



Effect of Bioslurry from Fixed Dome and Tubular (Flexi) Biodigesters on Selected Soil Chemical Properties, Maize (*Zea mays*) Growth, Yield and Quality

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Agricultural utilization of bioslurry plays a critical role in soil conditioning and hence crop production. It also reduces greenhouse gas emissions thus mitigating climate change. Although the effect of bioslurry on growth and yields is well researched, that of different biodigester types is under-researched. Therefore, a study was carried out in Waruhiu Agricultural Training Centre, Githunguri sub-county, Kiambu county in Kenya, to investigate the effect of bioslurry from flexi and dome biodigesters on soil chemical properties, maize growth, yield and grain quality. Treatments were laid out in a Randomized Complete Block Design (RCBD) and replicated three times. The treatments were bioslurry from both Fixed Dome and Flexi biodigesters, applied separately at a rate of 400mls per hill as basal and top dress fertilizer. Planting was done during the 2019 short and 2020 long

rains, using Duma 43 maize variety. The agronomic (germination percentage, number of leaves, leaf width, leaf length, plant height) and productivity data (stalk, stovers, grain yields and grain quality) were subjected to analysis of variance (ANOVA) through Proc general linear model (GLM) procedures. Mean separation was done using least square means (LS-Means). Results showed an increase in soil pH, total N and OC, exchangeable P, K, Mn and Na in both biodigester types. Total N and OC were higher in Dome treated soils by 38.89% and 37.00%, while in Flexi, it was 16.67% and 16.00% respectively. Exchangeable P and K was higher in Flexi treated soils with a 38.57% and 50.00% increase while in Dome it 37.86% and 47.22% respectively. Magnesium and Zn decreased after treatment by 34.30% and 22.59% in Dome while Flexi had 33.23% and 31.79% increase. Exchangeable Fe and acidity decreased in Dome but increased in Flexi treated soils. No statistical differences were observed on growth and yield parameters but Dome registered higher grain yields by 9.4% and 6.3% for short and long rains respectively. Flexi treated soils registered higher values in most grain nutrient content such as K, Fe, Cu, Mn and Zn in short rains and P, Ca, Fe, Cu, Mn and Zn in the long rains. Bioslurry from both biodigester types variably increased the evaluated soil chemical properties but decreased Mg and Zn. Despite the numerical differences noted between bioslurry from both biodigester types on maize growth and yield, there was no significant difference ($p \leq 0.05$). However, Dome bioslurry increased N, OC and maize grain yield more while exchangeable P and K and most of the grain nutrient content were higher in Flexi treated soils. Therefore, bioslurry from either biodigester type can be used in enhancing soil conditions, growth, yield and quality of maize. However, a long-term experiment is required validate the findings.

Keywords: Bioslurry; fixed dome; flexi; maize; soil chemical properties.

1. INTRODUCTION

The overarching goal of crop farming is high yields. However, this has been on the decline, contributed by nutrient mining due to continuous cropping, soil erosion, lack of or insufficient use of organic and inorganic fertilizers [1]. Maize (*Zea mays*), an important staple food in Kenya, has similarly been affected, and its production remains low, at 1.1 to 1.8t/ha in Africa compared to the world average of about 5t/ha [2,3]. Use of inorganic fertilizers has been the norm in increasing crop yields [4]. However, their excessive and long term use can affect the soil physical, chemical and biological properties [5,6], thus reducing soil productivity. Additionally, not all farmers can access the required amounts. Notably, crops require both macro and micronutrients for proper growth, but no single inorganic fertilizer contains all of the required nutrients. At the same time, the impact of agriculture on climate change cannot be overemphasized. According to the International Panel on Climate Change (IPCC) data, human activity has over the last 2 centuries increased the atmospheric content of carbon dioxide (CO₂) by 30%, methane (CH₄) by 145% and nitrous oxide (N₂O) by 15% (Greatorex, 2000). The UNFCCC (2004) singles out nitrous oxide as having higher global warming potential (approximately 310 times that of CO₂) making it a large contributor to GHG budgets. According to

Signor and Cerri [7], application of N-fertilizer is the greatest contributor to N₂O, underscoring the relevance of embracing measures to reduce its emission into the atmosphere.

It is upon this background that alternative, affordable, effective and sustainable methods such as bioslurry have been advocated [8-11,4]. Bio-slurry is a by-product in anaerobic production of gas (biogas) from organic wastes [12,13,14]. Bioslurry contains both macro and micro nutrients, and appreciable amounts of organic matter and fibre [15,16,17,11]. Similarly, biofertilizers such as bioslurry contain probiotic microbes [18] as well as humic acids and growth promoting bacteria [19]. Application of bioslurry improves soil physical properties such as porosity [11,20] and structure through increased macro-aggregation due to release of polysaccharides as well as organic acids [8]. Soil structure influences porosity, aeration and activities of the soil microorganisms. These contribute to better soil condition and crop growth. At the same time, bioslurry has been shown to contribute to increased soil pH [21,22,9] as well as macro- and micro-nutrients [8,10,23]. Equally, it enhances plant growth [24,25,4] (and crop yields [22,25,11]). This underpins the role of bioslurry in sustainable crop farming.

Despite the enormous role played by bioslurry in agriculture, its nutritional composition varies as influenced by different dynamics. These are substrate source (animal, human, kitchen waste), water quantity, breeds and age of the animals, types of feed, biodigester type, feeding rate and form [13,26] (Center for Energy studies, 2001). This therefore may contribute to varying effects on soils and crop growth and yields. Although the effect of bioslurry on growth and yields is well researched, that of different biodigester types is under-researched. The research study was therefore carried out to evaluate the effect of bioslurry from different biodigester types (Dome and Flexi) on soil chemical properties. At the same time, the study investigates the response of maize growth, yields and quality in an acidic soil to bioslurry from different biodigester types.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was set up in Waruhiu Agricultural Training Centre, Githunguri sub county, Kiambu county, in Kenya. The region falls on latitudes of 0° 22' 0" South and 37° 29' 0" East of Equator. It lies at altitude of 1500-1,800 metres above sea level and is generally a tea and dairy zone. The area experiences bi-modal type of rainfall with the long rains falling between mid-March to May and the short rains between mid-October to November averaging at 1200 mm per annum, with mean temperatures of about 26°C, but can get to 7°C in cold months. The area has deep well drained acidic humic nitisols derived from ultra-basic igneous rocks.

2.2 Experimental Materials, Design and Crop Husbandry

2.2.1 Description of experimental materials

Bioslurry was obtained from farmers in the neighbourhood of the experimental area. The cows were Friesian and Guernsey crosses, and fed mainly on maize germ, dairy meal at milking, nappier grass and maize stovers. The biodigesters were installed in the farmers' farms and were in use since July 2018. The chemical

composition of bioslurry used in the experiment is presented on (Table 1).

2.2.2 Experimental design and planting

The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. The plots measured 3m by 2.1m, separated by 0.5m pathway. The treatments were; 100% bioslurry from Dome, 100% bioslurry from Flexi. Land preparation was done by use of a fork jembe and planting done in two consecutive seasons during the 2019 short and 2020 long rains. Bioslurry quantity of 400mls per hill at planting and top dressing was used, following the farmers' practice of a cup per hill, which weighs about 450g. A total of 17,778l/ha in each treatment was used. Duma 43 seed variety was used, 1 seed per hill at a rate of 25kgs/ha, at a spacing of 75*30cm giving 5 rows per plot and 8 hills per row.

2.2.3 Crop husbandry

Top dressing was carried out when the crop was knee high using the measurements as for the basal rates by placing bioslurry around the plant in a 15cm ring. Weeding was done by hand about 21 and 45 days after sowing (DAS) for 1st and 2nd weeding in both seasons. There was minimal pest infestation, but Voliam Targo spray was done about 30 DAS at a rate of 20ml/20l of water to control caterpillars.

2.3 Data Collection

Data collected included; soil chemical properties, plant growth and yield parameters and grain quality.

2.3.1 Soil chemical properties

Soil chemical properties were evaluated before crop establishment and after second season harvesting. Initial soil sampling was carried out by taking soil from 9 random points at 15cm depth within the entire project field in a zigzag manner [27], mixed and a composite sample packaged, labelled and taken to the laboratory for chemical analysis. Final

Table 1. Chemical composition of bioslurry from Dome and Flexi biodigesters

Parameter	-ppm-						-cmol/kg-			
	pH	NH4 ⁺	NO ₃	P	Fe	S	HCO ₃	K	Ca	Mg
Dome	7.47	153	3.88	28.5	1.46	8.48	4440	2.37	0.264	0.44
Flexi	7.76	841	30.3	38.5	13.8	17.9	8310	2860	186	91.2

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

sampling was carried out by collecting soil samples at a depth of 15 cm from 5 points along a zigzag line after harvesting in corresponding treatments, mixed and composite samples taken to the laboratory for chemical analysis. The exchangeable P, K, Na, Ca, Mg and Mn analysis were done using the Mehlich Double Acid Method outlined by Mehlich *et al.* [28]. Total organic carbon was analyzed using the calorimetric method following Anderson and Ingram [29]. Total nitrogen was determined using the Kjeldahl method according to Page *et al.* [30]. The soil pH was determined in a 1:1 (w/v) soil-water suspension with pH-meter following Mehlich *et al.* [28], while exchangeable acidity was done following Okalebo *et al.* [31]. The available Fe, Cu and Zn were determined using Atomic Absorption Spectrophotometer (AAS) after extraction with 0.1 M HCl in procedures described by Mehlich *et al.* [28].

2.3.2 Maize growth and productivity

Five plants were randomly selected from the 3 inner rows per subplot and tagged at 14 days after sowing. Agronomic and productivity data was collected only from the tagged plants.

2.3.2.1 Maize growth

Germination percentage was determined by the number of days taken to germination of all the plants per subplot. Plant height was determined by measuring the height of each tagged plant per plot by taking measurements from the base/soil surface to the highest point of the arch of the topmost leaf whose tip was pointing downwards using a tailor's tape. Leaf width was taken at widest area of the leaf, just before the middle 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. For leaf length, measurements were taken from the same leaves as leaf girth, by measuring from the stem area to the leaf tip. The measurements were in cm. Leaf area index (LAI) was determined according to Onasanya *et al.*, [32] as leaf area ($LA=length \times width \times 0.75$), where LA, L and W are leaf area, leaf length and leaf width respectively, and 0.75 is a constant. Number of leaves were counted from the lowest green leaf to the topmost opened leaf with a visible collar.

2.3.2.2 Maize productivity

The tagged plants per subplot were harvested when at physiological maturity, when a black

layer had formed at the base of the kernel. During harvesting, the ears were removed from the maize plant and placed in labelled carrier bags per plot. Thereafter, the entire plant was uprooted by digging all around the plant with a hoe to loosen the soil and gently pulling out whole plant together with the roots. Roots were then cut off and washed in water to remove soil before air drying. Stovers were cut into pieces and placed in labelled carrier bags before drying. Roots, stovers and ears were air dried to constant weight separately for 14 days. Biological yield was determined by weighing roots, stovers and ears separately using an AKMA digital weighing machine. Economic yield was obtained by threshing the cobs from each plot, weighing the grains and converting it to kilograms per hectare at 14% grain moisture content which was measured using a digital grain moisture meter analyzer (Draminski Twistgrain Pro, Poland). Obtained grains were also analyzed for N, P, K, Ca, Mg, Zn, Fe, Cu and Mn content following the procedures described by Walinga *et al.* [33].

2.4 Statistical Analysis

Statistical analyses for the agronomic and productivity data were conducted using SAS version 9 (SAS Institute Inc., 2013) and subjected to analysis of variance (ANOVA) through Proc general linear model (GLM) procedures. Mean separation was done using least square means (LS-Means).

3. RESULTS

3.1 Effects of Biodigester Type on Soil Chemical Properties

Initial and final soil chemical properties for the composite soils are indicated in (Table 2). Both the initial and final soil pH was moderately acidic (5.0-6.0) according to Kanyanjua, *et al.*, [34], but increased after treatment by 4% and 1%, in Dome and Flexi respectively. Exchangeable acidity decreased by 20% in Dome while it increased by the same amount in Flexi. A similar trend was observed in exchangeable Fe.

The value for N, OC, exchangeable P, K, Mn and Na increased in both biodigester types compared to the initial soil. However, these values were higher in soils treated with Dome than in Flexi, except for Na. Increase in N caused a concomitant increase in OC, with Dome registering higher increase in both, 36.67% and

37.20% while Flexi caused a 17.78% and 16.20% increase respectively above initial values. The exchangeable P before and after treatment was very high (>25mg/kg), and treatment further increased the content by 37.86% and 38.57% in Dome and Flexi respectively. Exchangeable K values before and after treatment were rated as high (0.72-2.00cmol/kg), although Dome and Flexi caused a 47.22% and 50.00% increase respectively.

Exchangeable Ca before treatment was rated low (2-5cmol/kg), with Dome causing non-significant increase by 1.42%, while Flexi triggered a 32.08% decrease. The exchangeable Mg, rated moderate (1-3cmol/kg) decreased non significantly by 52.46% and 50.00% in Dome and Flexi respectively while Ca:Mg ratio, rated low (1-

4) before and after treatment improved more in Dome than Flexi. Sodium levels increased from very low (0-0.3cmol/kg) initial soils to low (0.1-0.3cmol/kg), a 350% and a 450% increase in Dome and Flexi respectively. Generally, the Zn value decreased from the initial soil by 22.59% in Dome and 31.79% in Flexi.

3.2 Effect of Bioslurry from Dome and Flexi Biodigesters on Maize Growth

The germination rate was 4.75% and 3.63% higher in long than short rains for Flexi and Dome respectively, (Fig. 1). Crops planted in plots containing Flexi bioslurry recorded higher percent germination 0.23% and 1.31% than Dome in short and long rains respectively.

Table 2. Effect of bioslurry from Dome and Flexi biodigesters on selected soil chemical properties

Parameter	Initial	Dome	Flexi
pH _(water)	5.07	5.26	5.10
Exch. acidity (cmol/kg)	0.40	0.32	0.48
Total N (%)	0.18	0.25	0.21
Total OC (%)	2.00	2.74	2.32
Exchangeable P (mg/kg)	28.00	38.60	38.80
Exchangeable K (cmol/kg)	0.72	1.06	1.08
Exchangeable Ca (cmol/kg)	2.80	2.84	2.12
Exchangeable Mg (cmol/kg)	1.86	1.22	1.24
Exchangeable Mn (cmol/kg)	0.48	0.91	0.84
Exchangeable Cu (mg/kg)	1.52	1.40	1.66
Exchangeable Fe (mg/kg)	29.20	24.90	30.92
Exchangeable Zn (mg/kg)	32.40	25.08	22.10
Exchangeable Na (cmol/kg)	0.04	0.18	0.22

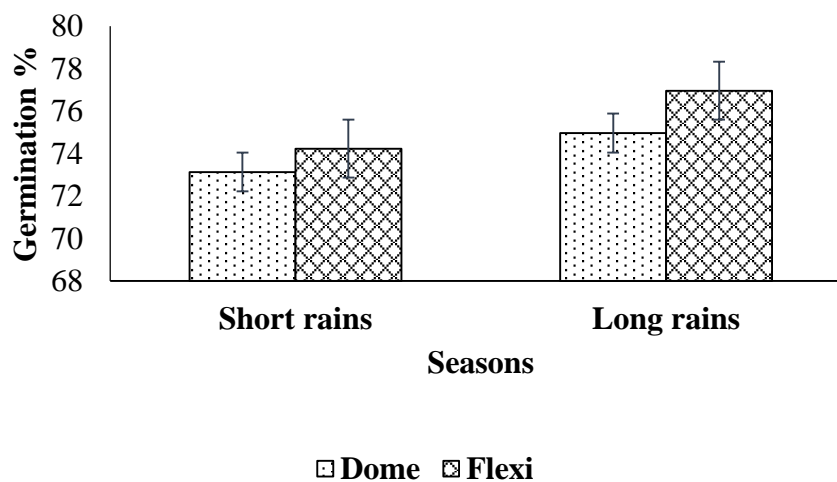


Fig. 1. Effect of Bioslurry from Flexi and Dome biodigesters on maize germination during the 2019 short and 2020 long rains

Increase in number of leaves in plots treated with Flexi and Dome bioslurry was not significantly different ($P \leq 0.05$), (Fig. 2). However, Dome registered higher number of leaves at 2 weeks after planting by 2.2% and 1.2% for short and long rains while at 10 weeks after planting, the number was 7.4% and 0.6% higher in both seasons in Flexi. The mean number of leaves for 10 weeks after planting was 3.6% and 0.9% higher in Dome in both seasons respectively.

Generally, plant height in the two biodigester types were statistically ($P \leq 0.05$) similar across the weeks and seasons, (Fig. 3), but were numerically higher in Flexi than Dome. At 10 weeks after planting, Flexi had higher plant heights by 5.59% and 2.93% while the mean plant height for 10 weeks was 1.3% and 0.8% in short and long rains respectively.

The leaf area index (LAI) during the 2019 short and 2020 long rains are presented on (Fig. 4). Treatment with Dome registered higher LAI compared to Flexi in both seasons, although the values across the weeks and the mean for 10 weeks were not significantly ($P \leq 0.05$) different. Dome registered 8.4% and 3% higher values than Flexi in week 2 during the short and long rains respectively. At 10 weeks, Dome had 1.26% and 3.0% higher values than Flexi while the mean LAI for 10 weeks was 1.5% and 5.7% higher.

Biodigester types were observed to have insignificant ($P \leq 0.05$) effect on tasseling and silking (Table 3), although numerical differences were observed. It took relatively 0.1% less days to reach 50% tasseling in Flexi than Dome during the short rains but took longer time by the same value to reach 50% silking in Flexi compared to Dome. The number of days to 50% tasseling was however observed to be 0.29% shorter in Dome during the long rains, compared to Flexi. Silking took 0.18% less days in Flexi compared to Dome. There was a 4.03-day difference between 50% tasseling and silking in Dome while Flexi registered a longer time (4.13 days) during the short rains, while during the long rains, this difference was less, 3.66 days for Dome and 3.33 in Flexi.

3.3 Effect of Bioslurry from Flexi and Dome Biodigesters on Maize Yield

There was no significant difference ($P \leq 0.05$) observed on both biomass and grain yield although numerical variations were noted, (Table 3). Dome registered higher yields across all the parameters in the short rains by 8.59%, 6.31% and 9.38% for stovers, stalks and grains respectively. On the other hand, Flexi gave higher yields than Dome for stovers and stalks by 2.35% and 3.85% but the grain yields were higher in Dome (6.33%) than Flexi during the long rains.

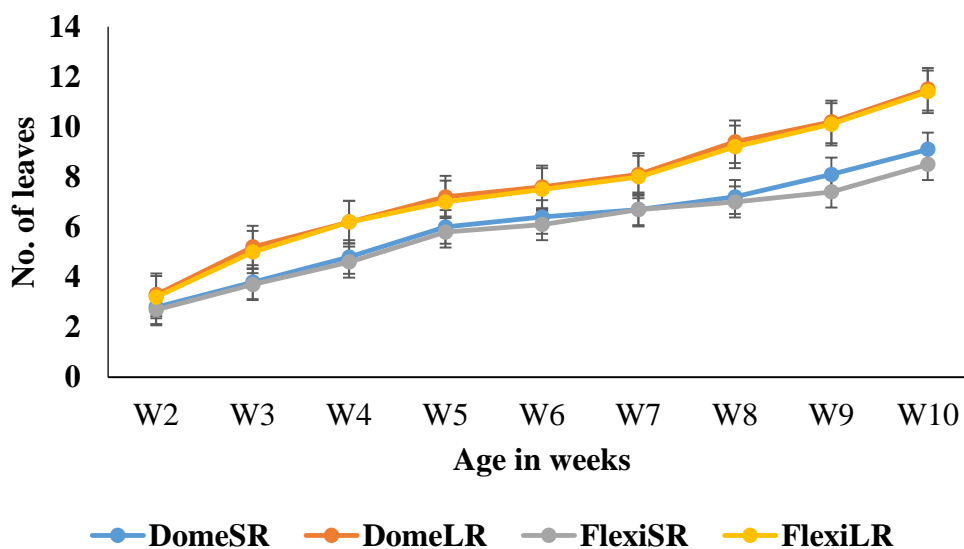


Fig. 2. Effect of biodigester type on the number of leaves of maize during the 2019 sort and 2020 long rains
SR=Short rains, LR=Long rains, W=Week

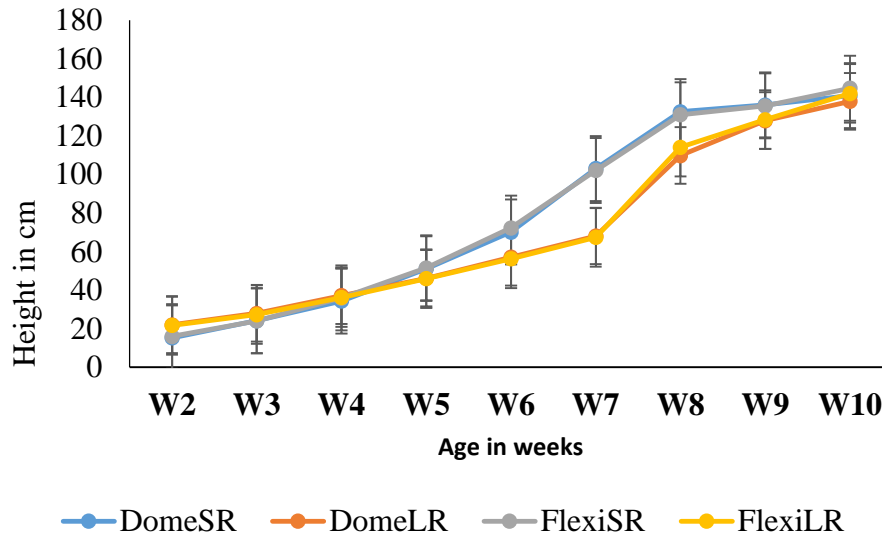


Fig. 3. Effect of Bioslurry from Dome and Flexi biodigesters on maize height during the 2019 short and 2020 long rains
 SR=Short rains, LR=Long rains, W=Week

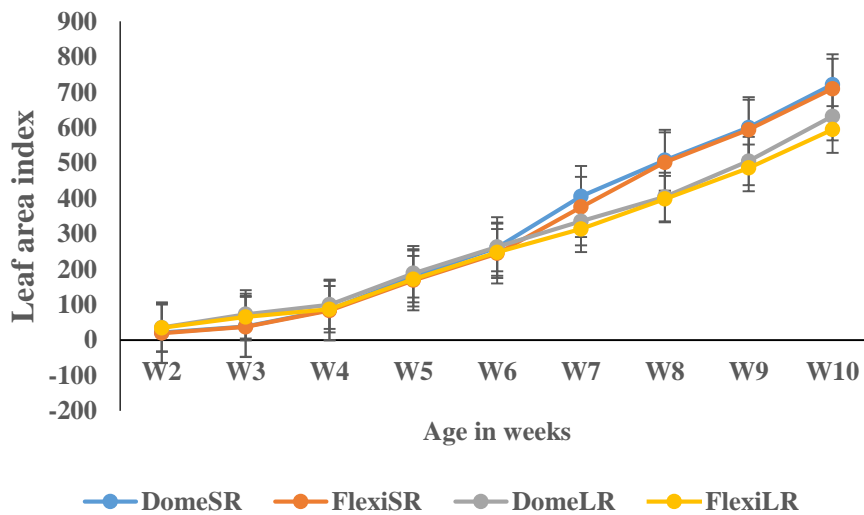


Fig. 4. Effect of Bioslurry from Dome and Flexi biodigesters on maize leaf area index (LAI) during the 2019 short 2020 long rains
 Key: SR=short rains, LR=long rains, W=week

Table 3. Effect of bioslurry from Dome and Flexi bio digesters on percent tasseling and silking during the 2019 short and 2020 long rains

Biodigester type	Short rains		Long rains	
	50%Tasseling	50%Silking	50%Tasseling	50%Silking
Dome	69.93a	73.93a	70.07a	73.73a
Flexi	69.87a	74.00a	70.27a	73.60a
LSD ($P \leq 0.05$)	1.25	0.29	1.49	1.03
CV%	4.3	4.3	4.3	4.3

Means within the same column followed by the same letter are not significantly different at $P \leq 0.05$, LSD=least significant differences; CV=Coefficient of variation

Table 4. Effect of bio slurry from Dome and Flexi biodigester type on dry matter weight (t/ha) and grain yields during the 2019 short and 2020 long rains

Biodigester type	2019 Short rains			2020 Long rains		
	Stovers (t/ha)	Stalks (t/ha)	Grain (t/ha)	Stovers (t/ha)	Stalks (t/ha)	Grains (t/ha)
Dome	6.70a	4.55a	7.11a	5.10a	3.60a	4.37a
Flexi	6.17a	4.28a	6.50a	5.22a	3.85a	4.11a
LSD ($P \leq 0.05$)	1.59	1.12	2.48	1.33	1.51	0.4
CV%	4.3	4.3	4.3	4.3	4.3	4.3

Means within the same column followed by the same letter are not significantly different at $P \leq 0.05$.
LSD=Least significant differences; CV=Coefficient of variation

Table 5. Effect of Bioslurry from Flexi and Dome biodigesters on grain quality during the 2019 short and 2020 long rains

Parameter	2019 Short rains		2020 Long rains	
	Dome	Flexi	Dome	Flexi
N (%)	1.21	1.19	1.51	1.51
P (%)	0.18	0.18	0.16	0.24
K (%)	0.14	0.17	0.18	0.17
Ca (mg/kg)	30.06	22.04	39.40	43.10
Mg (%)	0.06	0.05	0.04	0.04
Fe (mg/kg)	38.68	69.26	67.98	72.60
Cu (mg/kg)	3.33	5.67	8.00	6.66
Mn (mg/kg)	6.33	12.33	3.67	4.00
Zn (mg/kg)	21.02	26.34	13.02	14.68

3.4 Effect of Bioslurry from Flexi and Dome Biodigesters on Maize Grain Quality

Flexi showed higher nutrient levels in most of the analyzed parameters compared to Dome in both seasons, (Table 4). Nitrogen (N), Calcium (Ca) and Magnesium (Mg) values were higher in Dome than Flexi by 1.68%, 36.39% and 20% respectively during the short rains. Potassium (K), Iron (Fe), Copper (Cu), Manganese (Mn) and Zinc (Zn) were higher in Flexi than Dome. Iron and Zn were 79.06% and 12.75% higher in Flexi than Dome during the same period respectively, while phosphorus (P) registered similar values in both biodigesters. During the long rains, P, Ca, Fe, Mn and Zn contents were higher in Flexi, while K and Cu were higher in Dome. The N and Mg values were the same in both biodigesters, with higher values of N being seen in long compared to short rains. Phosphorus, Ca, Fe and Zn were 50%, 9.14%, 6.80% and 12.75% higher in Flexi than Dome respectively while K 5.88% higher in Dome than Flexi.

4. DISCUSSION

4.1 Chemical Properties of the Soils

As per the rating suggested by Landon, [35], the soils had low levels of Ca (<4.0cmol kg⁻¹) and

total Nitrogen (TN<10%), organic carbon (OC<0.7%) and high levels of exchangeable acidity (>20%) implying that the fertility status was low. High Al saturation is considered to be toxic to maize plants [36,37,38]. According to [34], the soils were moderately acidic with pH of 5.0-6.0. Such acid soils with high Al saturation and low bases are characteristic of highly weathered soils, which have lost most of the basic cations through leaching [36]. Additionally, the acidity could be attributed to the mineralogy of the parent materials [39] because most of these soils developed from non-calcareous parent materials such as syenites, phololites, trachytes and nepholites which are acidic in nature [40]. The soil attributes are congruent with research findings by Muindi et al., [41,37,38,42,43].

4.2 Effect of Bioslurry from Flexi and Dome Biodigesters on Soil Chemical Properties

The moderate soil pH increase observed in the study on application of bioslurry can be attributed to the role of organic matter on soil chemical properties. According to Kumar, et al., [44], No, (2012) and Weil and Brady, [45], organic matter acts as a strong buffering agent. It is produced in presence of heat in a 4-phase process of

fermentation, acetogenesis and methanogenesis in anaerobic conditions [13]. Bioslurry is therefore carbon-rich as it originates from organic material, and hence contains organic matter. Weak acids such as the organic acids in humus do not give up their H easily. However, the carboxyl groups on the humus develop negative charge as the positively charged H is removed through the role of organic matter on soil physical, chemical and biological components. Release of H from carboxyl groups helps to buffer pH change leading to either slight pH increase or reduction. Owing to the fact that minerals within bioslurry are readily available because of digestion in the biodigester, depending on bioslurry quality, cations within the bioslurry are associated with binding of negative charged sites leading to release of hydrogen ions in soil solution hence increased pH levels.

The higher pH increase in Dome bioslurry treated soil compared to Flexi bioslurry treated soil, considering the higher pH in Flexi bioslurry compared to Dome (Table 1), could be attributed to the working mechanism of the two biodigesters. In Flexi, there is a plug flow mechanism where addition of fresh substrate causes previously fed substrate to flow towards the other end of the tube in two-phase system leading to complete digestion [46]. The digested nutrients are readily available in the soil solution, hence prone to leaching. Dome on the other hand operates on the principle of gas pressure within the digester and as such the digestate is pushed into the compensation tank causing a back and forth flow of digestate, and hence undigested materials may flow out [47]. This allows the undigested material to act as adsorption sites and also lead to slow release of the nutrients thus reducing leaching rate. The insignificant increase in soil pH after two cropping season is in line with findings by other researchers. Application of 14t/ha bioslurry in the Thesis work of Biramo (2017) in Ethiopia reported a 2% increase in pH. A similar trend was reported in the Thesis work of Mwanga [21], where application of 6666.7l/ha bioslurry in two different sites in Tanzania raised soil pH by 8.7% and 5.6% respectively. Similarly, in establishing the effect of bioslurry on physico-chemical properties of soil in Ethiopia, Musse *et al.*, [11] reported a pH level of 7.4 from an initial 7.35 when 61.8kgN/ha bioslurry was applied. On the contrary, Terefe *et al.*, [9] reported a significant increase in pH in an Ethiopian soil when varying levels of bioslurry ranging from 10 to 90m³ were used.

Exchangeable acidity was observed to follow the same trend as soil pH. This trend can be attributed to the fact that exchangeable acidity is a factor of exchangeable Al, Fe, H and base cations. An increase in exchangeable Al and H ions in soil solution therefore leads to exchangeable acidity increase and vice versa [41]. The reduced exchangeable acidity in Dome compared to Flexi could be attributed to the same factors causing an increase in pH.

The higher exchangeable P in Flexi compared could be explained by the higher P levels in the bioslurry from Flexi compared to Dome (Table 1). Available soil P increase after treatment can be attributed to presence of already digested inorganic P supplied by bioslurry. Phosphorus mobility is low [48] and also plants may not uptake all the P present in a soil solution, explaining the reason for high exchangeable P in the initial soil. Continuous mineralization due to action of organic matter on soil physical, chemical and biological properties might also have led to the increased soil P levels [49,42,43]. Presence of organic matter reduces P chelation by lowering the activities of the polyvalent cations such as Ca, Al and Fe that form insoluble salts with P [42,43,50]. Observed increase in exchangeable P is in line with Musse *et al.*, [11] who reported an increase of 14.3 mg/kg available P up from 13 mg/kg in soils after application of 61.8 kgN/ha of bioslurry. Similarly, use of bioslurry of 10, 30, 50 and 70m³/ha increased available P to 73.76, 94.32, 92.63 and 97.76ppm [89]. In another experiment, P values increased from 80.9 to 87.5 mg/kg after 4 years of using 20t/ha of bioslurry [23].

The higher levels of TN and OC in soils treated with Dome compared to Flexi could be due to the digestion mechanism of Dome. Notably, bioslurry from Dome was thicker and more fibrous which may have led to its continued breakdown after application. This is especially so considering that Flexi bioslurry had higher concentrations of these elements compared to Dome (Table 1). Increase in OC and TN has similarly been obtained in Thesis work of Biramo (2017) from 1.64 to 2.45 and 2.38% OC while TN increased from 0.11 to 0.195 and 0.198% in two tomato varieties. Similarly, Barlog, *et al.*, [23] found increased OC levels from 15.2 to 15.6g/kg and from 1.48 to 1.53g/kg for TN. Similar results have been documented by Zheng *et al.* [8]; Biramo, *et al.*, [10]; Musse, *et al.*, [11]. The higher exchangeable K in Flexi treated soils compared to Dome could be due to the higher levels in the

bioslurry. The increased K levels after treatment is related to the K present in the bioslurry. The generally high K levels in the soils could also be due to the selective adsorption of Ca or Mg to K (Galindo and Bingham, 1997), as it has been shown that some soils may prefer K over Ca, Mg and Na [51] where soil K sorption of 10 times greater than that of Na [52] have been reported. Increased K levels have also been observed by other researchers, where Biramo (2017) found 16.6 and 21.2meq/100gm from an initial 19.7meq/100gm in two tomato varieties.

The increase in Ca upon application of bioslurry from Dome while Flexi caused a reduction could be due to increased adsorption sites in the former. The decrease in Mg in soils in both biodigesters may be contributed by its unique chemical properties where the ionic radius is smaller than that of other cations whereas its hydrated radius is larger [53]. This causes it to be more loosely bound to the CEC and hence readily mobile [54], leading to high leachability. The results agree with those in Thesis work of Biramo (2017) where sole application of bioslurry caused a reduction in Mg values to 1.68 and 1.52cmol/kg in two different tomato varieties against an initial value of 1.73cmol/kg. In contrast, a study by Barlog, *et al.*, [23] showed increase in Mg levels of 152.5mg/kg after a 4-year trial, from an initial 130.6mg/kg although Ca:Mg ratio decreased from 34 to 32. The higher increase in Ca:Mg in Dome treated soils could be due to higher Ca and OC levels in Dome treated soils compared to Flexi. It has been observed that high organic matter correlates positively with soil preference for Ca over Mg [55,56]. The higher increase in exchangeable Na in Flexi treated soils was due to its higher levels in Flexi bioslurry compared to Dome.

4.3 Effect of Bioslurry from Flexi and Dome Biodigesters on the Maize Growth, Yield and Grain Quality

It was observed that crop response to bioslurry from Dome and Flexi was not significantly ($P \leq 0.05$) in relation to germination, number of leaves, LAI, plant height and yields. The insignificant difference can be attributed to the fact that bioslurry quality is a function of quality of feed and digestion efficiency. Once the nutrients are applied in form of bioslurry, uptake and utilization is determined by the level of mineralization and other environmental factors. Similarly, although Flexi bioslurry had higher nutrient content than Dome (Table 1), this trait in Flexi and slow release in Dome may have

worked in favour of either, leading to insignificant difference between them. It is known that manure releases nutrients at a slower rate [57]. Nevertheless, the insignificant difference has the implication that both biodigester types have similar impacts, at least in the short run on maize growth and yields. Good results were also found by Jjagwe *et al.*, [17] where use of 10t/ha bioslurry from Dome among other amendments in Uganda showed comparably high number of leaves, plant height and yields in maize. The authors found a 45% and 48% increase in maize grain yield in season 1 and 2 respectively.

Numerically lower yields in Flexi compared to Dome in both seasons could be due to high levels of N in the soil. Increasing N levels in soils that already have sufficient N has been shown to decrease yields, [58,59]. Higher N levels were found in Flexi bioslurry compared to Dome. Ammonium and nitrate were 449.7% and 680.9% higher in Flexi bioslurry than Dome. Ammonium has been reported to inhibit NO_3 uptake [60]. This may have led to a counter effect on their utilization. The higher stalks and stovers yield in Flexi when the rainfall was lower could be due to reduced leaching of nutrients, and hence available for plant growth.

The higher grain N values in long compared to short rains could be due to the accumulation of the nutrients in the soil. Higher soil N levels have led to a reciprocal increase in grain N (Guo *et al.*, 2020). At the same time, there was less rainfall in the long compared to short rains, which may have reduced leaching of nutrients. High rainfall and temperatures increase N mobility [61]. In testing the efficacy of wet olive pomace in wheat varieties, Localla *et al.*, (2019) found an increase in the concentration of grain protein content in the Aureo cultivar with increase in pomace treatment. The grain N has been reported to depend on the availability of the N in the soil for plant absorption during grain filling (Gallais and Coque 2005) but also on the on re-mobilization of N during grain filling of the N absorbed before flowering (Triboï and Triboi-Blondel, 2002). The relatively higher grain nutrient content such as P, K, Fe, Mn and Zn in Flexi treated plots compared to Dome was due to the higher levels of nutrients present in the Flexi bioslurry.

5. CONCLUSIONS AND RECOMMENDATION

Bioslurry from either biodigester type was found to positively contribute to better soil chemical conditions through increase in most of the

analyzed soil nutrients. The increase in TN and TOC underpins bioslurry's ability to enhance the organic matter content and hence improve physical and biological properties of the soil. Considering the higher values of these two nutrients in Dome treated soils compared to Flexi, Dome bioslurry may contribute to a faster build-up of soil organic matter. Many farms in sub-Saharan Africa suffer high pH levels, which can be amended by continuous use of bioslurry as it was seen to raise the soil pH. As such, use of bioslurry from any of the biodigester types at a rate of 400mls/hill can be promoted for use as a sustainable organic fertilizer contributing to overall good soil health.

It was observed that although the response of crop growth and yield when bioslurry from either biodigester type was applied had no statistical difference, Dome bioslurry was found to support higher yields. However, both biodigesters have equal ability to support maize crop growth and yields. The higher nutrient values found in the bioslurry from Flexi compared to Dome were found to influence grain quality where micronutrients such as K, Fe, Cu, Mn and Zn were higher. Potassium, Fe and Cu were found to be higher in Flexi treated soils.

However, research into the cause of the higher positive effect of Dome bioslurry on improving soil chemical properties, considering that Flexi bioslurry had higher nutrients levels, need to be investigated. Flexi gave higher stovers and stalks yields when the rainfall was low but was lower in the season when rainfall was higher. This dynamic requires further investigation. A long term effect on the studied parameters is also recommended as the data was based on two seasons only.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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