Rwanda Journal of Agricultural Sciences, Vol 3, No. 2

Influence of Bioslurry and Nitrogen Fertilizer on Soil Properties and Maize (*Zea mays* L.) Performance in Terraced Lixisols of medium and Acrisols of high altitudes in Rwanda

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Abstract

Land terracing is promoted as a management practice for effective soil conservation in hilly areas. However, terraced lands are likely to have low crop productivity where management practices, especially fertilizer application, do not consider changes in soil properties following terracing. This study aimed to determine effects of integrated application of bioslurry and mineral nitrogen (N) rates on soil bio-chemical properties and maize growth, N uptake and yields in terraced medium and high altitudes areas of Rwanda. A factorial experiment in Randomized Complete Block Design with three replications was set up in two sites. Bioslurry rates of 0, 6, 12 and 18 t ha^{-1} at medium altitude and 0, 5, 10 and 15 t ha^{-1} at high altitude sites were combined with 0, 30, 60 and 90 kg N ha^{-1}. Results showed that bioslurry rates of 12 - 18 t ha^{-1} in medium altitude and 10 - 15 t ha^{-1} in high altitude sites combined with 60 - 90 kg mineral N ha^{-1} resulted in significantly ($P<0.05$) higher plant heights, N uptake and grain yields of 7.8 - 8.0 t ha^{-1} and 6.9 - 7.3 t ha^{-1} in medium and high altitudes sites, respectively. Their residual main effects resulted in higher bacteria and fungi populations. Bioslurry and N fertilizer applications should be adjusted from current recommendations for increased maize yields in terraced Lixisols and Acrisols of medium and high altitudes areas.

Key words: *Bacteria, bioslurry, fungi, maize yields, nitrogen uptake*

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Introduction

Maize (*Zea mays* L.) is an important food and security crop in Rwanda. It ranks first grown among cereals (76.6%) and the second after beans (88.6%) in annual production of staple crops (NISR, 2021). However, yields obtained at farm level are low (1.74 t ha^{-1}) as reported by NISR (2019) compared to the world average productivity of 5.52 t ha^{-1} (Yadav *et al.* 2016). The low yields in terraced lands might be attributed to low soil fertility and inadequate fertilizer rates applied.The fertilizer rates applied in the production of maize are based on recommendation established before land terracing (MINAGRI 2009; Kelly and Murekezi 2000) and therefore may be inadequate. Terrace construction changes soil properties, including the distribution of organic matter and nutrients (Fashaho *et al.* 2019; Ramos *et al*. 2007). The effects are more noticeable in soils with well-developed horizons. The soils in medium and high altitudes of eastern and north eastern Rwanda are Ferralsols, Lixisols and Acrisols. They have AEBtC profiles and therefore susceptible to land transformation (Verdoodt and Van Ranst 2003). Information on adequate fertilizer rates for maize production on terraced lands of Rwanda is lacking.

Integrated nutrient management has been advocated as a sound management principle for smallholder farming in the tropics (Vanlauwe & Zingore 2011). Crop yield is usually greater and sustainable when organic inputs and fertilizers are applied together (Mugwe *et al.* 2019; Fairhurst 2012) and they do not deteriorate soil fertility (Islam *et al.* 2013). Bioslurry is an environmental-friendly organic manure. It is a renewable source of nutrients for plants, and has no toxic or harmful effects (Islam *et al.* 2010; Islam 2006). It plays a vital role in restoring soil fertility by improving the physical and biological quality of soil. It improves soil structure and aeration, increases water-holding capacity, and diversifies nutrients for sustainable crop productivity (Shahbaz *et al.* 2014). The objective of the study was to determine the integrated effects of bioslurry and mineral nitrogen fertilizers on soil bio-chemical properties and maize performance in terraced lands of Rwanda.

Materials and methods

Study area

The study was done in Rwamagana and Gicumbi districts located in the medium- and high-altitude regions of eastern and north eastern Rwanda, respectively (Figure 1), from February 2017 to August 2018. The medium altitude site (1502 – 1647 m a.s.l.) is situated in the plateaux of Eastern Province agro-ecological zone (AEZ). Soils are mainly Ferralsols/ Lixisols (Verdoodt and Van Ranst, 2003). Mean annual rainfall received is 950 - 1000 mm and average annual temperature range is 19 - 30°C (Rwamagana District, 2013). The high-altitude site (1881 – 2130 m a.s.l.) is located in the Buberuka highlands AEZ. The predominant soils are Alisols / Acrisols (Verdoodt and Van Ranst, 2003). Mean annual rainfall received is 1200 - 1500 mm and average annual temperature range is 13.2 - 20.8°C (Gicumbi District, 2013).

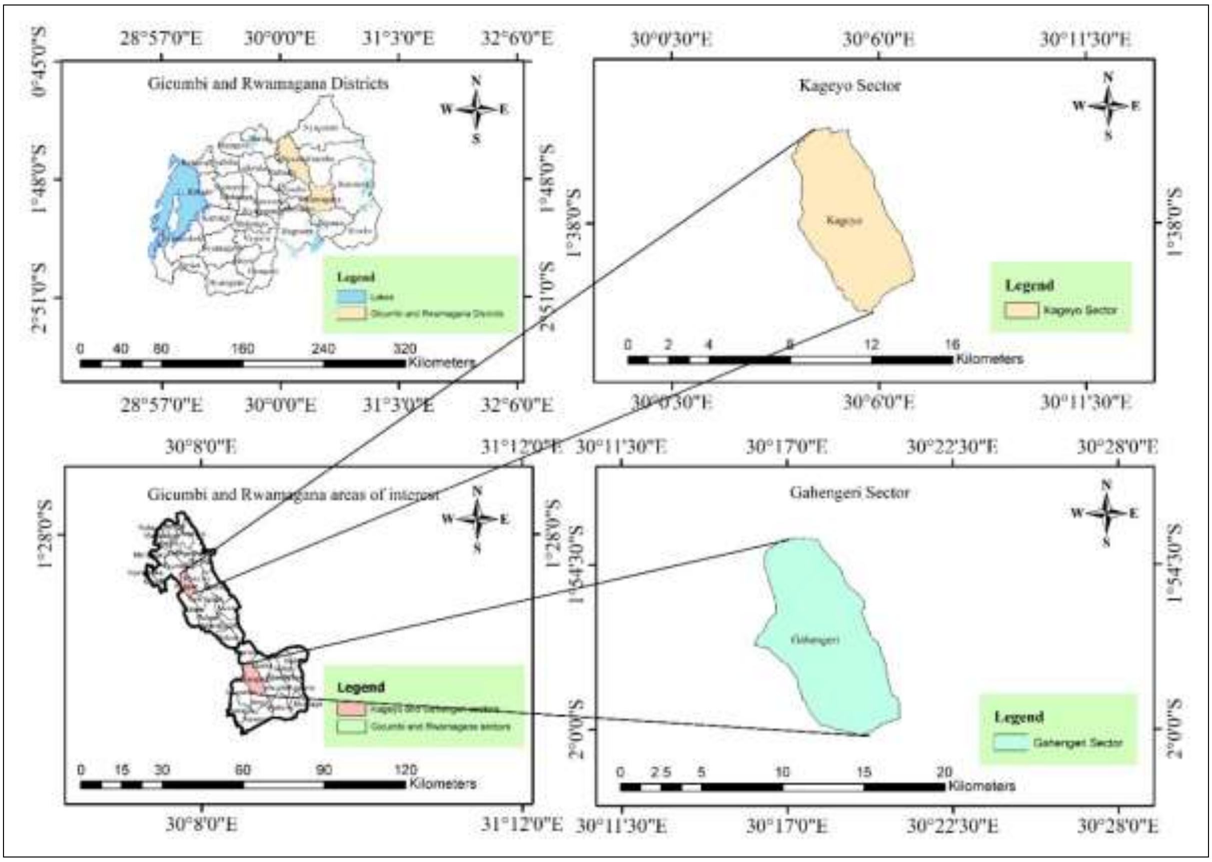

Figure 1. Study sites in Rwamagana and Gicumbi Districts

Experimental design and treatments

A factorial experiment in a Randomized Complete Block Design (RCBD) with 3 replications were established in each of the experimental sites of Gicumbi and Rwamagana Districts. At each site, the land was divided into three blocks. Each block was set up on a separate terrace and subdivided into 16 plots. Footpaths of 30 cm width were established between the plots. Each plot or experimental unit size was 8.4 m^2 (2.8 m × 3 m). The treatments consisted of four levels of mineral nitrogen (0, 30, 60 and 90 kg N ha^{-1}) and four levels of bioslurry (0, 60, 120, 180 kg bioslurry N ha^{-1}). The bioslurry used at the medium altitude site had lower nitrogen concentration (0.97% N) compared to that at high altitude (1.16% N) (Table 1). Therefore, bioslurry rates used were 0, 5, 10 and 15 tonnes ha^{-1} in high altitude site and 0, 6, 12 and 18 tonnes ha^{-1} in medium altitude, equivalent to 0, 60, 120 and 180 kg bioslurry N ha^{-1}.

Table 1. *Bioslurry characteristics and nutrients content on dry-matter basis*

Parameter	Medium altitude	High altitude
pH	7.27	7.83
Dry matter content (%)	16.69	8.89
Organic Carbon (%)	18.36	31.90
Total Nitrogen (%)	0.97	1.16
Total Phosphorus (mg kg^{-1})	2.5	6.3
Potassium (mg kg^{-1})	1.1	0.7
Magnesium (mg kg^{-1})	9.9	6.8
Calcium (mg kg^{-1})	10	8.4

Fertilizers application

Bioslurry in liquid form was collected from farmers' biogas plants that used cow dung as raw material. Full rates of well mixed bioslurry were uniformly spread in rows within the respective experimental plots and immediately covered with 5 cm of soil layer, two weeks before sowing. Urea was applied at one side of the planting hole to make sure that it does not come into direct contact with the seed. Half rate of urea (46% N) was applied at the time of sowing and the other half was top dressed 30 days after sowing. Triple Super Phosphate (TSP 46% P_2O_5) and muriate of potash (60% K_2O) were applied at sowing time as blanket rates, i.e. 80 kg P_2O_5 ha^{-1} (rate selected from the results of the trial conducted prior to this study) and 42.5 kg K_2O ha^{-1} (MINAGRI, 2009).

Sowing

Sowing was done by dibbling method. Two seeds were planted manually per hole at 5 cm depth, with spacing of 70 cm between rows and 30 cm within rows following the recommendation of MINAGRI (2009). Thinning to one seedling per hill was done two weeks after emergence to retain the recommended population of 47,619 plants per hectare.

Maintenance

Manual weeding was done twice during the vegetative cycle of maize as is the normal practice for farmers in the area. Pesticide (*Rocket* ™, Profenofos 40% + Cypermethrin 4%) was applied to control Fall Armyworm (FAW) which has become an important pest of maize in the region over the last few years.

Crop data collection and analysis

Growth and phenology parameters

Data on maize growth and phenology was collected on 8 tagged plants in two central rows of each plot. Plant height (cm) was measured from ground surface to the top of plant using a measuring tape, at 30, 60, and 90 days after sowing (DAS). Collar diameter (cm) was measured at the first node from the ground surface using a Vernier calliper on the same dates as for the plant heights as were the number of leaves per plant. The number of days to 50% tasselling was also determined.

Nitrogen concentration

Total tissue N content was determined by Kjeldahl method (Okalebo *et al.* 2002; Manjula & Yichang 2006). At 50% tasseling stage the leaves opposite ear from two plants per plot were chopped, mixed and packed in paper bags. The tissue samples were oven dried at 65°C to a constant weight, ground to pass through 1 mm sieve using a mill and stored in plastic bottles pending total N determination. Samples of grains were also taken from each plot at crop maturity, ground and used in determination of grain N concentration. N uptake was calculated using the formulae below (Wasonga *et al*. 2008):

Plant nitrogen uptake = NCP × PY
Grain nitrogen uptake = NCG × GY

Where: NCP and NCG are nitrogen concentrations in plant/leaf and grain, respectively. PY and GY are plant/leaf yield and grain yields, respectively.

Yield parameters

At maize physiological maturity, yield parameters for each plot were determined from the two central rows. The average number of cobs per plant were determined by counting the total number of cobs and plants in the two rows. The above ground portion of the plant was harvested and separated into stover and cobs. The stover (stalks and leaves) was chopped into small pieces and weighed. Sub-samples were weighed and oven-dried at 70°C in a ventilated oven to constant weight. The weights of oven-dry sub-samples were recorded and used to calculate total above-ground biomass yield. Grains on the cobs were shelled and weighed. The grain weight was adjusted to 13% moisture level and converted into grain yield per hectare (kg ha^{-1}). Hundred grain weight was determined using an electronic balance. Grain yield (at 13% moisture content) and total above-ground biomass yield (stover + cobs + grains) were determined using the formulae below (Tuyishime, 2012; Wasonga *et al.*, 2008).GY (kg ha^{-1}) = (GW/PLS) *10000 * [(100 - GMH)/ (100 – GMD)]Total dry matter yield (above-ground biomass) = (GY + SY + CY)

Where: GW, PLS, GMH and GMD are grain weight at harvest, plot size harvested, grain moisture content at harvest and grain moisture content at 13%, respectively. GY, SY and CY are grain, stover, and cob dry matter yields, respectively.

Soil sampling and analysis

Soil composite samples (0 - 30 cm) were collected form each site's replicate prior trial and from each plot at harvesting time in both cropping seasons to evaluate residual effect of treatments. The samples for chemical analysis were air dried and passed through 2 mm sieve and stored in polythene bags while those for microbial analysis were placed in open ended perforated containers and refrigerated at 4°C for a maximum of 48 hours before analysis. Samples were analyzed for pH in a 1: 2.5 soil - water solution using the glass electrode method, organic carbon (SOC) by Walkley Black method, total nitrogen (Kjeldahl method) and available phosphorus (Bray II method) as described by Pal (2013) and Okalebo *et al*. (2002). Cation exchange capacity (CEC) was determined using ammonium acetate extractant and exchangeable K^+, Mg^{2+} and Ca^{2+} in the extract was determined by atomic absorption spectrophotometry (Okalebo *et al*. 2002). Total bacteria population was determined using plate-count technique based incubating dilutions of soil suspension on Plate Count Agar (PCA), and counting colony-forming units (CFU) (Wallenius, 2011; Vieira and Nahas, 2005). Incubation was done at 28°C for 36 hours. For fungi population, the acidified Potato Dextrose Agar (PDA) was used as medium (Wallenius, 2011). Incubation was done at 28°C for 5 days. Colony forming units per gram (CFU g^{-1}) of soil was calculated using the equation of Johnson and Case (2007) described below:

CFU g^{-1} soil = [Number of colonies / Volume plated (ml)] * Dilution factor

Statistical data analysis

Data were organized using Excel data sheet and subjected to Bartlett Chi-square test of homogeneity. The combined analysis was performed for homogeneous data over two seasons in each site. The main and interaction effects of factors were analyzed through Analysis of Variance with General Linear Model using SAS version 9.2 (Meyers *et al.* 2009; SAS 2008). Means comparison was performed using Duncan's Multiple Range Test at 5% probability level of significance. Quadratic regression model was performed to predict optimum fertilizer rates (bioslurry and mineral N) for maximum maize grain yields (Faloye *et al.* 2019).

Results

Maize performance as influenced by bioslurry and nitrogen fertilizer in terraced Lixisols of medium altitude site

Plant height and stem collar diameter

Maize growth was significantly ($P<0.05$) increased by bioslurry and mineral N application. The combined application of 18 t ha^{-1} bioslurry and 90 kg ha^{-1} mineral N gave a 53.9% increase in plant height over the control, at 90 days after sowing (DAS), when the maize was at 100% tasselling (Table2).

Table 2. *Interaction effect between bioslurry and mineral N on maize growth, N uptake and yield components for combined analysis of two cropping season's data of A 2018 and B 2018 in terraced Lixisols of medium altitude area*

Bioslurry (t ha^{-1})	N (kg ha^{-1})	Plant height (cm) at 90 DAS	Stem collar diameter (cm) at 90 DAS	N uptake at 50% tasselling (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Grain yield (t ha^{-1})	Above-ground biomass (t ha^{-1})	Number of cobs $plant^{-1}$	100 grain weight (g)
0	0	189.9 ± 5.9^{f}	2.4 ± 0.1^{a}	51.61 ± 5.79^{j}	26.92 ± 3.20^{i}	2.4 ± 0.2^{h}	7.6 ± 0.6^{e}	1.0 ± 0.0^{f}	28.9 ± 0.3^{h}
	30	213.3 ± 5.8^{e}	3.0 ± 0.1^{a}	74.75 ± 3.84^{hij}	40.86 ± 4.46^{hi}	3.1 ± 0.3^{g}	12.6 ± 1.0^{d}	1.0 ± 0.0^{f}	31.0 ± 1.1^{gh}
	60	217.8 ± 6.1^{de}	3.0 ± 0.1^{a}	99.57 ± 3.23^{efgh}	53.74 ± 4.57^{gh}	3.6 ± 0.3^{fg}	13.0 ± 1.0^{d}	1.0 ± 0.0^{f}	32.0 ± 1.1^{fg}
	90	218.3 ± 3.4^{de}	3.1 ± 0.1^{a}	105.81 ± 2.81^{defg}	72.10 ± 3.22^{f}	4.5 ± 0.1^{e}	15.4 ± 1.5^{d}	1.0 ± 0.0^{ef}	33.2 ± 0.8^{efg}
6	0	210.3 ± 2.8^{e}	2.8 ± 0.1^{a}	63.83 ± 7.97^{ij}	59.48 ± 5.22^{fg}	4.4 ± 0.3^{ef}	14.0 ± 1.2^{d}	1.0 ± 0.0^{f}	35.5 ± 0.8^{de}
	30	265.2 ± 1.8^{c}	3.2 ± 0.1^{a}	109.53 ± 7.88^{def}	91.10 ± 4.15^{e}	6.2 ± 0.3^{cd}	20.0 ± 1.4^{c}	1.1 ± 0.0^{cdef}	37.4 ± 0.9^{cd}
	60	273.8 ± 2.1^{bc}	3.5 ± 0.2^{a}	131.90 ± 7.34^{d}	106.57 ± 5.26^{cd}	6.9 ± 0.3^{bc}	23.8 ± 2.4^{abc}	1.2 ± 0.0^{bc}	38.0 ± 1.1^{bcd}
	90	273.1 ± 7.5^{bc}	3.6 ± 0.2^{a}	159.89 ± 7.86^{c}	107.22 ± 3.46^{cd}	6.8 ± 0.3^{bcd}	22.7 ± 1.8^{abc}	1.1 ± 0.0^{bcde}	38.7 ± 0.9^{abc}
12	0	231.3 ± 7.5^{d}	3.0 ± 0.2^{a}	79.27 ± 10.57^{ghij}	59.85 ± 4.49^{fg}	4.1 ± 0.2^{ef}	12.6 ± 1.1^{d}	1.0 ± 0.0^{ef}	34.0 ± 0.3^{ef}
	30	273.1 ± 2.2^{bc}	3.3 ± 0.2^{a}	118.07 ± 12.26^{def}	95.81 ± 10.43^{de}	6.0 ± 0.6^{d}	21.3 ± 1.6^{bc}	1.1 ± 0.1^{bcd}	37.6 ± 1.1^{cd}
	60	287.4 ± 5.3^{ab}	3.7 ± 0.2^{a}	181.31 ± 17.33^{abc}	129.37 ± 4.41^{ab}	7.8 ± 0.2^{a}	24.7 ± 0.9^{ab}	1.2 ± 0.1^{bc}	39.8 ± 0.7^{abc}
	90	287.9 ± 4.1^{ab}	3.7 ± 0.1^{a}	191.64 ± 12.31^{ab}	139.04 ± 5.91^{a}	8.0 ± 0.3^{a}	23.9 ± 1.4^{abc}	1.2 ± 0.1^{abc}	40.6 ± 0.8^{ab}
18	0	230.5 ± 10.5^{d}	3.0 ± 0.2^{a}	88.92 ± 14.88^{fghi}	62.62 ± 7.06^{fg}	4.0 ± 0.3^{ef}	13.3 ± 1.4^{d}	1.0 ± 0.0^{ef}	32.8 ± 0.9^{fg}

Bioslurry (t ha^{-1})	N (kg ha^{-1})	Plant height (cm) at 90 DAS	Stem collar diameter (cm) at 90 DAS	N uptake at 50% tasselling (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Grain yield (t ha^{-1})	Above-ground biomass (t ha^{-1})	Number of cobs $plant^{-1}$	100 grain weight (g)
	30	277.8 ± 8.0^{abc}	3.5 ± 0.2^{a}	125.60 ± 10.37^{de}	116.91 ± 3.21^{bc}	7.2 ± 0.2^{ab}	23.2 ± 1.8^{abc}	1.1 ± 0.1^{bcd}	38.6 ± 1.0^{abc}
	60	287.5 ± 5.1^{ab}	3.7 ± 0.2^{a}	178.03 ± 11.10^{bc}	139.28 ± 3.55^{a}	7.9 ± 0.2^{a}	26.3 ± 1.2^{a}	1.3 ± 0.1^{a}	40.9 ± 0.8^{a}
	90	292.2 ± 3.1^{a}	3.6 ± 0.1^{a}	207.94 ± 3.81^{a}	138.31 ± 2.62^{a}	8.0 ± 0.2^{a}	26.2 ± 0.9^{a}	1.3 ± 0.0^{ab}	40.9 ± 0.8^{a}
Mean		**251.6**	**3.3**	**122.98**	**89.95**	**5.7**	**18.8**	**1.1**	**36.2**
N		**96**	**96**	**96**	**96**	**96**	**96**	**96**	**96**
CV (%)		**3.7**	**9.5**	**15.19**	**10.17**	**9.6**	**14.5**	**7.5**	**5.2**

A 2018 – September 2017 to January 2018; B 2018 – March to July 2018; Different letters in the same column indicate significantly different values at $P < 0.05$; n – Number of observations / treatments; CV - Coefficient of variation; DAS – Days after sowing; 90 DAS were recorded at 100% tasselling stage

Nitrogen uptake at 50% tasselling and grain N uptake

At 50% maize tasselling, relatively higher N uptake was recorded with higher applied rates of mineral N (60 and 90 kg ha^{-1}) combined with higher applied rates of bioslurry (12 and 18 t ha^{-1} in medium altitude, and 10 and 15 t ha^{-1} in high altitude); i.e. N uptake of 191.30 kg ha^{-1} given by the combination of 18 t bioslurry ha^{-1} and 90 kg N ha^{-1} (Table 2). At the physiological maturity of maize, relatively higher N uptake in grain were given by higher applied rates of bioslurry (12 and 18 t ha^{-1}) combined with higher applied rates of mineral N (60 and 90 kg ha^{-1}). The increases in N uptake were reflected by increases of growth and grain yield (Tables 2).

Yield and yield components

Higher grain yield and above-ground biomass resulted from higher applied rates of mineral N (60 and 90 kg ha^{-1}) combined with higher applied rates of bioslurry (12 and 18 t ha^{-1}) (Table 2). Grain yield increased by 3.3 while biomass increased by 3.4 over the control. The number of cobs $plant^{-1}$ increased by 30% over the control in plots treated with the combination of 18 t ha^{-1} of bioslurry and 60 kg ha^{-1} mineral N (Table 2). Hundred grain weight increased by 41.5% over the control in plots treated with 18 t ha^{-1} of bioslurry combined with 60 – 90 kg ha^{-1} mineral N (Table 2). The combined application of bioslurry and mineral N fertilizer resulted in higher maize performance than when either bioslurry or mineral N was applied alone.

Days to 50% tasselling

Number of days to 50% tasselling decreased as bioslurry and mineral N rates increased. The plants with a smaller number of days to 50% tasselling were recorded in plots treated with bioslurry rates of 12 and 18 t ha^{-1} with decreases of 0.9 and 1.1 days over the control, respectively (Figure 2). They were also observed in plots receiving 60 and 90 kg N ha^{-1} with decreases of 1 and 1.2 days to the control, respectively (Figure 3).

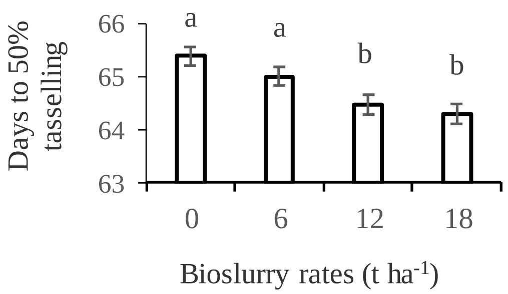

Figure 2. Main effect of bioslurry on number of days to 50% tasselling at medium altitude area.

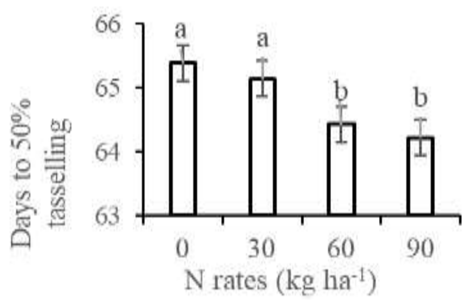

Figure 3. Main effect of mineral N on number of days to 50% tasselling at medium altitude area

Error bars represent standard error and different letters indicate significantly different values at $P < 0.05$. N – Nitrogen.

Maize performance as influenced by bioslurry and nitrogen fertilizer in terraced Acrisols of high-altitude site

Plant height and stem collar diameter

Maize growth was significantly ($P<0.05$) increased by bioslurry and mineral N application. The taller plants were observed in plots supplied with combined bioslurry (t ha^{-1}): mineral N (kg ha^{-1}) rates of 15:90, 15:60, 10:90, 10:60 and 5:90. Plant height increased by 1.9 – 2.0 times over the control at 90 DAS in these treatments (Table 3).

Nitrogen uptake at 50% tasselling and grain N uptake

At 50% maize tasselling, relatively higher N uptake was recorded with higher applied rates of mineral N (60 and 90 kg ha^{-1}) combined with higher applied rates of bioslurry (10 and 15 t ha^{-1}); i.e. N uptake of 194.39 kg ha^{-1} given by the combination of 15 t bioslurry ha^{-1} and 90 kg N ha^{-1} (Table 3). At the physiological maturity of maize, relatively higher N uptake in grain were given by higher applied rates of bioslurry (10 and 15 t ha^{-1}) combined with higher applied rates of mineral N (60 and 90 kg ha^{-1}). The increases in N uptake were reflected by increases of growth and grain yield (Table 3).

Yield and yield components

Higher grain yields resulted from higher applied rates of mineral N (60 and 90 kg ha^{-1}) combined with higher applied rates of bioslurry (15 t ha^{-1}) (Table 3). Similarly, higher above-ground biomass was recorded in plots treated with the combination of higher rates of bioslurry (10 and 15 t ha^{-1}) and mineral N (60 and 90 kg ha^{-1}) (Table 3). The grain yield increased by 3.0 - 3.2 over the control while biomass increased by 3.3 - 3.6 over the control. The number of cobs $plant^{-1}$ increased by 30% over the control in plots treated with the combination of 10 - 15 t ha^{-1} of bioslurry combined with 60 - 90 kg ha^{-1} of mineral N (Table 3). The combined application of bioslurry and mineral N fertilizer resulted in higher maize performance than when either bioslurry or mineral N was applied alone.

Table 3. *Interaction effect between bioslurry and mineral N on maize growth and yield components for combined analysis of two cropping season's data of A 2018 and B 2018 in terraced Acrisols of high-altitude area*

Bioslurry (t ha^{-1})	N (kg ha^{-1})	Plant height (cm) at 90 DAS	Stem collar diameter (cm) at 90 DAS	Plant N uptake at 50% tasselling (kg ha^{-1})	Grain N uptake (kg ha^{-1})	Grain yield (t ha^{-1})	Above-ground biomass (t ha^{-1})	Number of cobs plant^{-1}	100 grain weight (g)
0	0	121.4 ± 6.6^{e}	1.9 ± 0.1^{g}	39.10 ± 3.20^{h}	26.24 ± 1.29^{h}	2.3 ± 0.1g	6.8 ± 0.5^{h}	1.0 ± 0.0^{d}	27.5 ± 1.8^{a}
	30	180.5 ± 6.2^{d}	2.7 ± 0.2^{ef}	65.89 ± 2.40^{g}	44.52 ± 3.12^{fg}	3.4 ± 0.2^{e}	11.1 ± 0.3^{fg}	1.0 ± 0.0^{d}	30.4 ± 1.2^{a}
	60	195.0 ± 4.0^{cd}	2.9 ± 0.0^{cdef}	99.85 ± 1.90d^{def}	59.68 ± 3.85^{de}	4.1 ± 0.3^{d}	13.9 ± 0.7^{def}	1.1 ± 0.1^{cd}	31.3 ± 1.1^{a}
	90	189.7 ± 5.2^{cd}	2.8 ± 0.0^{def}	108.26 ± 2.71^{cde}	65.41 ± 3.36^{d}	4.2 ± 0.2^{d}	14.8 ± 0.7^{cde}	1.1 ± 0.1^{cd}	32.2 ± 1.1^{a}
5	0	195.2 ± 4.5^{cd}	2.6 ± 0.1^{f}	64.22 ± 6.67^{g}	36.25 ± 2.63^{gh}	2.7 ± 0.2fg	10.2 ± 1.0^{g}	1.0 ± 0.0d	30.3 ± 1.3^{a}
	30	216.9 ± 6.2^{b}	2.9 ± 0.2^{def}	93.32 ± 8.70^{ef}	66.76 ± 2.32^{d}	4.5 ± 0.1d	13.9 ± 0.9^{def}	1.1 ± 0.1^{cd}	32.1 ± 1.9^{a}
	60	229.5 ± 6.7^{ab}	3.1 ± 0.1^{abcde}	113.25 ± 6.79^{cde}	84.96 ± 4.21^{bc}	5.5 ± 0.2^{bc}	16.4 ± 1.1^{bcd}	1.1 ± 0.0^{cd}	32.3 ± 1.6^{a}
	90	237.4 ± 10.0^{a}	3.3 ± 0.1^{ab}	120.16 ± 11.85^{cd}	93.99 ± 5.34^{b}	5.93 ± 0.31^{b}	18.8 ± 1.2^{b}	1.1 ± 0.1^{bc}	34.7 ± 0.5^{a}
10	0	198.6 ± 3.2^{c}	2.7 ± 0.2^{ef}	80.73 ± 7.84^{fg}	43.03 ± 2.86^{fg}	2.9 ± 0.1ef	11.1 ± 0.9^{fg}	1.0 ± 0.0^{d}	31.6 ± 1.0^{a}
	30	232.0 ± 5.1^{ab}	3.0 ± 0.1^{bcdef}	112.69 ± 11.92^{cde}	81.54 ± 4.34^{c}	5.2 ± 0.2^{c}	15.0 ± 1.2^{cde}	1.1 ± 0.0^{cd}	30.1 ± 2.2^{a}
	60	235.3 ± 9.2^{a}	3.0 ± 0.2^{abcdef}	159.83 ± 4.80^{ab}	111.56 ± 4.54^{a}	6.9 ± 0.2^{a}	23.1 ± 1.6^{a}	1.3 ± 0.0^{a}	32.7 ± 1.4^{a}
	90	233.1 ± 5.4^{ab}	3.4 ± 0.0^{a}	157.38 ± 7.78^{b}	119.10 ± 4.18^{a}	7.1 ± 0.1^{a}	22.4 ± 1.2^{a}	1.3 ± 0.0^{a}	35.4 ± 1.3^{a}
15	0	196.7 ± 3.2^{cd}	3.0 ± 0.1^{bcdef}	82.56 ± 5.51^{fg}	49.54 ± 3.75^{ef}	3.3 ± 0.2^{ef}	12.6 ± 1.2^{efg}	1.0 ± 0.0^{d}	31.4 ± 1.6^{a}

Bioslurry (t ha-1)	N (kg ha-1)	Plant height (cm) at 90 DAS	Stem collar diameter (cm) at 90 DAS	Plant N uptake at 50% tasselling (kg ha-1)	Grain N uptake (kg ha-1)	Grain yield (t ha-1)	Above-ground biomass (t ha-1)	Number of cobs plant-1	100 grain weight (g)
	30	232.2 ± 6.3ab	3.3 ± 0.1abc	129.43 ± 6.06c	89.30 ± 4.36bc	5.4 ± 0.3bc	18.1 ± 2.0bc	1.1 ± 0.1cd	36.1 ± 1.3a
	60	238.1 ± 6.3a	3.1 ± 0.1abcd	178.78 ± 9.40a	115.77 ± 4.96a	7.1 ± 0.3a	24.3 ± 1.4a	1.2 ± 0.1ab	34.8 ± 1.9a
	90	236.9 ± 6.8a	3.2 ± 0.1abcd	178.10 ± 9.14a	120.82 ± 4.49a	7.3 ± 0.2a	23.2 ± 1.0a	1.3 ± 0.0a	32.9 ± 1.3a
Mean		**210.5**	**2.9**	**111.47**	**75.53**	**4.9**	**16.0**	**1.1**	**32.2**
N		**96**	**96**	**96**	**96**	**96**	**96**	**96**	**96**
CV (%)		**7.0**	**10.4**	**14.46**	**12.12**	**10.2**	**16.1**	**8.9**	**8.8**

A 2018 – September 2017 to January 2018; B 2018 – March to July 2018; Different letters in the same column indicate significantly different values at $P < 0.05$; n – Number of observations / treatments; CV - Coefficient of variation; DAS – Days after sowing; 90 DAS were recorded at 100% tasselling stage

Days to 50% tasselling

Number of days to 50% tasselling decreased as bioslurry and mineral N rates increased. The plants with a smaller number of days to 50% tasselling were found in plots receiving 10 and 15 t ha^{-1} bioslurry with decreases of 0.7 and 0.8 days observed over the control, respectively (Figure 4). They were also observed in plots receiving 90 kg N ha^{-1} with decrease of 1.2 days compared to the control (Figure 5).

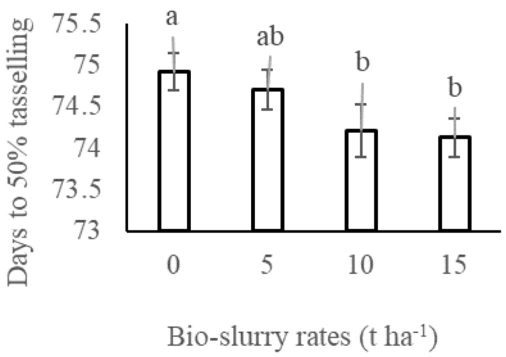

Figure 4. Main effect of bioslurry on number of days to 50% tasselling at high altitude area.

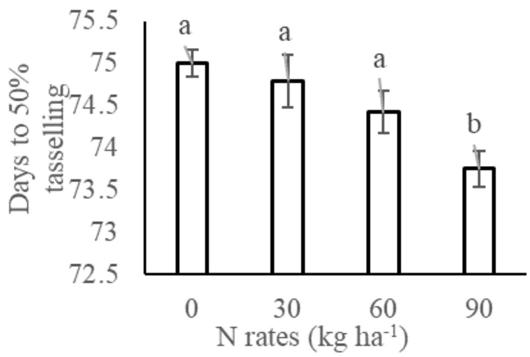

Figure 5. Main effect of mineral N on number of days to 50% tasselling at high altitude area

Error bars represent standard error and different letters indicate significantly different values at $P < 0.05$.

Influence of cropping seasons on maize performance

Maize growth, N uptake and yields were influenced by cropping seasons. Significantly ($P < 0.05$) higher plants (258.9 cm), larger stem collar diameter (3.4 cm), N uptake (134.7 kg ha^{-1}), grain yield (5.9 t ha^{-1}), hundred grain weight (36.9 g) and above-ground biomass yield (19.6 t ha^{-1}) were observed in season A 2018 at medium altitude site (Table 4).

Similarly, at high-altitude site, higher maize performance was recorded in season A compared to season B; higher plants (215.7 cm), larger stem collar diameter (3.0 cm), N uptake (114.2 kg ha^{-1}), grain yield (5.0 t ha^{-1}), hundred grain weight ((33.9 g) and above-ground biomass (16.5 t ha^{-1}) (Table 4).

Table 4. *Effect of season on maize growth, nitrogen uptake and yields for medium and high-altitude sites*

Site location (altitude)	Season	Plant height at 90 DAS (cm)	Stem diameter at 90 DAS (cm)	Number of days to 50% tasselling	Number of cobs plant^{-1}	100 grain weight (g)	Above-ground biomass (t ha^{-1})	Grain yield (t ha^{-1})	N uptake at 50% tasselling (kg ha^{-1})	Grain N uptake (kg ha^{-1})
Medium altitude	A 2018	258.9^{a}	3.4^{a}	64.8^{a}	1.1^{a}	36.9^{a}	19.6^{a}	5.9^{a}	134.7^{a}	96.2^{a}
	B 2018	244.3^{b}	3.1^{b}	64.7^{a}	1.1^{b}	35.6^{b}	17.9^{b}	5.5^{b}	111.3^{b}	83.7^{b}
Mean		251.6	3.3	64.8	1.1	36.2	18.8	5.7	123.0	90.0
N		96	96	96	96	96	96	96	96	96
CV (%)		3.7	9.5	1.2	7.5	5.2	14.5	9.6	15.2	10.2
High altitude	A 2018	215.7^{a}	3.0^{a}	74.6^{a}	1.1^{a}	33.9^{a}	16.5^{a}	5.0^{a}	114.2^{a}	78.1^{a}
	B 2018	205.4^{b}	2.9^{a}	74.4^{a}	1.1^{a}	30.6^{b}	15.5^{b}	4.7^{b}	108.7^{a}	72.9^{b}
Mean		210.5	2.9	74.5	1.1	32.2	16.0	4.9	111.5	75.5
N		96	96	96	96	96	96	96	96	96
CV (%)		7.0	10.4	1.5	8.9	8.8	16.1	10.2	14.5	12.1

A 2018 – September 2017 to January 2018; B 2018 – March to July 2018; Different letters in the same column indicate significantly different values at $P < 0.05$; n – Number of observations / treatments; CV - Coefficient of variation; DAS – Days after sowing; 90 DAS were recorded at 100% tasselling stage

Estimating optimum rates of bioslurry and mineral N fertilizer

To estimate optimum bioslurry and mineral N rates, a quadratic polynomial regression analysis was performed between experimental factors (bioslurry and mineral N) which are predictors or explanatories and grain yield (predicted). Main effects of factors were considered. By projecting grain yield as a function of increasing rates of bioslurry and mineral N, the optimum rates were estimated by the zero-solutions of the derivatives of the projection equations. Results indicated that optimum rates were 14.3 t ha^{-1} of bioslurry with maximum grain yield of 6.9 t ha^{-1} (Figure 6) and 75.2 kg ha^{-1} of mineral N with maximum grain yield of 6.6 t ha^{-1} (Figure 7) in terraced Lixisols of medium altitude.

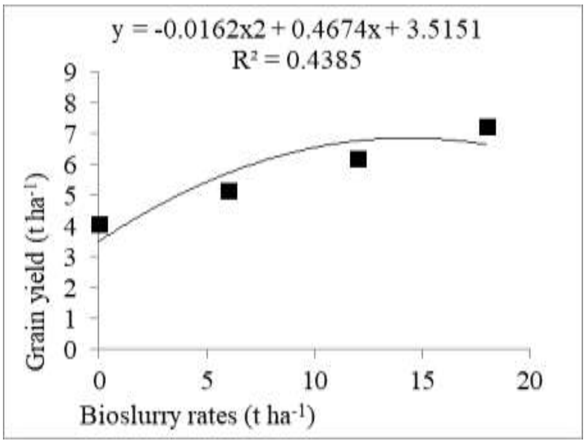

Figure 6. Effect of increasing applied rates of bioslurry on grain yield at medium altitude area

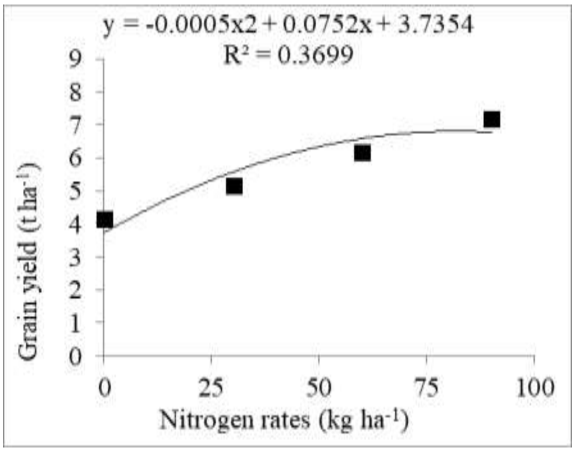

Figure 7. Effect of increasing applied rates of mineral N on grain yield at medium altitude area

In terraced Acrisols of high altitude, the optimum rate was 78.4 kg N ha^{-1} of mineral N with maximum grain yield of 5.8 t ha^{-1} (Figure 9).

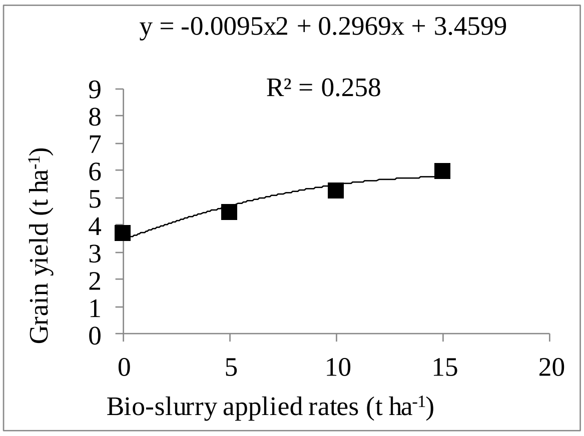

Figure 8. Effect of increasing applied rates of bioslurry on grain yield at high altitude area

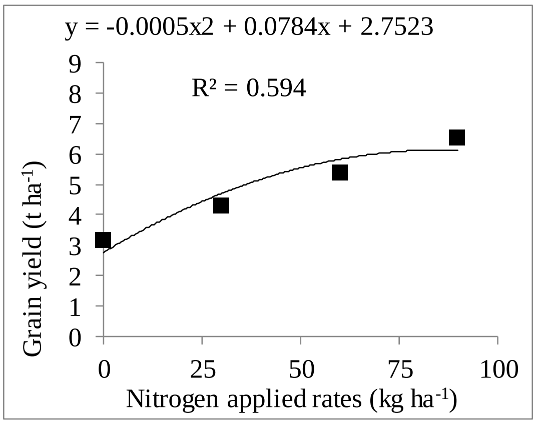

Figure 9. Effect of increasing applied rates of mineral N on grain yield at high altitude area

Integrated effects of bioslurry and mineral N on soil bio-chemical properties

Soil chemical properties

Table 5. *Initial soil physical and chemical properties prior to the trial*

Soil properties	Terraced Lixisols of medium altitude site	Terraced Acrisols of high-altitude site
Bulk density (g cm^{-3})	1.56	1.29
Moisture content (%)	8.1	10.3
pH $_{(water)}$	5.43	4.91
Organic carbon (%)	1.08	1.96
Total N (%)	0.06	0.08
Available P (ppm)	18.63	14.82
CEC ($cmol_{(+)}$ kg^{-1})	7.12	5.81
K^+ ($cmol_{(+)}$ kg^{-1})	0.25	0.15
Mg^{2+} ($cmol_{(+)}$ kg^{-1})	1.10	0.94
Ca^{2+} ($cmol_{(+)}$ kg^{-1})	4.55	3.30

The main effect of bioslurry was significant ($P < 0.05$) on SOC, total N and available P in terraced Acrisols of high-altitude site (Table 6), and SOC and total N in terraced Lixisols of medium altitude. Relatively higher levels were given by higher rates of bioslurry applied; 15 and 18 t ha^{-1} in high and medium altitudes sites, respectively (Table 6 and Figures 10 and 11).

Table 6. *Main effect of bioslurry rates on soil organic carbon (SOC), total nitrogen (N) and available phosphorus (P) contents in high altitude area*

Bioslurry (t ha^{-1})	SOC (%)	Total N (%)	Available P (ppm)
0	1.89 ± 0.11^{b}	0.09 ± 0.00^{c}	13.28 ± 0.34^{c}
5	2.13 ± 0.07^{a}	0.10 ± 0.00^{b}	13.60 ± 0.45^{bc}
10	2.20 ± 0.09^{a}	0.11 ± 0.00^{ab}	14.76 ± 0.61^{ab}
15	2.26 ± 0.08^{a}	0.12 ± 0.01^{a}	15.43 ± 0.60^{a}
Mean	2.12	0.11	14.27
n	96.00	96.00	96.00
CV (%)	17.44	20.13	15.35

Different letters in the same column indicate significantly different values at $P < 0.05$; n – Number of observations / treatments.

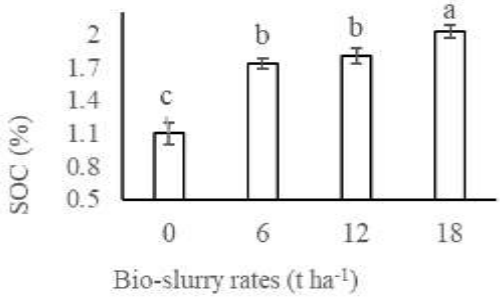

Figure 10. Main effects of bioslurry rates on SOC in medium altitude area. SOC – Soil organic carbon; Error bars represent standard error.

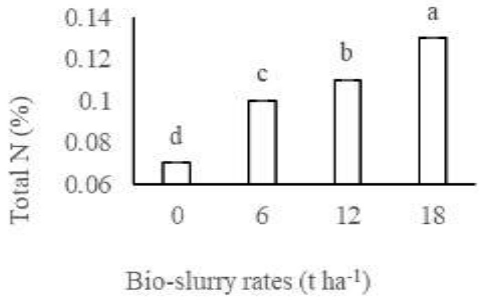

Figure 11. Main effects of bioslurry rates on total N content in medium altitude area. Different letters indicate significantly different values at P < 0.05

Soil bacteria and fungi populations

Bacteria and fungi populations were significantly ($P < 0.05$) influenced by the application of bioslurry and mineral N. Relatively higher populations were observed in plots treated with bioslurry rates of 12 - 18 and 10 - 15 t ha^{-1} in medium and high-altitude sites, respectively, as well as 60 - 90 kg mineral N ha^{-1} in both sites (Table 7).

Table 7. *Main effects of bioslurry and mineral N application rates on soil bacteria and fungi populations in medium and high-altitude sites*

Fertilizer rates		Medium altitude site		High altitude site	
		Bacteria (log_{10} CFU g^{-1})	Fungi (log_{10} CFU g^{-1})	Bacteria (log_{10} CFU g^{-1})	Fungi (log_{10} CFU g^{-1})
Bioslurry	B0	6.37± 0.06^{b}	4.07 ± 0.04^{c}	6.08 ± 0.05^{c}	4.14 ± 0.04^{b}
	B1	6.41 ± 0.07^{b}	4.17 ± 0.03^{b}	6.22 ± 0.05^{b}	4.18 ± 0.05^{ab}
	B2	6.54 ± 0.03^{a}	4.33 ± 0.04^{a}	6.26 ± 0.05^{b}	4.23 ± 0.05^{a}
	B3	6.57 ± 0.03^{a}	4.31 ± 0.04^{a}	6.42 ± 0.03^{a}	4.25 ± 0.04^{a}
	Mean	6.47	4.22	6.24	4.20
	CV (%)	3.29	2.99	2.31	3.26
Mineral N (kg ha^{-1})	0	6.30 ± 0.00^{b}	4.09 ± 0.03^{c}	6.02 ± 0.05^{c}	4.03 ± 0.03^{c}
	30	6.47 ± 0.04^{a}	4.18 ± 0.04^{b}	6.24 ± 0.03^{b}	4.17 ± 0.04^{b}
	60	6.55 ± 0.04^{a}	4.29 ± 0.04^{a}	6.32 ± 0.04^{ab}	4.29 ± 0.04^{a}
	90	6.56 ± 0.04^{a}	4.33 ± 0.04^{a}	6.39 ± 0.04^{a}	4.32 ± 0.04^{a}
	Mean	6.47	4.22	6.24	4.20
	CV (%)	3.29	2.99	2.31	3.26

N – Nitrogen; n – Number of observations / treatments; CV - Coefficient of variation; B0 – Bioslurry 0 t/ha; B1 – Bioslurry 5 t/ha at high altitude site and 6 /ha at medium altitude site, B2 – Bioslurry 10 t/ha at high altitude site and 12 /ha at medium altitude site, B3 – Bioslurry 15 t/ha at high altitude site and 18 t /ha at medium altitude site; CFU – Colony forming unit; Same letters in the same column indicate values with non-significant differences at $P < 0.05$.

Discussion

Maize height and collar diameter

Bioslurry decomposes slowly releasing N which then becomes available to plant over longer period of growth and thus increases uptake of mineral N and other nutrients in addition to benefiting the soil physical conditions. The improved assimilation of N improves root system and results in better plant growth. Moreover, N is an important component of proteins, increases the photosynthetic capacity aiding rapid conversion of synthesized carbohydrates to proteins and protoplasm, and therefore allows the plant to grow faster (Reddy *et al.* 2018;

Om *et al.* 2014). The results are in agreement with findings of Islam *et al.* (2010) who reported increase of maize plant height with increase in bioslurry N rates up to 70 kg N ha^{-1}. Many other researchers reported improvement of plant growth by bioslurry N supply (Warnars and Oppenoorth 2014; Shahbaz *et al.* 2014).

Days to 50% tasselling

Increasing bioslurry and mineral N rates decreased number of days to 50% tasselling due to improved nutrient availability which subsequently enhanced growth rate and tasselling process. This result is in agreement with findings of Jassal *et al.* (2017) and Kaur (2016) who found that number of days to 50% tasselling decreased as N supply increased.

Nitrogen uptake

The increases in N uptake were reflected by increases of growth and grain yield. This might be attributed to higher N assimilation with the higher application levels. Tenorio *et al.* (2018) and Setiyono *et al.* (2010) similarly reported increase of grain N uptake with increase of N fertilizer applications.

Yield and yield components

The increases in grain yield, above-ground biomass and other yield components can be attributed to the enhanced N supply from both inorganic and organic fertilizer sources. The results are in agreement with findings of Tuyishime (2012) who reported higher maize grain yield given by the combination of urea at 50 kg N ha^{-1} and bioslurry at 10 t ha^{-1} in northern Rwanda. Khan *et al.* (2015) and Warnars and Oppenoorth (2014) also reported improvement in maize yields with application of bioslurry. Increased N supply has also been reported to increase biomass accumulation and stover yield in maize (Nasielski *et al.*, 2019; Reddy *et al.* 2018 and Om *et al.* 2014).

Influence of cropping seasons on maize performance

The higher maize growth, N uptake and yields observed in season A 2018 compared to season B 2018 at both medium and high-altitude sites might be attributed to favourable climatic conditions including higher rainfall received over a long period in season A 2018, i.e. from September 2017 to January 2018, compared to season B 2018 (March to May 2018). Maize growth and yield positively responded to higher moisture that facilitated easier and higher nutrient uptake resulting in higher growth and yield. These results are similar to those reported by Mallarino *et al.* (2011) who attributed higher growth to adequate moisture and associated higher nutrient uptake.

Integrated effects of bioslurry and mineral N on soil bio-chemical properties

Soil chemical properties

The relatively higher levels of SOC, total N and available P obtained in plots treated with higher rates of bioslurry may be attributed to enhanced uptake of N and P nutrients released upon decomposition and mineralization of applied bioslurry. Terracing enhanced decomposer populations (Fashaho *et al*. 2019). The greater increases in crop growth and yields observed in plots treated with bioslurry rates of 15 and 18 t ha^{-1} in high and medium altitudes sites are in agreement with findings of Khan *et al*. (2015), Shahbaz *et al*. (2014) and Tuyishime (2012) who reported slight improvements in nutrients due to application of bioslurry after a cropping season.

Soil bacteria and fungi populations

Bacteria and fungi populations were influenced by the application of bioslurry and mineral N, in both study areas. Higher populations were observed in plots treated with bioslurry rates of 12-18 t ha^{-1} and 10-15 t ha^{-1} in medium and high altitudes, respectively, as well as 60 - 90 kg mineral N ha^{-1} in both sites. This may be due to higher provision of nutrients by the fertilizers. The bacteria and fungi decomposed bioslurry availing nutrients to maize crop. Thus, improved growth and yield were observed in plots treated with the bioslurry rates of 12 - 18 and 10 - 15 t ha^{-1}. Nitrogen fertilization affects soil biological traits and bacterial communities across different soil types (Yu *et al.*, 2019). Fungi growth also tends to be promoted in soils fertilized with high amounts of organic matter (Swer *et al.*, 2011).

Conclusion

Maize (*Zea mays* L.) growth, nutrient uptake and yield were significantly enhanced by integrated application of bioslurry and mineral N. Significantly higher increases were obtained by the combination of mineral N rates of 60 - 90 kg ha^{-1} and bioslurry rates of 12 - 18 t ha^{-1} in terraced Lixisols of medium altitude and 10 - 15 t ha^{-1} in terraced Acrisols of high-altitude sites. The optimum fertilizer rates for maximum grain yield were 14.3 t ha^{-1} of bioslurry (i.e. 138.7 kg bioslurry N ha^{-1}) and 75.2 kg mineral N ha^{-1} in terraced Lixisols of medium altitude, and 78.4 kg N ha^{-1} in high altitude site. The combined application of bioslurry and mineral N fertilizer results in higher maize performance than when either bioslurry or mineral N is applied alone. Land use needs to adjust fertilizer application to these optimum rates for enhanced maize yields in this area and other regions with similar agro-ecological characteristics.

Acknowledgements

Authors would like to acknowledge the Carnegie Cooperation of New York and the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for funding the study. They thank the University of Rwanda for allowing them to use laboratory facilities for the soil analyses and Egerton University for the library facilities.

Conflicts of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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