International Scholars Journals

African Journal of Crop Science ISSN: 2375-1231 Vol. 10 (5), pp. 001-016, May, 2022. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Integrated effect of liquid bioslurry and inorganic fertilizer on selected soil chemical properties, maize (Zea mays) growth, yield and grain quality

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Accepted 05 November, 2021

Abstract

A bottle-neck to maize production in Kenya is expensive fertilizers and insufficient knowledge on use of organic fertilizers, which can be remedied by informed bioslurry use. Field experiments were conducted at Waruhiu Farmers' Training Centre, during 2019 short and 2020 long rains to evaluate effect of bioslurry, inorganic fertilizers and their integrations on soil chemical properties, maize growth and yield and grain quality. Treatments were: 100%bioslurry (BS), 75%BS+25%fertilizer, 50%BS+50%fertilizer, 100%fertilizer and Control. Soils were tested before and after two cropping seasons for selected chemical properties. Growth and yield parameters were evaluated. The 100%bioslurry increased pH, TN, TOC and Mn most by 5.9%, 46.4%, 35.5% and 112.5% respectively. Soil pH decreased only in 100%fertilizer. The 100%fertilizer increased exchangeable P and K most by 46.4% and 73.6% respectively but decreased Ca, Mg and Zn most. No significant difference ($P \leq 0.05$) was noted in most growth parameters except control. Stovers and stalk yields were highest in 100%bioslurry in short rains by 45.5% and 42.2% while grain yields were in 100%fertilizer by 29.3%. In long rains, 100%fertilizer increased stovers and stalk yields most by 49.6% and 51.9% respectively while 75%BS+25%fertilizer gave higher grain yields by 82.3%. The tested levels of bioslurry and its integrations improved evaluated parameters, though long term experiment is required to ascertain results.

Keywords: Bioslurry, fertilizer, soil chemical properties, maize, grain quality.

INTRODUCTION

Kenya is an agricultural country, with agriculture contributing 26% and 25% Gross Domestic Product (GDP) directly and indirectly respectively, accounting for 65% of export earnings, employing 57.2% of Kenyan population and 70% of rural people (World Bank and CIAT, 2015; KIPPRA, 2020; FAO, 2021). Further, World Bank and CIAT (2015), states that 78% of the agricultural production and 70% of commercial production is contributed by smallholder farmers. Therefore, the sector has the potential to positively affect livelihoods of more than 60% of the Kenyan population that depend on it by increasing incomes and enhancing food and nutritional security. Maize is the most important cereal crop within the country (Santpoort, 2020). Despite its importance, sta-

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tistics show that local production has been declining over the years leading to overreliance on imports (World Bank, 2018). According to Government of Kenya, (2018), per capita average production has remained below 80kg/person/year, against a required 103kgs/person. On average, annual production of about 3.71 million tonnes, about 2 tonnes per hectare against an expected 6 tonnes per hectare (Nyaanga and Barasa, 2019) is produced. The continuous decline in production has over the years been attributed to increasing population leading to land degradation, limited farmers' knowledge base, weather variabilities, increased pest and diseases associated with climate change, low purchasing power as well as nutrient mining with inadequate replenishment (Muindi *et al*., 2015; Njogu, 2019; Cairns *et al*., 2021).

Although inorganic fertilizers provide nutrients necessary for plant growth, their excessive and long term use negatively affect soil physical, chemical and biological properties (Dong *et al.,* 2016; Serrano *et al.,* 2017; Zhang *et al*., 2017). Similarly, they increase global warming. Application of N-fertilizer is the greatest contributor to nitrous oxide (N_2O) (Signor and Cerri, 2013; Millar, *et al*. 2014). Among the greenhouses, N_2O has a higher global warming potential, approximately 298 times that of CO_2 (Yi, *et al*., 2017). Bioslurry offers an important alternative. Kenya is well placed to adopt bioslurry in farming. Strides have been made to increase uptake of biodigesters through subsidies, loans and massive sensitization. Adoption in Kenya is currently at 0.03% of the 1.2 million household with potential for adoption (Wamwea, 2017). Various companies are promoting different biodigester types and the need for clean energy and hence Kenya will continue to see a rise in adoption of the technology. Bioslurry, dubbed as 'brown gold' in Groot and Bogdanski, (2013) is a by-product of anaerobic fermentation of organic material to produce biogas (Bonten, 2014). It is estimated that about 70-75% of the total solids fed into a biodigester as substrate is discharged (Holm-Nielsen *et al.,* 2009). This gives a substantial amount of nutrient rich bioslurry that can be used in farming. Bioslurry contains both macro and micronutrients and organic matter (Nyang'au *et al*, 2016; Jjagwe *et al*., 2020; Barlog *et al*., 2020). It has about 30% more total nitrogen and its C/N ratio is lower than FYM (Nyang'au *et al*., 2016). Low C/N ratio speeds up nitrogen mineralization thus increasing soil N supply. The role of bioslurry in chemical, physical and biological properties has seen it being promoted in crop production as sole application or integrated with inorganic fertilizer. Some researchers on long and short term experiments have reported high yields in bioslurry (Haile and Ayalew, 2018; Musse, *et al*., 2020; Rewe *et al*., 2021), fertilizer (Jjagwe *et al*., 2020; Nyaanga and Barasa, 2019) or their integration (Shahbaz, *et al*., 2014; Terefe, *et al*., 2018). However, the specific quantities to be utilized in maize production in acid soil is not well researched, neither effect well documented. This study was thereby established to *i.* evaluate the effect of bioslurry, its integration with inorganic fertilizer and inorganic fertilizer on soil chemical properties, *ii.* assess the effect of bioslurry, its integration and inorganic fertilizer on maize growth, yield and grain quality.

MATERIALS AND METHODS

Study area

The study was carried out in Waruhiu Agricultural Training Centre which is located in Githunguri, Kiambu County. The area receives bi-modal type of rainfall with long rains from March-May and short rains from October-November averaging at 1200mm per annum. Mean temperatures are 26^0C but cold months can be 7^0C. The area falls on latitudes of 0^0 22' 0'' South and 37^0 29' 0'' East of Equator, with an altitude of 1500-1800 metres above sea level. It is generally a coffee and dairy zone, but other crops such as maize are grown. The soils are dominated by humic nitisols that are characterised by well drained, extremely deep, dusky red to dark reddish brown, very friable clay, with an acid humic topsoil (Jaetzold, *et al*., 2006).

Experimental materials, design and crop husbandry

Description of experimental materials

Bioslurry was obtained from biodigester in a farmers' farm within the experimental area who participated in the National Research Fund (NRF) project. Biodigester was installed and operational since July 2018. Substrate was from Friesian and Guernsey crosses fed mainly on nappier grass, maize stovers, maize germ and dairy meal at milking. Bioslurry was stirred in collection tank, collected in 2-litre bottle and sent for analysis according to procedures laid out in CROPNUTS Laboratory Services manual. Atomic emission spectrometry (ICP-OES) was used to analyze P, K, Ca, Mg, Na, Mn, Fe, Cu, and S while in ammonium, nitrate nitrogen and bicarbonate, calorimetric method was used. The pH was analyzed using potentiometric method. The chemical composition of bioslurry used is presented on (Table 1). The inorganic fertilizer was NPK (23:23:0) while maize variety was Duma 43. Crops were sprayed with abamectin and chlorantraniliprole (Voliam Targo) to control pests.

Experimental design and planting

Experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated thrice on plots measuring 3m by 2.1m, separated by 0.5m pathway. Treatments were; 100%bioslurry, 75%bioslurry+25%fertilizer,50%bioslurry+50%fertilizer,100%fertilizer and control (no amendment). Bioslurry rates were 400mls, 300mls and 200mls for 100%, 75% and

50%, giving a total of 17,778l/ha, 13,333l/ha and 8,889 l/ha respectively. The 400mls was informed by the farmers' practice of a cupful per hole weighing about 450g. The NPK fertilizer at a rate of 100kgs/acre was used, a bottle top (about 5g), ½, and ¼ bottle top for 100%fertilizer, 50% and 25% respectively. A fork jembe was used in land preparation. Planting was done in two consecutive seasons during the 2019 short and 2020 long rains at a spacing of 30*75cm (25kgs/ha seeds), giving 5 rows and 8 hills per plot. At planting, treatments were placed in the hole and mixed with soil before placing a single seed. Regular agronomic practices such as weeding, top dressing, earthing up and pest and control were carried out accordingly. During topdressing, the treatments were placed in a 15cm diameter ring around the plant.

Data collection

Soil sampling and characterization

Soil chemical properties were evaluated before planting during short rains and after harvest in long rains. Initial soil sampling was done by taking soil from 9 points at 15cm depth within the entire field in a zigzag manner (Ackerson, 2018), mixed and a composite sample drawn for chemical analysis. In final sampling, soil samples at a depth of 15cm from 5 points along a zigzag line after long rains harvest in corresponding treatments was collected, mixed and composite samples taken for chemical analysis. Exchangeable P, K, Na, Ca, Mg and Mn analysis was done using the Mehlich Double Acid Method according to Mehlich *et al*., (1962). Total organic carbon was analyzed using the calorimetric method after Anderson and Ingram (1993) while TN was determined using the Kjeldahl method following Page *et al*, (1982). The soil pH was determined with pH-meter in a 1:1 (w/v) soil-water suspension following Mehlich *et al*., (1962), while exchangeable acidity was done after Okalebo *et al*., (2002). Available Fe, Cu and Zn were determined using Atomic Absorption Spectrophotometer (AAS) after extraction with 0.1 M HCl in procedures described in Mehlich *et al*., (1962).

Growth data

Five plants were randomly selected from 3 inner rows per plot and tagged at 14 days after sowing. Agronomic data was collected only from the tagged plants. Germination percentage was calculated from all the plants germinated per plot against the total planted. Plant height was determined by measuring height of tagged plants per plot by taking measurements from the base to highest point of the arch of topmost leaf whose tip was pointing downwards using a tailor's tape. Leaf width was taken at widest area of the leaf using tailor's tape from three topmost leaves with an open collar, up to cob development after which the three leaves to the cob leaf were used. Leaf length measurements were taken from the same leaves as width, by measuring from stem area to the leaf tip. Measurements were in cm. Leaf area index (LAI) was determined according to Onasanya, *et al.,* (2009) as LA=length×width×0.75, where LA, L and W are leaf area, leaf length and leaf width respectively, and 0.75 a constant. Number of leaves were counted from the lowest green leaf to the topmost opened leaf with a visible collar.

Yield and grain quality data

Tagged plants per subplot were harvested at physiological maturity. During harvesting, ears were removed from the maize plants and placed in labelled carrier bags per plot. Thereafter, entire plant was uprooted by digging around the plant with a hoe and gently pulling out whole plant together with the roots. Roots were cut off and washed in water to remove soil before air drying. Stalks were cut into pieces and placed in labelled carrier bags before drying. Roots, stalks and ears were air dried to constant weight separately for 14 days. Biological yield was determined by weighing roots, stalks and ears separately using an AKMA digital weighing machine. Economic yield was obtained by threshing the cobs from each plot, weighing grains and converting it to kilograms per hectare at 14% grain moisture content which was measured using a digital grain moisture meter analyser (Draminski Twistgrain Pro, Poland). For grain quality evaluation, a kilogram of well dried samples from each treatment after short and long rains were taken to the laboratory. They were analyzed for N, P, K, Ca, Mg, Zn, Fe, Cu and Mn content following the procedures described in Walinga *et al.*, (1989).

Statistical analysis

Growth and yields data were analyzed using SAS version 10 (SAS Institute Inc.). Data were subjected to analysis of variance (ANOVA) using Proc general linear model (GLM) procedures. Treatment effects were tested for significance using F-test. Significant means at F-test, were separated using least square means (LS-Means). All analysis was performed at 5% level of significance.

RESULTS

Effect of integrating fertilizer and cow dung bioslurry on soil chemical properties

Soil chemical properties before treatment

The soils were observed to have moderate acidic pH (5.0-6.0), high exchangeable acidity (>2.5%), high levels of exchangeable Fe (>24mg/kg) and Zinc. They had medium (0.15-0.25%), total nitrogen (TN) while total organic carbon (TOC) was high (1.8-3.0%). Similarly, excha-

Table 1 Chemical properties of bioslurry used in the experiment.

	-ppm-										-cmol/kg-		
Parameter	pH	$NH4^+$	$N0_3$	P	Fe	S	HCO_3	Mn	Cu	Na	K	Ca	Mg
Value	7.6	497.0	17.1	33.5	7.6	13.2	6375.0	1.5	0.2	503.5	1893.0	119.4	72.1

ppm: parts per million, cmol/kg:centimoles/kilogram

Table 2. Effect of integrating fertilizer and cow dung bioslurry on selected soil chemical properties

		After 2 seasons				
Parameter	**Initial**	**100%BS**	**75%BS+25% Fertilizer**	**50%BS+50% Fertilizer**	**Fertilizer**	**Control**
pH (water)	5.07	5.37	5.29	5.13	4.84	5.28
Exch. acidity (cmol/kg)	0.40	0.25	0.35	0.45	0.65	0.30
Tot. N (%)	0.18	0.25	0.25	0.24	0.22	0.20
TOC (%)	2.00	2.71	2.70	2.67	2.46	2.15
Exch. P (mg/kg)	28.00	39.50	38.00	37.00	41.00	38.00
Exch. K (cmol/kg	0.72	1.06	1.03	1.10	1.25	0.93
Exch. Ca (cmol/kg)	2.80	2.80	3.00	2.10	2.00	2.50
Exch. Mg (cmol/kg)	1.86	1.38	1.32	1.12	1.03	1.33
Exch. Mn (cmol/kg)	0.48	1.02	0.70	0.86	0.93	0.89
Exch. Cu (mg/kg)	1.52	1.43	1.59	1.75	1.56	1.34
Exch. Fe (mg/kg)	29.20	24.60	28.45	23.55	25.60	37.35
Exch. Zn (mg/kg)	32.40	22.40	28.00	22.50	21.45	23.60
Exch. Na (cmol/kg)	0.04	0.20	0.19	0.19	0.20	0.22

ngeable phosphorus (P) was very high (>25%) while exchangeable potassium (K) was high (0.7-2.0cmol/kg) although exchangeable sodium (Na) was very low (0.0-0.1cmol/kg). On the other hand, moderate levels of exchangeable magnesium (Mg) (1-3cmol/kg), low levels (2-5cmol/kg) of exchangeable calcium (Ca) and Ca:Mg ratio (1-4) were noted.

Soil chemical properties after two seasons of treatment

Soils registered a non-significant increase in pH in all treatments after two seasons compared to initial pH except in 100%fertilizer with a 4.5% decrease to strongly acidic (4.5-5.0), (Table 2). A concomitant increase in soil pH with increase in bioslurry quantity and decrease with increase in fertilizer quantity was noted. Similarly, a positive correlation between increasing exchangeable acidity with increase in quantity of fertilizer was observed. Exchangeable iron (Fe) decreased in all the treatments except in control, where a 27.91% increase was noted. All treatments exhibited a non-significant increase in total nitrogen (TN) and organic carbon (TOC), exchangeable phosphorus (P) and potassium (K). Higher levels of bioslurry (100%bioslurry and 75%BS+25%fertilizer) registered higher TN by 38.9%. These soils also registered higher TOC, increasing by 35.5% and 35.0% respectively. Effect of 100%fertilizer on exchangeable P and K was higher by 46.4% and 73.6% respectively. Least increase in TN, TOC and K was noted in control. Sodium increased significantly to low (0.1-0.3) in all treatments, with an increase ranging from 375% to 450%, where control caused highest increase.

A decrease in exchangeable magnesium (Mg) and zinc (Zn) after treatment was noted. Exchangeable Mg decreased with increase in the level of fertilizer, decreasing least in 100%bioslurry (25.8%), while exchangeable Zn decreased most by 33.8% in 100%fertilizer. Exchangeable calcium (Ca) increased non-significantly only in 75%BS+25%fertilizer by 7.10% while no effect was observed in 100%bioslurry. However, a decrease in other treatments with greatest decrease in 100%fertilizer by 28.6% was noted. An increase in Ca:Mg ratio from 1.5 to 2.03, 2.27, 1.87, 1.94 and 1.88, for 100% bioslurry, 75%BS+25% fertilizer, 50%BS+50% fertilizer, 100% fertilizer and control respectively was observed.

Effect of integrating different levels of fertilizer and cow dung bioslurry on maize growth

Higher germination percentages during long rains compared to the short rains (Figure 1) were observed. Treatments did not affect germination percentage signifi-

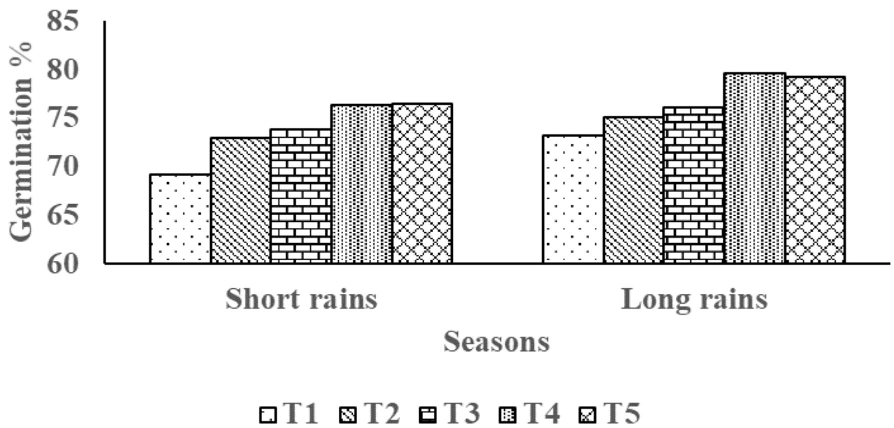


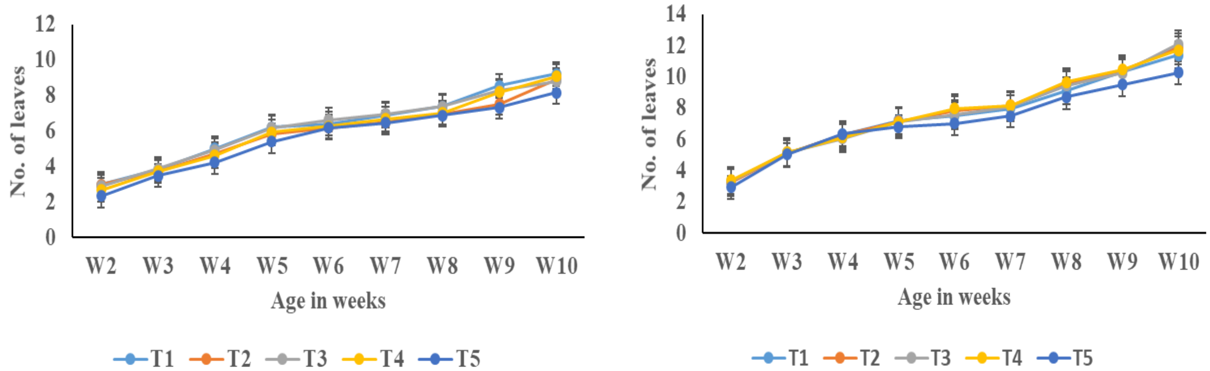
Figure 1. Effect of integrating fertilizer and cow dung bioslurry on germination percentage during the 2019 short and 2020 long rains.
T1=100% bioslurry (BS), T2=75%BS+25% fertilizer, T2=50%BS+50% fertilizer, T4=100% fertilizer, T5=Control.

cantly (P≤0.05). However, numerical differences were observed with T5 and T4 registering higher percentages. During short rains, T5 had 75.8% and T4 73.3% while in long rains, T4 registered 80.0% and control 79.0%. Treatment T1 gave lowest values in both seasons at 69.0% and 73.0% respectively.

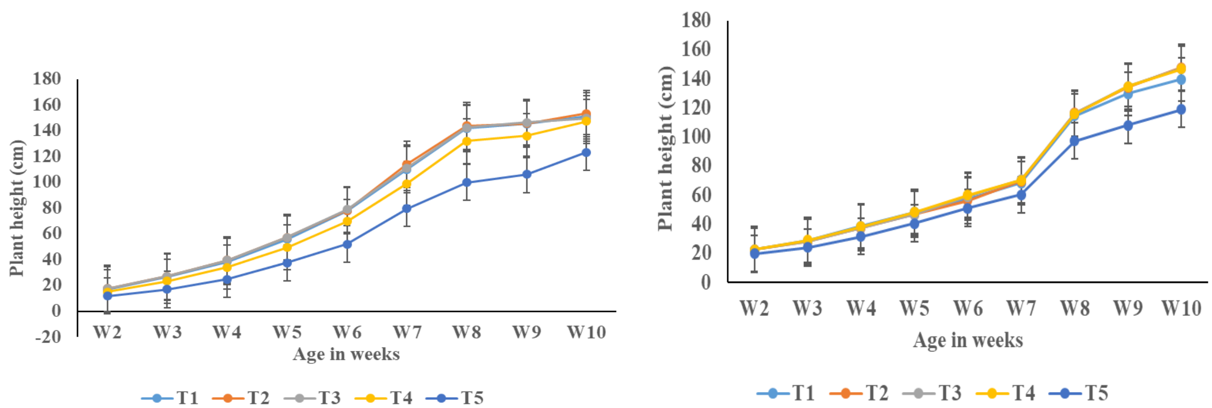
Average number of leaves were significantly (P≤0.05) influenced by treatments during the short rains at 2 weeks after planting (WAP). The highest number of leaves (2.97) was found in T1 and T2 which were significantly different (P≤0.05) from the rest, while T3 and T4 increased by 23.18% and 14.60% above T5 (Figure 2a). However, during the long rains, the treatments did not significantly (P≤0.05) influence the number of leaves except T5, although T4 had numerically the highest number by 15.4% above T5 (Figure 2b). Higher bioslurry levels caused higher number of leaves in the short rains while higher fertilizer levels caused higher leaves in the long rains. Similarly, the number of leaves were not significantly (P≤0.05) affected by the treatments during the short rains at 10 WAP, except in T5, although T1 gave numerically higher number of leaves by 12.9%. However, the effect of treatment on number of leaves at 10 WAP in long rains was significant (P≤0.05), where T3 and T2 did not differ and gave higher number of leaves by 17.8% and 15.9% respectively. Mean number of leaves for 10 WAP were not significantly (P≤0.05) affected by treatment in both seasons except T5. The trend in short rains was T1>T3>T4>T2>T5 with a 13.0%, 11.7%, 8.3% and 6.3% increase over T5 while long rains displayed T4>T2>T3>T1>T5, with 8.8%, 8.4% 7.4% and 6.7% increase.

A variation on the effect of treatment on plant height was displayed. Average plant height at 2 weeks after planting (WAP) in short rains was higher in T2 and T3 by 50.6% and 49.8% respectively and differed significantly from the rest (P≤0.05), (Figure 3a). Treatment T1 and T4 increased by 41.7% and 28.2% respectively. However, there was no influence of treatment on plant height (P≤0.05) at 2 WAP during long rains except in T5 although T1 and T4 gave highest height by 15.4% while T3 and T2 recorded 15.0% and 14.7% (Figure 3b). Similarly, no effect was noted at 10 WAP in short rains except in T5, but highest increase was in T2 by 24.4% while T1, T3 and T4 increased by 22.7%, 21.3% and 19.5% respectively. Plant height at 10 WAP during long rains in T2, T3 and T4 did not significantly (P≤0.05) differ and increased by 24.2%, 23.8% and 23.3% over T5 while T1 had 17.5% increase. Mean plant height for 10 WAP in short rains was only statistically different (P≤0.05) in T4 and T5 and increased by 40.6%, 39.5%, 38.4% and 27.9% in T2>T3>T1>T4>T5. However, the interaction was not significantly different (P≤0.05) in long rains except T5, with the trend T4>T3>T2>T1>T5, with 20.7%, 20.2%, 19.5% and 17.6% increase over T5 respectively.

The interaction of treatments on average leaf area index (LAI) varied. Leaf area index at 2 weeks after planting (WAP) in short rains increased the most in T3 by 25.6%, and differed significantly (P≤0.05) from the rest while T1, T4 and T2 were statistically similar (P≤0.05) and increased by 11.34%, 10.25% and 8.88% over T5 (Figure 4a). Similarly, in long rains, T2 and T1 registered higher values by 37.6% and 35.7% respectively over T5, and differed significantly (P≤0.05) from the rest where T4 and T3 increased by 25.0% and 23.2% respectively (Figure 4b). However, there was no effect of treatment at 10 WAP in short rains except in T5, but increased by 55.1%, 50.9%, 50.3 and 48.6% T3, T4, T2 and T1 respectively. The highest increase in long rains was in T4 by 57.3% and differed significantly (P≤0.05) from the rest while T2 and T3 were similar and increased by 44.1% and 42.9% with T1 having 28.4% increase over T5. The mean LAI for 10 WAP in SR showed the trend T3>T2>T1>T4>T5, at 351.0, 341.3, 330.8, 322.4 and 198.2 respectively. In long rains, it was T4>T2> T3>T1>T5 with 314.2, 296.2, 288.9, 262.2 and 210.2 respectively and differed



Figures 2a and b Effect of integrating fertilizer and cow dung bioslurry on number of leaves during the 2019 short and 2020 long rains
T1=100%bioslurry (BS), T2=75%BS+25% fertilizer, T2=50%BS+50% fertilizer, T4=100% fertilizer, T5=Control, W=Week



Figures 3a and b Effect of integrating fertilizer and cow dung bioslurry on plant height during the 2019 short and 2020 long rains.
T1=100% bioslurry (BS), T2=75%BS+25% fertilizer, T2=50%BS+50% fertilizer, T4=100% fertilizer, T5=Control, W=Week

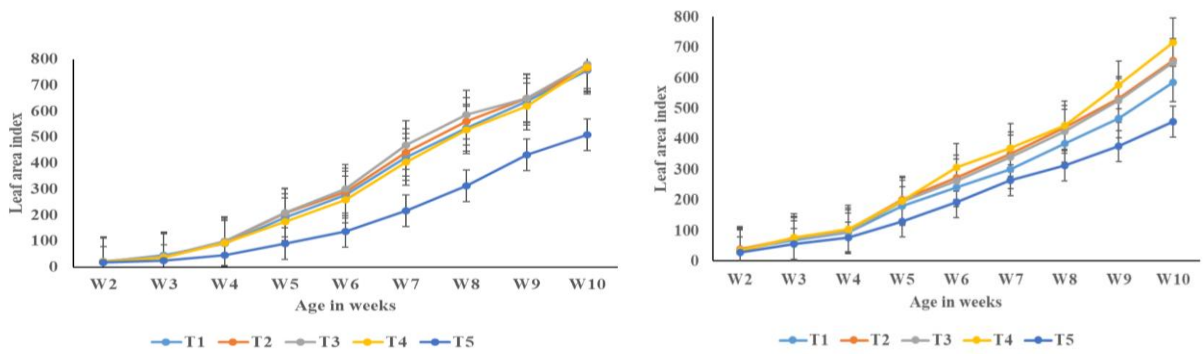
significantly (P≤0.05) in long rains but not in short rains. Effect of treatment on days to 50%tasselling and 50%silking in short rain was significant (P≤0.05). Less variation to 50%tasselling and 50%silking was observed during long rains compared to short rains (Table 3). The shortest time to 50%tasselling and 50%silking in short rains was observed in 50%BS+50%fertilizer. The longest time to 50%tasselling was noted in 100%bioslurry while to 50%silking, it was in control. Though the effect of treatment on both parameters was not significant (P≤0.05), 50%BS+50%fertilizer registered shortest time to 50%tasselling while shortest time to 50%silking was in 100%fertilizer with control taking longest time in both parameters.

Effect of integrating different levels of fertilizer and bioslurry on dry matter and grain yields

The interaction between treatments in stovers, stalks and grain yields in short rains was not significant (P≤0.05) except in control (Table 4). However, 100%biolsurry had highest stovers and stalks yield by 45.5% and 42.2% above control while grain yield was highest in 100%fertilizer, 29.3% above control. Treatments affected stovers and stalks significantly (P≤0.05) in long rains with higher yields registered in 100%fertilizer by 49.6% and 51.9% above control. However, no significant difference (P≤0.05) was noted in grain yields although greatest increase (82.3%) was observed in 75%BS+50%fertilizer.

Effect of integrating different levels of fertilizer and bioslurry on grain quality

Effect of treatment on grain quality varied between seasons (Table 5). All treatments caused an increase in grain N and Ca except T1. However, all treatments caused a decrease in Mg and Zn, with the least decrease in Mg observed in T1 (25%) while in Zn it was in T4 (26%). An increase in Fe was noted in all treatments except T3, increasing the most in T1 by 74%.



Figures 4a and b. Effect of integrating fertilizer and cow dung bioslurry on leaf area index (LAI) during the 2019 short and 2020 long rains.
T1=100% bioslurry (BS), T2=75%BS+25% fertilizer, T2=50%BS+50% fertilizer, T4=100% fertilizer, T5=Control, W=Week

Table 3 Effect of integrating fertilizer and cow dung bioslurry on tasselling and silking of maize during the 2019 short rains and the 2020 long rains.

Treatment	Tasselling SR	Silking SR	Tasselling LR	Silking LR
100%bioslurry	70.67a	74.00b	70.00b	73.83b
75%BS+25%fertilizer	69.67b	73.83b	70.00b	73.33b
50%BS+50%fertilizer	69.33b	73.33c	69.67b	73.33b
100%fertilizer	69.83b	73.67bc	69.83b	73.17b
Control	70.00ab	75.00a	71.33a	74.67a
LSD(P≤0.05)	0.82	0.42	0.71	0.73
CV%	2.12	2.12	2.12	2.12

Means followed by the same letter within a column are not significantly different at p≤0.05. BS=bioslurry, LSD=least significant difference, CV=Coefficient of variation SR=Short rains, LR=Long rains

Table 4 Effect of integrating fertilizer and cow dung bioslurry on dry matter and grain yields during the 2019 short and 2020 long rains.

	2019 Short rains			**2020 Long rains**		
Treatment	**Stovers (t/ha)**	**Stalks (t/ha)**	**Grains (t/ha)**	**Stovers (t/ha)**	**Stalks (t/ha)**	**Grains (t/ha)**
100%bioslurry	7.16a	4.95a	6.82a	5.00ab	3.53bc	4.31a
75%BS+25% fertilizer	6.83a	4.74a	6.92a	5.40a	4.04ab	5.56a
50%BS+50% fertilizer	6.41a	4.29a	7.12a	5.39a	3.63bc	4.56a
100%fertilizer	6.85a	4.61a	7.42a	6.00a	4.48a	4.72a
Control	4.92b	3.48b	5.74b	4.01b	2.95c	3.05b
LSD (P≤0.05)	1.00	0.88	0.73	1.04	0.71	0.73
CV%	2.1	2.1	2.1	2.1	2.1	2.1

Means followed by the same letter within a column are not significantly different at p≤0.05. BS=bioslurry, LSD=least significant difference, CV=coefficient of variation

DISCUSSION

Chemical properties of the soil before treatment

As per the rating suggested by Landon, (1984), the soils had low levels of Ca (<4.0cmol kg^{-1}) and high levels of exchangeable acidity (>20%) implying that the fertility status was low. According to Kanyanjua *et al*., (2002), the soils were moderately acidic, a pH of 5.0-6.0. Such acid soils with high exchangeable acidity and low bases depict highly weathered soils, which have lost most of the basic cations through leaching (Landon, 1991). The acidity could also be attributed to parent material mineralogy since most of these soils developed from non-calcareous parent materials such as phololites, syenites, nepholites and trachytes which are acidic in nature (Sombroek *et al.,*

Table 5 Effect of integrating fertilizer and cow dung bioslurry on grain quality during the 2019 short and 2020 long rains.

		Parameter								
		-%-				-mg/kg-				
Treatment	Season	N	P	K	Mg	Ca	Fe	Mn	Cu	Zn
T1	SR	1.35	0.16	0.14	0.05	51.75	45.85	8.33	3.33	21.70
	LR	1.23	0.21	0.20	0.04	41.75	80.00	5.00	6.66	15.00
T2	SR	1.17	0.23	0.17	0.06	22.55	57.50	10.82	4.17	30.85
	LR	1.57	0.16	0.16	0.04	32.60	83.15	4.17	7.50	13.35
T3	SR	1.11	0.19	0.15	0.06	15.90	67.50	13.34	5.84	25.00
	LR	1.57	0.19	0.20	0.04	27.55	61.65	4.17	6.66	14.20
T4	SR	1.23	0.17	0.16	0.06	19.20	52.35	5.83	4.17	20.00
	LR	1.69	0.28	0.14	0.04	46.75	66.65	1.67	7.50	15.85
T5	SR	1.17	0.18	0.17	0.06	20.85	46.65	8.34	5.00	20.85
	LR	1.52	0.18	0.18	0.03	57.60	60.00	4.17	8.33	10.85

T1=100%bioslurry (BS), T2=75%BS+25%fertlizer, 50%BS+50%fertilizer, T4=100%fertilizer, T5=Control, SR=Short rains, LR=Long rains

2002). The High levels of exchangeable P (>25mg/kg) in the soils can be attributed to the previous soil management practices. According to Brady and Weil, (2007) and Muindi, (2019), P has low mobility and if not lost from the soils through erosion, plant uptake or adsorption, it can persist in the soils for a long period causing a build-up of soil P 'bank' (Nascimento, *et al*., 2018). Only about 1.5-11% of all the soil P is readily available (Olsen P) (Stutter *et al*. 2012).

There exists a negative correlation between exchangeable Fe and soil pH, and a positive correlation between exchangeable acidity and exchangeable Fe (Brady and Weil, 2007; Muindi, 2016). The observed high levels of exchangeable Fe can therefore be attributed to soil pH and exchangeable acidity levels. According to Brady and Weil., (2007), exchangeable Zn is a factor of minerology, soil pH and management levels. The present high levels of Zn can be attributed to the acidic parent materials as well as the previous soil management. The medium TN (Bruce and Rayment 1992), high OC (Emerson, 1991; Charman and Roper, 2000) and very high exchangeable P (Holford and Cullis, 1985) implies that the soils have good fertility to support maize production. The levels are influenced by continuous research in the study site. However, the low pH, Ca and high exchangeable acidity would limit soil productivity. The recommended pH levels for maize growth is 5.8-7.0 (Albrecht, *et al*., 2005; Crouse and Denny, 2015).

Effect of integrating fertilizer and cow dung bioslurry on soil chemical properties

Increase in soil pH upon use of bioslurry alone or integrated compared to 100%fertilizer could be due to its alkaline nature, necessary for survival of methanogenic bacteria (Khalid *et al*., 2011; Rajendran, *et al*., 2012), and organic matter content (Nyang'au, *et al*., 2016; Musse *et al*., 2020). Organic matter contains weak acids with a carboxyl (-COOH) whereby increased pH causes release of H^+ which reacts with hydroxyl to form water thus buffering pH (Bot and Benites, 2005). A negative charge is also created in the exchange complex to take in more cations such as base cations. Integrated application of bioslurry at 20.6m^3/ha and fertilizer at 41kgN/ha was found to increase CEC by 120% (Musse *et al*., 2020). Therefore, addition of bioslurry creates more sites for cations to adsorb to. Bioslurry contains good amounts of base cations such as Ca, Mg, K and Na. Similarly, breakdown of plant materials to ammonium by soil microbes through mineralization increases pH (McCauley, *et al*., 2017), since organic anions formed during decomposition consume protons from the soil (Haynes and Mokolobate, 2001).

The increase in pH found here has been reported in other research works. Thesis work of Mwanga (2016), reported an increase by 8.7% and 5.6% in two different sites in Tanzania on use of 6666.7l/ha of liquid bioslurry. On integrating 3333.35l/ha and 0.05kgs DAP in a 3*1.5m plot, the authors found lower pH increase by 2.96% and 1.81%. The results are also corroborated by Terefe, *et al*., (2018) where increasing pH values of 6.71, 6.65, 6.82 and 7.14 from an initial pH of 6.36, on use of 10, 30, 50 and 90m^3 of bioslurry except at 30m^3 was found. The authors also found lower pH levels when lower bioslurry levels (10m^3/ha) and inorganic NP fertilizers were integrated at 25%, 50% and 100%, compared to where higher bioslurry levels (70m^3/ha) was used. At the same time, Rewe *et al*., (2021) found increased pH levels by 4% and 1% when 400mls/hill bioslurry from Dome and Flexi biodigesters were used in a maize crop respectively, attributing the increase to the high pH and organic content in bioslurry. On the contrary, Musse, *et al*., (2020) reported a decrease in soil pH by 0.7% when 20.6 and 41.2m^3/ha liquid bioslurry was used. However, when higher levels (61.8m3/ha) were added, the authors reported pH increase by a similar percentage. Contrary to increase in pH with increase in bioslurry levels in integrations, Biramo, *et al*., (2019) reported a 6.19% decrease in pH when bioslurry and fertilizer were integrated, but a 2% increase was noted when 14t/ha bioslurry was used. However, Musse, *et al*., (2020) reported varying effects where integrating 20.6, 41.2 and 61.2m^3/ha of bioslurry with either 20.5, 41 or 61.5kg/ha of inorganic fertilizer caused a pH change of between 7.2-7.4, from an initial pH of 7.35.

The decrease in pH noted when fertilizer alone was used could be ascribed to nitrification or absorption by plants. Presence of ammonium N leads to release of H^+ through nitrification, but also its absorption by the plant roots triggers a corresponding secretion of H^+ to maintain charge balance across cell wall membranes (Guan, *et al*., 2016; Brookside, 2021). As such, when plants absorb an ammonium ion they release a hydrogen ion (H^+), and if a nitrate ion they release a hydroxide ion (OH^-) leading to a corresponding increase in pH when nitrate-N is uptaken while uptake of ammonium-N reduces pH (Hinsinger, *et al*., 2003). Similarly, leaching of nitrates causes twice as much net acidification of the ammonium molecule as compared to uptake by plants since there is consumption of one H^+ ion (or excretion of OH^-) for each molecule of nitrate taken up (Smiley and Cook, 1973). This decrease found in the current experiment has been observed in the research work of Biramo, *et al*., (2019) where a percentage decrease by 11.52% and 9.89% in two different tomato varieties were reported on using urea and TSP fertilizer. Similarly, using TSP at 60kg P/ha in Kakamega and Bukura, Opala, *et al*., (2012) reported a pH decrease by 7.82% and 12.94% at 16 weeks after incubation. However, increase in pH levels on application of varying levels of TSP fertilizer (20.5, 41 and 61.5kgs/ha), ranging from 7.4-7.5, have been reported (Musse, *et al*., 2020). The authors also found a 0.68% increase in pH in control, in agreement with the current results. However, a decrease in pH in control by 12.57% and 12.99% has also been reported in Biramo, *et al.,* (2019). The decrease in exchangeable acidity when bioslurry was added could be due to complexation by soluble organic matter (Opala, *et al*., 2012), as seen in pH increase. Exchangeable acidity is made up of exchangeable Al, Fe, H and base cations and therefore an increase in exchangeable Al and H ions in soil solution causes an increase in exchangeable acidity (Muindi *et al*., 2015).

The higher TN and TOC on use of higher levels of bioslurry compared to fertilizer could be due to increased soil organic matter found in bioslurry. Research in Shahzad *et al*., (2015) found higher levels of soil organic matter (SOM) at 5.90g/kg when 8.4t/ha of bioslurry was used compared to use of 135kgN/ha inorganic fertilizer (5.0g/kg), while integrating 50% of each gave 5.15g/kg with control giving 4.95g/kg. Addition of organic material can cause SOC increase by 50-150 kg/ha (Lar, 2004) as it is noted that SOM contains 58% organic carbon (De Brogniez, *et al*., 2015). At the same time, application of organic material is said to increase the proportion of clay particles and aggregates, increase cation exchange capacity as well as NO_3^--N immobilization in the soil (Bot and Benites, 2005). This minimizes NO_3^--N that can potentially leach increasing its accumulation in the soil. The current results are supported by Rewe *et al*., (2021) where TN and SOC increased by 36.67% and 37.20% using Fixed Dome bioslurry respectively. Similarly, Barłóg, *et al*., (2020) reported higher SOC levels in bioslurry (15.4g/kg) compared to NPK fertilizer (15.3g/kg) and control (15.2g/kg) in a four-year experiment. On the other hand, Shahzad *et al*., (2015) found fertilizer alone to yield the highest OC concentration at 0.54g/kg, 50%BS+50%fertilizer at 0.47g/kg, bioslurry alone at 0.33g/kg while control was 0.22g/kg. However, results in Musse, *et al*., (2020) found varying effects although use of lower levels of fertilizer at 20.5kg/ha integrated with bioslurry at 41.2kgN/ha yielded the highest OC by 58.8%. The authors also found increasing TN values with increase in bioslurry as noted in the current experiment where bioslurry at 61.3m^3 gave the highest TN by 39%. Further, the authors reported varying effects upon integration, where integration at 41kgN/ha and 41.2m^3/ha caused the greatest increase by 17.4%. The findings are also corroborated by Rewe *et al*., (2021) where bioslurry caused increase in both elements concomitantly, attributable to the organic matter in bioslurry. The correlation between TN and TOC contradicts with Barłóg, *et al*., (2020) where no relationship was noted. Correlation between SOC and TN depends on soil texture, temperature and moisture (Bai *et al*., 2005) while their content in the soil is controlled by various groups of soil microorganisms (Cameron, *et al*., 2013; Abubaker *et al*., 2015).

The increasing levels of exchangeable P observed in the research can be attributed to the quality of bioslurry and P levels in fertilizer. According to *Muindi et al*., (2015), there exists a negative correlation between adsorbed P, organic amendments and soil pH. As a rich source of base cations and organic carbon, bioslurry triggers increase in soil pH leading to reduced soil P adsorption and availability in the exchange complex. Increased P values with increase in bioslurry levels obtained in the current study agree with those in Musse, *et al*., (2020) where highest amount of bioslurry used, 61.8m^3/ha caused an increase by 17.2%. However, the authors found the highest increase to be in 41kgsN/ha bioslurry and 41.2m^3/ha fertilizer integration. Contrary to these findings, Shahzad *et al*., (2015) reported bioslurry to yield the highest available P at 2.50mg/kg followed by 50%BS

+50%fertilizer (2.35mg/kg) while fertilizer and control had 1.63 and 1.26g/kg respectively. Similarly, Barłóg, *et al*., (2020) found higher mean P values of 94.6mg/kg when bioslurry was used while NPK and control gave 90.9 and 84.0mg/kg respectively. On the other hand, Biramo, *et al*., (2019) found the highest levels of available P (14.4ppm) when bioslurry was integrated with fertilizer but bioslurry and fertilizer alone gave 9.8ppm each. Similar findings have been reported by Mwanga (2016) where DAP at 2g/plant yielded the highest extractable P (29.55mg/kg) while bioslurry alone (6666.7l/ha), 50%BS+50%fertilizer and control registered 13.25, 11.86 and 6.66mg/kg respectively.

Increased pH favours base cations causing them to be higher in the exchangeable complex as observed in bioslurry treated soils. Research in Shahzad *et al*., (2015) found bioslurry to yield higher K values at 147.1mg/kg while 50%BS+50%fertilizer, fertilizer and control had 131.1mg/kg, 55.8mg/kg 46.5mg/kg respectively. Similarly, Mwanga (2016) also reported higher K values of 2.09cmol/kg in bioslurry while DAP gave 1.49cmol/kg and an integration of both gave 1.59cmol/kg. The authors found the highest K values to be in control, at 1.79cmol/kg. Biramo, *et al.,* (2017) on the other hand found the highest available K values in integration at 27.2meq/100g while fertilizer and bioslurry yielded 18.4 and 17.8meq/100g respectively. Although higher levels of organic matter in the soil provide more adsorption sites for exchangeable K thus preventing fixation (Li *et al*., 2020), the same may have caused immobilization due to their effect on physical, chemical and biological factors (Zhang *et al*., 2019). This explains the reason for lower exchangeable K in soils treated with bioslurry. The higher exchangeable Mg levels with increase in bioslurry levels and control compared to fertilizer found in this study is in contrast with the work of Barłóg, *et al*., (2020) who found higher levels in fertilizer, 144.3mg/kg, than bioslurry, 144mg/kg, while control had the least (135mg/kg). Similarly, Biramo (2017) found higher exchangeable Ca and Mg levels of 7.01cmol/kg and 1.95cmol/kg in bioslurry and fertilizer integration that increased from 5.41cmol/kg and 1.73cmol/kg respectively. The authors found lower levels in bioslurry compared to fertilizer, contrary to the current study. The notable decrease in Ca in some treatments and general reduction in Mg after treatment can be explained by various factors. High concentration of H^+ found in acidic soils displaces Ca and Mg, causing leaching (Norton, 2013), hence acidic soils have low contents of these elements. Similarly, Mg is less strongly bound to CEC, and therefore its concentration in the soil solution is higher (Gransee and Führs, 2013), increasing leaching. This is because Mg has an ionic radius that is smaller than Ca, K or Na, while its hydrated radius is larger (Maguire and Cowan, 2002) as it is known to bind water more strongly (Jensen, *et al*., 2020).

Effect of integrating fertilizer and cow dung bioslurry on the growth and yield of maize

The relatively comparable effect of treatments on growth and yields except control could be due to increased soil nutrients and better soil physical, chemical and biological properties. Bioslurry improves soil aggregation due to its organic matter content. Soils high in aggregate structure are friable, encourages better gaseous exchange, regulates water retention and infiltration, reduce erosion, contain more nutrients and organic matter, host more microbes and are easily penetrated by roots, (Jackson, 2014; Rai *et al.,* 2017; Rabot *et al.,* 2018; Alagoz and Yilmaz, 2019). Similarly, bioslurry increases colonization by mycorrhiza fungi, which enhances nutrient acquisition. Research by Ryan and Angus (2003) found higher concentrations of mycorrhiza fungi in organic compared to conventional wheat systems. Inorganic fertilizers on the other hand improves soil chemical property by supplying nutrients that are readily soluble in water and present in high quantities. Integrating the two augments each other and hence better plant performance in provision of nutrients and creation of a conducive environment for their absorption. The macro- and micro-nutrients present in bioslurry enhances plants growth. Nitrogen is an integral part of chlorophyll and plays a pivotal role in plant growth by enhancing meristematic growth (Islam *et al*., 2010; Razaq *et al*., 2017). Various enzymes for instance nucleic acid, nucleotides, coenzymes, phospholipids as well as cytokinins are composed of proteins and N is a component of protein (Ye, *et al*., 2019), further emphasizing the importance of the nutrient in a plant's growth. Combining NH_4^+ and NO_3^- as present in bioslurry helps the plant to utilize N more efficiently (Juan, *et al*., 2007), since less oxygen is required in NO_3^- assimilation compared to NH_4^+ (Devaux, *et al*., 2003; Abbasi, *et al*., 2017). The saved energy can be channelled to other growth processes. The improved pH may have enhanced assimilation of some nutrients by plants. Optimal uptake of NH_4^+ and NO_3^- is said to be influenced by pH, (George, 2014). Similarly, plant growth is increased by biofertilizers due to the presence of humic acids and growth promoting bacteria (Blouin *et al*., 2019). Phosphorus was found to be very high in soils after treatments, and it plays an important role in energy currency, enhances photosynthesis and carbohydrates metabolism, influences cell division (Islam, *et al*., 2010; Razaq, *et al*., 2017). Additionally, P stimulates seed germination, root, stalk and stem development, flowering and seed formation as well as crop yields and quality (Malhotra *et al*., 2018). Improving soil conditions and provision of the required nutrients enhances crop growth and yields. All these work together to contribute to good plant growth and yields observed in bioslurry, fertilizer and their integration compared to control.

The good germination percentages found across all the treatments implies no interference on seed germination such as "burning" occurred. The results are in agreement with Rewe *et al*., (2021) where germination percentages >70 were obtained using bioslurry from Fixed Dome and Flexi biodigesters. Similarly, Nyaanga and Barasa (2019) found no statistical difference in control, fertilizer and bioslurry germination percentage. However, the authors found bioslurry applied in the hole and mixed with soil to yield highest germination percentage in season 1 and 2 in maize (88.8 and 90.8%), which they ascribed to improved moisture around the seed. Similarly, Farouq and Islam (2007) found higher germination percentages in cow dung (65.33%) than control (64%) in eggplant and in tomato, with was 70.3% in cow dung and 67.7% in control. In contrast, Fredrick, *et al*., (2018) found the lowest mean germination percentage (29.6%) when poultry manure was mixed with top soil compared to other treatments in soursop (Annona *muricata* Linn).

Higher number of leaves as influenced by bioslurry, fertilizer or their integrations observed here have been reported elsewhere. Application of 60, 70 and 82kg of bioslurry N in maize resulted in increased leaf number with increase in bioslurry up to 70kgsN/ha (Islam *et al*., 2010), although no significant difference was found. In testing the effect of different levels of bioslurry and fertilizer on kales, Haile and Ayalew (2018) found the highest number of leaves in bioslurry (11), followed by fertilizer (10) while 75%bioslurry+25%fertilizer had 8 leaves, and control 4.2 leaves. The numerically lower number of leaves in control (4.1) compared to bioslurry (4.3) were also noted by Alam *et al.,* (2014) in tomato. Shahbaz *et al.,* (2016) found higher number of leaves in Okra that were statistically similar ($P \leq 0.05$) to fertilizer (13.5) and 600kgs/ha bioslurry (12.7) but integrating both at 50, 75 and 100% levels gave higher number of leaves at 14.2, 15.1 and 15.5 respectively, while control had 7.3. Generally, the number of leaves is a function of the genetic makeup of the plant as well as environmental factors such as weather (Islam *et al*., (2010) and nutrient management, and explains the minimal differences noted, with the lower leaves in control attributed to lower nutrients in untreated plots. The lower number of leaves in fertilizer in the short rains compared to bioslurry treatments may be attributed to higher rainfall during this season which may have increased leaching of nutrients. Soil TN and TOC were lower while Ca and Mg decreased the most in this treatment after the two seasons.

The varying numerical differences in plant height found in this study have been found by other researchers. Higher plant heights were found in integration at 25, 50 and 100% fertilizer and 600kgs/ha (132, 135 and 140cm) compared to fertilizer (116cm) or bioslurry alone (78cm) while control was the least (52cm) (Shahbaz *et al*., 2016). On the other hand, bioslurry was found to contribute to the highest growth in height (37.3cm) in kales, fertilizer at 28.9cm while integration at 75%bioslurry+25%fertilizer followed at 24.33cm (Haile and Ayalew, 2018). The lower LAI in control compared to other treatments may be inherent and environmental factors. The leaf area is determined by leaf shape/size, agronomic practices, CO_2 and environmental factors (Jonckheere *et al*., 2004). The mean LAI values obtained in the current study are corroborated by Rewe *et al*., (2021) values of 311 and 306 during the short rains and 281 and 266 in long rains using bioslurry from Dome and Flexi biodigesters respectively were obtained. However, Berdjour *et al*., (2020) realized higher values where application of 120:60:60 and 60:30:30 NPK/ha on maize resulted in leaf area of 459.66 and 439.31 compared to use of 2 and 4 tonnes of poultry manure which registered lower values of 394.20 and 370.70 with 341.96 in control at 10 WAP. However, longer days to 50%tasseling and 50%silking noted in 100%bioslurry followed by control during the short rains and in long rains in control followed by 100%bioslurry could be due to prolonged vegetative growth at the expense of flowering in bioslurry. Imran *et al*., (2015) found longer time to tasselling and silking in maize when higher rates of N were used. In control, reduced growth due to inadequate availability of nutrients may have caused plant starvation slowing growth and delaying flowering. The longer days in control is corroborated by the research work of Golla and Chalchisa (2019) who found increased days to 50%tasseling at 84.44 and 81.78 days when N levels of 0 and 23kgsN/ha were used but decreased with increasing N levels, a similar trend being noted in silking. On the contrary, less days to 50% tomato flowering (33.3days) in control have been reported followed by fertilizer alone (35.0days) although bioslurry alone (14t/ha) took longer (35.7days) (Biramo, 2017). The researcher reported longer days to reach 50% flowering (38.7days) when half of the recommended fertilizer was integrated with 7tonnes/ha of bioslurry, contrary to the current study, where less days were found in integration and fertilizer alone. In establishing the effect of different sources of N on maize growth and yield, Waseem *et al*., (2014) reported less days to 50%tasselling in control (40.67days), while inorganic source took longer (46.67days) than the organic sources, with a similar trend in silking. The greater difference noted between days to 50%tasselling and 50%silking in control could be due to increased apical dominance favouring tasselling and hence pollen dispersal as opposed to ear and silk development since its protandrous development pattern is enhanced by stress such as inadequate nutrients or drought (Sangoi and Salvador, 1998b). This characteristic was also noted in Sangoi *et al*., (2001) where delayed silking with no N side-dressing was reported.

The positive response of stovers, stalks and grain yields to treatment except in control is indicative of sufficient nutrients in all the treatments. It is well-known that providing plants with a well-balanced nutrition enhances plants growth, development and productivity. Although 100%bioslurry did not register the highest height or LAI, higher stovers and stalks yields noted could be contributed to higher number of leaves but possibly thicker or heavier stalks. Stem girth increased with increasing bioslurry quantity applied to maize fodder up to a maximum, with 70kgs bioslurryN/ha giving the highest circumference at 9.14cm at 56 days after planting (Islam, *et al*., 2010). However, the higher stovers and stalks yields did not translate into the highest grain yields. The reduced yields in 100%bioslurry could be as a result of high N level favouring vegetative growth over seed setting. Haile and Ayalew (2018) found the highest leaf fresh weight (455.1g/plant) when bioslurry was applied while fertilizer alone gave 376.09g/plant and integration gave varied yields that were statistically similar at 5% level of significance. Similarly, the higher root yields noted in 50%BS+50%fertilizer during the short rains did not prompt the highest stovers, stalks or grain yields. Higher root yields could have been due to an improved soil condition around the root zone, although Brady and Weil (2016) reported that organic matter influences the availability of inorganic P. Phosphorus enhances root development. The higher root and grain yields in fertilizer noted in the short rain could be due to higher N and P in the NPK. Root proliferation is higher when N and P are supplied together, due to rapid growth of the smaller roots (Razaq, *et al.,* 2017). The higher grain yield in fertilizer found in short rains agree with those in Shahzad *et al*., (2015), where higher grain yields were found when 135kgN fertilizer was used (4.44t/ha), followed by integration of 50%N from fertilizer and 4.2t/ha bioslurry (3.44t/ha) while bioslurry alone at 8.4t/ha yielded 2.67t/ha while control was the least at 2.37t/ha during the 2013 season. Similarly, Jjagwe, *et al*., (2020) found non statistically different but higher grain yields in fertilizer than bioslurry at 67% and 45% above control in season 1 while season 2 had 50% and 48% for fertilizer and bioslurry respectively. The higher grain yields when bioslurry was integrated with fertilizer found during the long rains has been reported by other authors. Research by Biramo (2017) found higher fruit yield in tomatoes in integration (35.76t/ha) compared to sole application of fertilizer (30.17/ha) or bioslurry 29.15t/ha, although the latter two were not significantly different ($P \leq 0.05$). Similarly, integrating 10/ha bioslurry with varying levels of fertilizer at 25, 50, 75 and 100kgs N/ha yielded the highest fresh weight of soybean (240.7g) when 25kgs N/ha was used and decreased with increase in N, while bioslurry alone had (92.3g) and control (78.4g) (Yafizham and Sutarno, 2018). However, Musse, *et al*., (2020) found great statistical differences ($P \leq 0.05$) of marketable pod yield in beans upon various treatments with 61.5kgsN/ha integrated with 41.2m^3/ha bioslurry giving the highest yields (14.3t/ha) while fertilizer alone at 61.5kgsN/ha yielded 13.9t/ha and bioslurry alone at 61.8m^3/ha gave 11.8t/ha. The authors found integrating lower fertilizer levels (20.5kgsN/ha) with 41.2m^3/ha bioslurry gave 13t/ha, but control was lowest in both experiments.

Effects of biodigester type on grain quality

Soil macro- and micro-nutrient management is important as it in turn affects growth and productivity as well as crop quality due to the inherent source-sink relationships. The quality of the product is influenced by nutrient supply influenced by photosynthate partitioning to harvested plant organs which is controlled by the ability of these organs to utilize assimilates for growth and storage (sink strength) (Engels, *et al*., 2012). Improving nutrient status of soil and hence plants with minerals such as N plays a pivotal role in uptake, distribution and accumulation of these minerals in edible parts of crops (Erenoglu *et al*., 2011).

The varying effects of treatment on grain quality has been found by other researchers. Use of 70kgs bioslurryN/ha was shown to contribute to highest N, P, K and S values as a percentage of dry matter in maize fodder (Islam *et al*., 2010). Similarly, higher N (3.29 and 3.49%) and P (0.24 and 0.26%) contents in Galilea variety of tomato were reported when bioslurry alone and its integration with fertilizer were applied compared to fertilizer alone with 3.23% N and 0.23% P while control was the lowest (Biramo, 2017). In maize, Shahzad *et al*., (2015) found higher N values when fertilizer alone was used (15.11g/kg) while bioslurry alone, integration and control gave 12.35, 14.55 and 4.89g/kg respectively during the 2013 season. However, the P and K values were higher in bioslurry followed by the integration. The authors found the seed protein to be highest in the fertilizer (8.64%) followed by integration (7.39%) while bioslurry and control registered 6.60 and 5.66%. The higher grain N content in bioslurry in the short rains and in fertilizer in long rains corresponds to higher stovers and stalk yields noted, which may be as a result of higher N values in the plant tissues that enhanced grain N content. Conversion of higher N contents in the leaves into proteins during seed development and subsequent translocation into seed for protein synthesis has been shown (Khan, 2008). Research has shown that application of varying contents of N has variable effect on concentration of nutrients, leading to high or low concentrations of different nutrients. Research in Hao *et al*., (2007) reports that moderate N levels promoted accumulation of micronutrients such as Cu, Fe, Mn and Zn in brown rice, while Lin, *et al*. (2014) showed that N promoted Fe accumulation but reduced Zn. This supports the results of the current study where it was noted that concentration of the micronutrients such as Fe, Cu, Mn and Zn were higher in the integration compared to bioslurry or fertilizer alone in short rains. At the same time, Murphy *et al*., (2008) noted higher Cu, Mg, Mn, P and Zn concentrations (2.78, 97.1, 45.1, 2845 and 17.1mg/kg) in wheat when organic compared to conventional methods with 2.4, 92.9, 43.6, 2650 and 15.8mg/kg respectively.

CONCLUSIONS AND RECOMMENDATIONS

Use of 400mls/hill of bioslurry and its integration with lower fertilizers (75%BS+25%fertilizer) was able to cause higher residual TN and TOC and is indicative of the ability of bioslurry to enhance build-up of SOM and hence improve other soil properties. The positive effect of these treatments in increasing pH and lowering the exchangeable acidity shows that they are able to enhance nutrient uptake as influenced by soil pH and organic matter levels. The 100%fertilizer was superior in enhancing soil P and K. However, it was also found to cause the greatest decrease in Zn, Mg and Ca and lowest increase in TN and TOC while it increased pH decreased and exchangeable acidity increased. As such, continued use may cause increase in acidity.

Variations in growth and yield parameters were mostly not significantly different across treatments except in control. Most farmers grow maize for grain, and all the treatments except control was found to support high grain yields. The choice of the treatment would therefore be informed by broader objectives such as sustainable crop production, cost implications and climate change mitigation.

The experiment was carried out in a site regularly used for research work and hence most soil chemical properties were higher than would be expected in a continuously farmed land. Therefore, conducting the experiment in a farmers' field would give valuable inputs into the dynamics of the treatments on the studied parameters. The maximum bioslurry used was 400mls/plant, research into the effect of higher levels is recommended. Notably, inorganic fertilizer gave higher yield parameters when rainfall was less while bioslurry performed better in higher rainfall. Further investigation of the underlying causes is recommended. The experiment was carried out only in two seasons, and long term assessment is needed to reaffirm the results

ACKNOWLEDGEMENT

The authors are grateful to the National Research Fund (NRF) for funding the research, Waruhiu Farmers' Training Centre for providing a research site and Trans-African Hydro-Meteorological Observatory (TAHMO) for providing weather data.

Competing Interest

No competing financial or personal interests among the authors that affect the study.

REFERENCES

Abbasi, H. N, Vasileva, V. and Lu, X. (2017). The Influence of the Ratio of Nitrate to Ammonium Nitrogen on Nitrogen Removal in the Economical Growth of Vegetation in Hybrid Constructed Wetlands, Environments, 4, 24.

Alagoz, Z. and Yilmaz, E. (2009). Effects of different sources of organic matter on soil aggregate formation and stability: A laboratory study on a Lithic Rhodoxeralf from Turkey. *Soil and Tillage Research*. 103(2): 419–424.

Alam, Md. A., Vandamme, D., Chun, W., Zhao, X., Foubert, I., Wang, Z., Muylaert, K. and Yuan, Z. (2016). Bioflocculation as an innovative harvesting strategy for microalgae. *Reviews in Environmental Science and Bio/Technology*, *15*(4), 573–583.

Albrecht, G., Kettering, Q. M. and Beckham, J. E. N. (2005). *Soil pH in field crops. Cornel University, College of Agriculture and Life Science*.

Anderson, J. M. and Ingram, J. S. I. (1993). Tropical Soil Biology and Fertility: Handbook of Methods. Second edition. CBA International. Wallingford, UK.

Barlog, P., Hlisnikovský, L., & Kunzová, E. (2020). Effect of Digestate on Soil Organic Carbon and Plant-Available Nutrient Content Compared to Cattle Slurry and Mineral Fertilization. *Agronomy*, *10*(3), 379.

Berdjour, A., Dugje, I. Y., Rahman, N. A., Odoom, D. A., Kamara, A. Y., & Ajala, S. (2020). Direct Estimation of Maize Leaf Area Index as Influenced by Organic and Inorganic Fertilizer Rates in Guinea Savanna. *Journal of Agricultural Science*, *12*(6), 66.

Biramo, G. D. (2017). Effects of dry bioslurry and chemical fertilizers on yield, yield components of tomato and soil chemical properties in Arba Minch Zuria, southern Ethiopia, Thesis.

Biramo, G., Abera, G., and Biazin, B. (2019). Effects of dry bioslurry and chemical fertilizers on tomato growth performance, fruit yield and soil properties under irrigated condition in Southern Ethiopian. *African Journal of Agricultural Research*, *14*(33), 1685–1692.

Blouin, M., Barrere, J., Meyer, N, Lartigue, S., Barot, S. and Mathieu, J. (2019). Vermicompost significantly affects plant growth. A meta-analysis. *Agronomy for Sustainable Development.* 39:34.

Bonten, L. T. C., Zwart, K. B., Rietra, R. P. J. J., Postma, R., Haas, M. J. G. de and Nysingh, S. L. (2014). Bio-slurry as fertilizer: Is bio-slurry from household digesters a better fertilizer than manure?: a literature review (No. 2519; p.). Alterra, Wageningen-UR

Bot, A. and Benites, J. (2005). The importance of soil organic matter Key to drought-resistant soil and sustained food production, accessed 14/9/2021, http://www.fao.org/3/a0100e/a0100e00.htm#Contents.

Brady, N. C. and Weil, R. R. (2007). The nature and properties of soil, 14th edition. Pearson Publishers, London, pp980.

Brookside Laboratories Inc., Accessed 02/09/2021. https://www.blinc.com/role-nitrogen-fertilizer-soil-ph.

Bruce, R. C. and Rayment, G. E. (1982). *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys.*

Cairns, J. E., Chamberlin, J., Rutsaert, P., Voss, R.C., Ndhlela, T. and Mnagorokosho, C. (2021). Challenges for sustainable maize production of smallholder farmers in sub-Saharan Africa. *Journal of cereal science*, 101, 103274.

Charman, P. E. V. and Roper, M. M. (2007). Soil organic matter. In 'Soils-their properties and management'. 3rd edn. (Eds P. E. V. Charman and B. W. Murphy.) pp. 276–285. (Oxford University Press: Melbourne).

Ciceri, D. and Allanore, A. (2019). Local fertilizers to achieve food self-sufficiency in Africa. Science of the Total Environment, 648:669–680.

Crouse, K. K. and Denny, G. (2015). Soil pH and fertilizers

De Brogniez, D.; Ballabio, C.; Stevens, A.; Jones, R.J.A.; Montanarella, L.; van Wesemael, B. A map of the topsoil organic carbon content of Europe generated by a generalized additive model. Eur. J. Soil Sci. 2015, 66, 121–134.

Devaux, C., Baldet, P., Joubès, J., Dieuaide-Noubhani, M., Just, D., Chevalier, C. and Raymond, P. (2003). Physiological, biochemical and molecular analysis of sugar-starvation responses in tomato roots. Journal of Experimental Botany, 54, 1143–1151.

Emerson, W. W. (1991). Structural decline of soil, assessment and prevention. *Australian Journal of Soil Research* 29, 905–922.

Engels, C., Kirkby, E. and White, P. (2012). Chapter 5- Mineral Nutrition, Yield and Source-Sink Relationships. In P. Marschner (Ed.), *Marschner's Mineral Nutrition of Higher Plants (Third Edition)* (pp. 85–133). Academic Press.

Erenoglu, E. B., Kutman, U. B., Ceylan, Y., Yildiz, B. and Cakmak, I. (2011). Improved nitrogen nutrition enhances root uptake, root-to-shoot translocation and remobilization of zinc (65Zn) in wheat. *New Phytologist*, *189*(2), 438–448.

FAO, 2021. The agriculture sector in Kenya. https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/, accessed 29/10/2021

Faruq, A.N. and Isam, M.I. (2007) Effect of selected soil amendments on seed germination seedling growth and control of damping off of eggplant and tomatoes seedlings Journal of Agriculture Education and Technology, 10(1&2):43-48.

Golla, B., Chalchisa, D., Golla, B. and Chalchisa, D. (2019). Response of maize phenology and grain yield to various nitrogen rates and plant spacing at Bako, West Ethiopia. *Open Journal of Plant Science*, *4*(1), 009–014.

Gransee, A. and Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. *Plant and Soil*, *368*(1), 5–21.

Groot, L. de and Bogdanski, A. (2013). Bioslurry = brown gold? A review of scientific literature on the co-product of biogas production. FAO, Rome, Italy. 32p

Haile, A., and Ayalew, T. (2018). Comparative study on the effect of bio-slurry and inorganic N-fertilizer on growth and yield of kale (Brassica oleracea L.). *African Journal of Plant Science*, *12*(4), 81–87.

Hao, H. L., Wei, Y. Z., Yang, X. E., Feng, Y. and Wu, C. Y. (2007). Effects of different nitrogen fertilizer levels on Fe, Mn, Cu and Zn concentrations in shoot and grain quality in rice (*Oryza sativa*). *Rice Science*, 14:289–294.

Haynes, R. J. and Mokolobate, M. S. (2001). Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: A critical review of the phenomenon and the mechanisms involved. *Nutrient Cycling in Agroecosystems*, *59*(1), 47–63.

Hinsinger, P., Plassard, C.,Tang, C. and Jaillard, B. (2003). "Origins of root-mediated pH changes in the rhizosphere and their responses to environmental constraints: a review. *Plant and Soil*, 48, 1-2: 43–59.

Holford, I. C. R. and Cullis, B. R. (1985). Effects of phosphate buffer capacity on yield response curvature and fertilizer requirements of wheat in relation to soil phosphate tests. *Soil Research*, *23*(3), 417–427.

Holm-Nielsen, J. B., Al Seadi, T. and Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology*, *100*(22), 5478–5484.

Hue, N. V., Craddock, G. R. and Adams, F. (1986). Effect of Organic Acids on Aluminum Toxicity in Subsoils. *Soil Science Society of America Journal*, *50*(1), 28–34.

Imran, M. K., Rehman, C. A., Aslam, U. and Bilal, A. R. (2016). What's organization knowledge management strategy for successful change implementation? *Journal of Organizational Change Management*, *29*(7), 1097-1117.

International Fertilizer Development Center, (2012). Annual Report, Accessed 15/8/2020 https://www.ctc-n.org/resources/ifdc-2012-annual-report.

Islam, M. R., Rahman, S. M. E., Rahman, M. M., Oh, D. H., and Ra, C. S. (2010). The effects of biogas slurry on the production and quality of maize fodder. *Turkish Journal of Agriculture and Forestry*, *34*(1), 91–99.

Jackson, R. S, 2014. Wine Science: Principles and applications. *Eslevier*, 997pp

Jaetzold, R., Schmidt, H., Hornet, Z.B. and Shisanya, C.A. (2006) Farm management handbook of Kenya. Natural conditions and farm information. 2nd Edition. Vol.11/ C. Eastern Province. Ministry of agriculture/GTZ, Nairobi, KenyaJjagwe, J., Chelimo, K., Karungi, J., Komakech, A. J and Ledere, J. (2020). Comparative Performance of Organic Fertilizers in Maize (Zea mays L.) Growth, Yield and Economic Results. Agronomy, 10, 69

Jensen, A. C. S., Imberti, S., Habraken, W. J. E. M. and Bertinetti, L. (2020). Small Ionic Radius Limits Magnesium Water Interaction in Amorphous Calcium/Magnesium Carbonates. *Journal of Physical Chemistry*, 124, 11, 6141–6144

Jonckheere, I., Fleck S., Nakaerts, K., Muys, B., Coppin, P., Weiss, M. and Baret, F. (2004). Review of methods for in situ leaf area index determination: part I. Theories, sensors and hemispherical photography. Agricultural and Forest Meteorology, 121 (1-2), pp. 19-35.

Juan, L., Zhou, J. M. and Duan, Z.Q. (2007). Effects of elevated CO_2 concentration on growth and water usage of tomato seedlings under different ammonium/nitrate ratios. *Journal of Environmental Science,* 19, 1100–1107.

Kamprath, E. J. (1967). Residual Effect of Large Applications of Phosphorus on High Phosphorus Fixing Soils. *Agronomy Journal*, *59*(1), 25–27.

Kanyanjua, S. M., Ireri, L., Wambua, S., Nandwa, S. M. (2002). Acid soils in Kenya: Constraints and remedial options. KARI Technical Note, 11:24.

Kenya Institute for Public Policy Research and Analysis, (2020). Kenya Economic Report, Creating and enabling environment for inclusive growth in Kenya. https://kippra.or.ke/wp-content/uploads/2021/02/Kenya-Economic-Report-2020.pdf, accessed 29/10/2021

Khalid, A., Arshad, M., Anjum, M., Mahmood, T. and Dawson, L. (2011). The anaerobic digestion of solid organic waste. *Waste Management*, *31*(8), 1737–1744.

Kumar, A., Kumar, R. and Sudarsan, J. S. (2010). Biogas manure (BGM) from mixed kitchen waste: A trial study. *Journal of Environmental Research and Development*, *5*(1), 164–171.

Landon, J. R. (1991). Booker Tropical Soils Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. John Wiley and Sons, New York. 465pp.

Li, X., Li, Y., Wu, T., Qu, C., Ning, P., Shi, J. and Tian, J. (2020). Potassium fertilization combined with crop straw incorporation alters soil potassium fractions and availability in northwest China: An incubation study. *PLoS ONE* 15(7): e0236634.

Ligeyo, D. O. (2007). Genetic analysis of maize (Zea mays L) tolerance to aluminium toxicity and low phosphorus stress and development of synthetics for use in acid soils of Western Kenya. PhD Thesis, Moi University. Eldoret Kenya. Pp1-68

Lin, Z. M., Ning, H. F., Bi, J. G., Qiao, J. F., Liu, Z. H., Li, G. H., Wang, Q. H., Wang, S. H. and Ding, Y. F. (2014). Effects of nitrogen fertilization and genotype on rice grain macronutrients and micronutrients. *Rice Science*, 21:233–242.

Lovanh, N., Warren, J. G., & Sistani, K. R. (2008). *Ammonia and Greenhouse Gases Emission from Land Application of Swine Slurry: A Comparison of Three Application Methods*. https://doi.org/10.13031/2013.25510.

Maguire, M. E. and Cowan, J. A. (2002). Magnesium chemistry and biochemistry. *Biometals*, *15*(3), 203–210.

Malhotra. H., Vandana, Sharma, S. and Pandey, R. Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In Plant Nutrients and Abiotic Stress Tolerance.Springer Nature Singapore Pte Ltd. 2018 M. Hasanuzzaman *et al*. (eds.), Plant Nutrients and Abiotic Stress Tolerance, pp 171-190.

McCauley, A., Jones, C. and Olson-Rutz, K. (2017). Soil pH and organic matter. Nutrient management module No. 8. *Bozeman: Montana State University.*

Mehlich, A., Pinkerton, A., Robertson, W. and Kepton, R. 1962. Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agric. Laboratories, Nairobi.

Metson, G. H. (1961). The conductivity of oxide cathodes. Part 10: Spontaneous generation of negative ions. *Proceedings of the IEE - Part C: Monographs*, *108*(14), 438–449.

Millar, N., Doll, J. E. and Robertson, G. P. (2014). Management of nitrogen fertilizer to reduce nitrous oxide N2O emission from field crops. Climate change and Agriculture Fact Sheet Series. https://www.canr.msu.edu/uploads/resources/pdfs/management_of_nitrogen_fertiler_(e3152).pdf, Accessed 29/10/2021

Moller, K. and Muller, T. (2012). Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. *Engineering in Life Sciences*, *12*(3), 242–257.Muindi, E.M., Semu E., Mrema J.P., Mtakwa P.W., Gachene C.K., Njogu M.K. (2016). Soil Acidity Management by Farmers in the Kenya Highlands*. Journal of Agriculture and Ecology Research International, 5(3): 1-11.*

Muindi, E. M. (2016). Phosphorus retention and the interactive effects of phosphorus, lime and tillage on maize in acid soils of the Kenya highlands. PhD Dissertation. Department of soil and earth sciences, Sokoine Universty, Tanzania, 191pp.

Muindi, E. M. (2019). Understanding soil Phosphorus. A review. *International Journal of Soil Science. 31(2):1-18*

Muindi, E. M., Mrema, J. P., Semu, E., Mtakwa, P.W., Gachene. C. K., Njogu, M. K. (2016)**.** Effects of Lime-Aluminium-Phosphorus interactions on maize growth in acid soils. *American Journal of Agriculture and Forestry, 3(6):244-252.*

Muindi, E. M., Mrema, J. P., Semu, E., Mtakwa, P.W., Gachene. C. K., Njogu, M. K. (2015)**.** Lime-Aluminium-Phosphorus interactions in the Kenya Highlands. *American Journal of Experimental Agriculture, 9 (4):1-10.*

Murphy, J. T. (2001). Making the energy transition in rural East Africa: Is leapfrogging an alternative? *Technological Forecasting and Social Change*, *68*(2), 173–193.

Musse, Z. A., Samago, T. Y. and Beshir, H. M. (2020). Effect of liquid bio-slurry and nitrogen rates on soil physico-chemical properties and quality of green bean (Phaseolus vulgaris L.) at Hawassa Southern Ethiopia. *Journal of Plant Interactions*, *15*(1), 207–212.

Mwanga, K. E. (2016). Effects of bio-slurry and farm yard manure on soil amelioration and chinese cabbage (Brassica rapa var. Chinensis) yields in Njombe region, Tanzania, Thesis.

Nieves-Cordones, M., Ródenas, R., Lara, A., Martínez, V. and Rubio F. (2019). The combination of K^+ deficiency with other environmental stresses: what is the outcome? *Physiologia Plantarum*, 165:264-276.

Njogu, C. (2019). Factors Affecting Maize Production among Registered Small Scale Farmers in Trans-Nzoia

County, Kenya. Msc. Thesis. Strathmore Universty, Nairobi, Kenya. 70Pp.

Norton, R. (2013). Focus on calcium: Its role in crop production. Accessed on 18/07/2021 https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2013/02/focus-on-calcium-its-role-in-crop-production

Nyang'au, J., Erastus, G., Christopher, N. and Steve, A. (2016). Evaluation of biogas slurry as an alternative organic fertilizer. *International Journal of Extensive Research*, *9*, 10–14.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual. Second edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya.

Olsen, S. R. (1986). The Role of Organic Matter and Ammonium in Producing High Corn Yields. In: The Role of Organic Matter in Modern Agriculture, Chen, Y. and Y. Avnimeleck (Eds.). Martinus Nijhoff, Dordrecht, pp: 29-54.

Onasanya, R. O., Aiyelari, O. P., Onasanya, A., Oikeh, S., Nwilene F. E. and Oyelakin O. O. (2009). Growth and Yield Response of Maize (Zea mays L.) to Different Rates of Nitrogen and Phosphorus Fertilizers in Southern Nigeria. *World Journal of Agricultural Sciences*, 5 (4): 400-407.

Opala, P. A., Okalebo, J. R. and Othieno, C. O. (2012). Effects of Organic and Inorganic Materials on Soil Acidity and Phosphorus Availability in a Soil Incubation Study. *ISRN Agronomy*, *2012*, 1–10.

Rabot, E., Wiesmeier, M., Schlüter, S. and Vogel, H.-J. (2018). Soil structure as an indicator of soil functions: A review. *Geoderma*, *314*, 122–137.

Rai, R. (2017). Study on Soil Structure Interaction. A Review*. Control Science and Engineering*, *1*(1), 4.

Rajendran, K., Aslanzadeh, S. and Taherzadeh, M. J. (2012). Household Biogas Digesters-A Review. *Energies*, *5*(8), 2911–2942.

Razaq, M., Zhang, P., Shen, H. and Salahuddin (2017). Influence of nitrogen and phosphorus on the growth and root morphology of Acer mono. *PLoS One,* 12:1–13.

Rewe, M. K., Muindi, E., Ndiso, J., Kinusu, K., Mailu, S., Njeru, P. and Rewe, T. (2021). Effect of Bioslurry from Fixed Dome and Tubular (Flexi) Biodigesters on Selected Soil Chemical Properties, Maize (Zea mays) Growth, Yield and Quality. *International Journal of Plant and Soil Science*, *33*(20), 158-171.

Ryan, M. H. and Angus, J. F. (2003). Arbuscular mycorrhizae in wheat and field pea crops on a low P soil, increased Zn-uptake but no increase in P uptake or yield. *Plant Soil* 250, 225–239.

Sangoi, L. (2001). Understanding plant density effects on maize growth and development: an important issue to maximize grain yield. *Ciencia Rural, SciELO* 31 (1).

Sangoi, L. and Salvador, J. R. (1998). Maize susceptibility to drought at flowering: A new approach to overcome the problem. *Ciencia Rural, SciELO.* http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84781998000400027&lng=en&nrm=iso&tlng=en

Santpoort. R. (2020). The Drivers of Maize Area Expansion in Sub-Saharan Africa. How Policies to Boost Maize Production Overlook the Interests of Smallholder Farmers. *Land*, 9;68

Sombroek, W. G., Braun, H. M. H and van de Pouw (1982). Exploratory soil map and agro-climatic zone map of Kenya. Scale 1:1000, 000. Exploratory soil survey report No. E1. Kenya Soil Survey, Nairobi. pp. 1-78.

Stutter, M. I., Roberts, W. M., & Haygarth, P. M. (2012). Phosphorus Retention and Remobilization in Vegetated Buffer Strips: A Review. *Journal of Environmental Quality*, *41*(2), 389–399. https://doi.org/10.2134/jeq2010.0543.

Terefe, T., Ayalew, T. and Beshir, H. (2018). Combined Application of Bioslurry and Inorganic Fertilizers on Quality Traits of Cabbage and Soil Properties. *Asian Journal of Biological Sciences*, *11*, 24–32.

Walinga, I., Vark, W. van, Houba, V. J. G. and Lee, J. J. van der. (eds.) 1989. Soil and plant analysis. Part 7. Plant analysis procedures. Syllabus. Wageningen Agricultural University, the Netherlands.

Wamwea, S. N. (2017). *Success and failure of biogas technology systems in rural Kenya: An analysis of the factors influencing uptake and the success rate in Kiambu and Embu counties*. Accessed 07/06/2021 https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/2482883.

Waseem, M., Ali, Q., Ali, S., Ali, A., Ahmed, S. and Tayyab, H. (2014). Correlation analysis for morpho-physiological traits of maize (Zea mays L.). *Life Science Journal*, *11*(12), 9-13.

World Bank and CIAT (2015). *Climate-smart agriculture in Kenya*. CSA Country Profile. Washington D.C.: The World Bank Group. Accessed 17/06/2020 https://cgspace.cgiar.org/handle/10568/69545.

World Bank Group (2018). *Kenya Economic Update, April 2018, No. 17: Policy options to advance the Big 4*. World Bank, Nairobi. Accessed 17/06/2020 https://openknowledge.worldbank.org/handle/10986/29676.

Yafizham and Sutarno (2018). Fermentation of Anaerobic Cow Waste as Bio-Slurry Organic Fertilizer and Nitrogen Chemical Fertilizer on Soybean IOP Conference Series: Earth and Environmental Science 119 012050.

Ye, Y., Ngo, H. H., Guo, W., Chang, S. W., Nguyen, D. D., Liu, Y., Nghiem, L. D., Zhang, X. and Wang, J. (2019). Effect of organic loading rate on the recovery of nutrients and energy in a dual-chamber microbial fuel cell. *Bioresource Technology*, *281*, 367–373.

Yi, Q., Tang, S., Fan, X., Zhang, M., Pang, Y., Huang, X. and Huang, Q. (2017). Effects of nitrogen application rate, nitrogen synergist and biochar on nitrous oxide emissions from vegetable field in south China. *PLoS ONE* 12(4)

Zhang, X., Zhu, J., Wendroth, O., Matocha, C. and Edwards, D. (2019). Effect of Macroporosity on Pedotransfer Function Estimates at the Field Scale. *Vadose Zone Journal*, *18*(1), 180151.