|--------|
| 0                      | 0/0                     | 216.91  | 4.53           | 5.7               | 1.17           | 19.36  |
|                        | 50/50                   | 311.29  | 9.10           | 12.14            | 3.03           | 24.98  |
|                        | 100/100                 | 326.64  | 11.03          | 15.90            | 4.83           | 30.45  |
|                        | 5                       | 248.58  | 5.97           | 7.53             | 1.56           | 20.36  |
|                        | 50/50                   | 318.29  | 8.85           | 12.42            | 3.57           | 28.72  |
|                        | 100/100                 | 338.15  | 11.36          | 16.81            | 5.45           | 32.43  |
|                        | 10                      | 278.41  | 6.09           | 7.82             | 1.73           | 25.58  |
|                        | 50/50                   | 323.28  | 9.77           | 14.17            | 4.40           | 31.06  |
|                        | 100/100                 | 358.60  | 12.55          | 18.62            | 6.07           | 32.57  |

Means in a column followed by different letters are significantly different at $p < 0.05$. LSD = least significance difference, CV = coefficient of variation, TGW = thousand grain weight, SY = straw yield, AGDB = above ground dry biomass, GY = grain yield.
The results also showed that the application of compost either alone or combined with mineral fertilizers increased soil OC content compared to sole mineral fertilizers application and the control treatments. This could be due to addition of carbon from compost, increased root biomass and crop residues (Walpole and Hettiarachchi, 2020). Conversely, application of mineral fertilizers alone decreased the contents of soil OC compared to the control. The finding is in line with Cao et al. (2017) who reported highest level of soil OC (1.19%) from plots amended with compost and chemical fertilizer while the lowest (0.83%) was recorded from plots that received sole chemical fertilizer. Admas (2015) also found the highest content of OC (2.53%) in plots treated with combination of 60 kg N, 10 t ha\(^{-1}\) compost and 30 kg ha\(^{-1}\) S.

The increase in the content of TN under combined application of compost and mineral fertilizer could be ascribed to the direct addition of nitrogen from mineral fertilizers and decomposition of compost added to the soil (Bedada et al., 2014). Furthermore, high TN content from integrated use of fertilizers may be due to slow release of N from organic amendments, results in lower losses of N (Liu et al., 2010). Aziz et al. (2010) reported that TN after maize harvest was increased in response to addition of farmyard manures whereas the lowest TN was found from plots that were treated with compost and mineral fertilizer while the lowest (0.83%) was recorded from plots that received sole chemical fertilizer. Admas (2015) also found the highest content of OC (2.53%) in plots treated with combination of 60 kg N, 10 t ha\(^{-1}\) compost and 30 kg ha\(^{-1}\) S.

The increase in levels of AP from integrated treatments is believed to be due to the decrease of phosphorus fixation consistent with increased pH, phosphate mineralization from compost and addition of P containing mineral fertilizers (Opala et al., 2010; Sharma et al., 2013). In addition, fixed phosphorus could be made available to plants following complexation of soluble Al and Fe by release of organic molecules from compost added to the soil (Takeda et al., 2009). The result is in agreement with Bedada et al. (2014) who reported that the highest AP (10.88 mg kg\(^{-1}\)) was obtained under plots treated with compost along with mineral fertilizer and the lowest (4.49 mg kg\(^{-1}\)) was in the control. The result is also in agreement with Fekadu et al. (2017); Mengistu et al. (2017) and Sarwar et al. (2008) who found that application of compost combined with mineral fertilizers increased the content of available phosphorus.

Similarly, the increase in the content of AS under treatments that received compost combined with mineral fertilizer could be due to the application of sulphur containing mineral fertilizers and better sulphate mineralization from the compost (Moharana et al., 2015). The result is in agreement with the findings of Admas (2015) who reported that applying 10 t ha\(^{-1}\) compost combined with 120 kg ha\(^{-1}\) N and 30 kg ha\(^{-1}\) S fertilizers provided 4.03 mg kg\(^{-1}\) available sulphur which was much higher than the initial value (2.9 mg kg\(^{-1}\)). This result is also similar with that of Zhihui et al. (2007) who reported that addition of OM increased AS and up to 98% of total soils could be present as organic sulphur compounds. Furthermore, Zhao et al. (2009) stated that the application of farmyard manure combined with mineral fertilizer resulted in higher contents of soil organic matter, available nitrogen and available phosphorus.

The highest exchangeable Ca from plots amended with sole compost and combined treatments are clearly associated with the high Ca content in the experimental compost (Table 2). Moreover, the increase in exchangeable Ca in the treatments that received compost combined with mineral fertilizer might be due to increased root biomass, crop residues and organic matter content. This result is similar with that of Sarwar et al. (2010) who found that considerable amount of basic cations such as Ca\(^{2+}\), Mg\(^{2+}\), K\(^{+}\) and Na\(^{+}\) were released during decomposition of compost. This result is also in line with Kebede et al. (2019); Mengistu et al. (2017) who found an increase in exchangeable Ca due to the addition of organic amendments either alone or combined with mineral fertilizers.

The highest content of CEC in plots received compost combined with mineral fertilizers is believed due to the improvements in soil organic matter content which can retain and release essential nutrients (Sarwar et al., 2010). In contrast, the decrease in CEC contents from plots that received sole mineral fertilizers could be attributed to the decrease in soil pH and exchangeable bases. The result is in agreement with Mengistu et al. (2017) who reported highest CEC (23.42 cmol (+) kg\(^{-1}\)) in the plots that were treated with compost and the lowest (20.61 cmol (+) kg\(^{-1}\)) was from the control followed by sole mineral fertilizer (20.92 cmol (+) kg\(^{-1}\)). Similarly, the result is in concord with Agegnehu et al. (2016) who found that addition of compost alone or combined with mineral fertilizers increased CEC of the soil compared to sole mineral fertilizers and the control. The result is also similar with Nathan and Amadou (2005) who reported that compost addition increased the organic matter content, exchangeable bases and CEC of the soil.

### 4.2. Effects of compost and mineral fertilizer application on maize yields

The combined addition of compost and mineral fertilizers increased yield components and yield of maize compared to individual application of either fertilizer. The increase in TGW from plots amended with 10 t ha\(^{-1}\) compost and 100/100 kg urea/NPSB ha\(^{-1}\) could be ascribed to greater availability of nutrients during the grain filling stage compared to sole compost treatments and the control (Agegnehu et al., 2016; Fanuel and Gifole, 2013). This result is in accordance with Admas et al. (2015) who reported that integrated application of 120 kg N, 15 kg S, and 10 t ha\(^{-1}\) FYM provided the highest TGW (492 g) while the lowest (240 g) was obtained from the control plots. Similarly, application of 260 kg ha\(^{-1}\) urea along with 15 t ha\(^{-1}\) FYM provided the highest TGW (327.54 g) while the lowest (284.39 g) was recorded from sole application of 15 t ha\(^{-1}\) FYM (Shah et al., 2009). This result is also similar with that of Onasanya et al. (2009) who found higher TGW due to addition of higher nitrogen fertilizer rate compared with the control.

Similarly, the increase in straw and AGDB yields from combined use of compost and inorganic fertilizers could be related to their synergistic
effects for increasing the status, availability and uptake of nutrients by the crops which can increase the vegetative growth performance of maize compared to individual addition of any fertilizers and the control treatments (Admas et al., 2015). This result is in agreement with Shah et al. (2009); Tomar et al. (2017) who reported that integrated nutrient management produced significantly higher maize straw yield than sole application of either fertilizers. This result is also in line with Agegnehu et al. (2016) who reported that the dry biomass yield of maize was higher in combined addition of inorganic and organic fertilizers compared to application of sole chemical fertilizers.

The highest maize grain yield under integrated use of compost and mineral fertilizer could be attributed to greater availability of nutrients relative to individual addition of fertilizers (Makinde and Ayoola, 2010). Agegnehu et al. (2016) reported combined application of compost and mineral fertilizer increased maize grain yield due to improvements in soil properties, particularly soil water content, OC, CEC and nutrients which leads to better root development and nutrient use efficiency. This result agreed with Admas et al. (2015) who found that combined use of 120 kg N, 15 kg S, and 10 t compost ha⁻¹ provided the highest maize grain yield (7.9 t ha⁻¹) while the lowest (1.4 t ha⁻¹) was recorded under the control. Similarly, Bedada et al. (2014) reported that integrated use of compost and mineral fertilizer results in 78 and 26% higher maize yield compared to the control and sole mineral fertilizers application, respectively. The result is also in line with Fanuel and Gifole (2013) who found that higher maize grain yield was recorded under integrated use of organic and mineral fertilizer compared to addition of any fertilizers alone.

5. Conclusion

This on-farm experiment examined the effects of compost and mineral fertilizers in isolation and combination on soil properties and maize yields. This study showed that the experimental soil was deficient in major plant nutrients that are translated in to low crop yields. The addition of compost increased soil pH, organic carbon, total nitrogen, available phosphorus, sulphur, and exchangeable bases but did not boost maize yields compared to application of sole mineral fertilizers. Conversely, mineral fertilizers addition alone aggravated soil acidity, depletion of soil organic carbon and soil nutrients although provided higher maize yields over plots amended with sole compost and the control treatments. The addition of compost along with mineral fertilizers significantly increased soil pH, organic carbon, total nitrogen, available phosphorus and sulphur but decreased soil bulk density over their sole applications and the control. Moreover, integrated nutrient management provided the highest dry biomass and grain yield of maize and was found to be economically feasible. Therefore, addition of 10 t ha⁻¹ compost combined with 100/100 kg urea/NPSB ha⁻¹ could be recommended to increase soil fertility and maize yield in the study area. However, the long-term effects and synergy between compost and mineral fertilizer need to be explained through further study.

Declarations

Author contribution statement

Workineh Ejigu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Yihnew G. Selassie; Eyasu Elias: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.
Mateie Damtew: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

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Data availability statement

Data included in article supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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