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RESEARCH ARTICLE

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# Smallholder farmers' knowledge on the use of bioslurry as a soil fertility amendment input for potato production in Kenya

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## Abstract

A survey was conducted on farmers' fields at Werugha and Wusi-Kishamba wards in Taita Taveta County, Kenya, to assess the factors influencing farmers' decisions on the use of bioslurry in the management of soil fertility. Knowledge gaps on bioslurry use provide contrasting claims about the value of bioslurry from source, storage and handling, crop types, soil, and climate conditions, and as a fertilizer. The majority of the farmers in the study sites double up as dairy farmers which has resulted in enormous production of under-utilized cow dung. Over-dependence on the use of inorganic fertilizers leads to the destruction of soil physical and biological properties; hence, the provision of essential nutrients required by plants for growth and development is not achieved at the maximum recommended rates. This results in a yield decrease with potato yield ranging from 8 to 15 t ha$^{-1}$, which is 2- to 3-times below the achievable yield of 40 t ha$^{-1}$. A survey questionnaire was developed and administered to 120 small-scale farmers within the two wards. Results showed that the use of bioslurry has not been well adopted by farmers from the two wards as only 18% responded to using bioslurry on their farms whereas 78% relied on chemical fertilizers and other forms of manures such as farmyard manure. However, even those using slurry had since been reported to have challenges with its use and application. The 36% of farmers who applied bioslurry alone did so due to its availability considering the high cost of inorganic fertilizers while those who combined it with inorganic fertilizers had faith in chemical fertilizers and that they aimed at achieving high crop yields. The major challenges farmers faced while using slurry on their farms were reported to be on lack of knowledge on the exact quantity to be applied per unit area and on the storage of excess slurry from biodigesters. This implied that even though slurry was available, it was still not useful to the farmers due to under/over application and poor storage. The study, therefore, recommends capacity-building programs and agricultural extension services to be developed, to ensure adequate knowledge on bioslurry use and adoption by smallholder farmers in the management of soil fertility in enhancing crop productivity.

**KEYWORDS**
bioslurry, farmyard manure, land degradation, potato, soil fertility

  

## 1 | INTRODUCTION

In Africa, according to Food and Agriculture Organization (FAO) statistics, potato (*Solanum tuberosum* L.) is categorized as the fourth most consumed staple food crop and is highly priced in developing countries (FAOSTAT, 2011; Scott et al., 2013). The crop acts as a cash crop for small-scale farmers and it contributes greatly to their sustenance (Wachira et al., 2014). Potato farming has predominantly increased farmers' profits and job creation among community members in urban areas due to the high consumption of processed crisps (Muthoni et al., 2013; Mwakidoshi et al., 2023).

African soils are majorly obtained from granite by weathering and hence, contain an inadequate amount of required plant nutrients for sustainable crop productivity (Bationo et al., 2006). Soil fertility is extremely variable and so is the response to inputs. Soil fertility is tremendously diversified with large on-farm variation across the fields besides being too much variation across the African continent (Otieno, 2021). Furthermore, the majority of soils respond lowly to fertilizers when solely applied hence resulting in reduced agronomic efficiency. It can be elevated by complementary management of soil organic matter.

Experiments conducted over a long-term period have given a lead role in appreciating the changes in soil fertility that brought up poor crop farming (Mugwe et al., 2019; Otieno, Kiboi et al., 2021). Such outcomes have shown a positive incline in crop productivity, on treatments supplied with fertilizers. However, it was noted from the same treatments that continuous sole application of inorganic fertilizers also resulted in low crop yields, which was largely attributed to soil acidification by fertilizers, nutrient mining, leaching, and reduced soil organic matter (SOM) (Cheptoek et al., 2022; Nyawade, Gachene et al., 2019). Introduced application of organic fertilizers such as manure was also noted to increase crop yields, however, which declined with the only application of organic compounds (Mugo et al., 2021; Mwadalu et al., 2022; Mwakidoshi et al., 2021; Nyawade et al., 2021).

The adoption and utilization of Integrated Soil Fertility Management (ISFM) technologies are believed to be the best solution for curbing the decline in soil fertility (Nyawade et al., 2020a, b; Mugwe et al., 2019; Otieno et al., 2021; Mwadalu et al., 2022). However, it has been troublesome for small-scale farmers in adopting ISFM technologies which has prompted a need for research due to the existence of an information gap in farmers' knowledge base on the management of soil fertility using organic fertilizers such as bioslurry.

Land degradation has been a challenge in potato production in Kenya and largely Africa due to soil fertility loss through soil nutrient mining, deforestation, desertification, drought, and water erosion (Kisaka et al., 2023; Mugo et al., 2021; Mwakidoshi et al., 2021; Nyawade et al., 2019, 2020). This has resulted in consecutive reductions in crop yield productivity. The continued yield decline is also attributable to the unavailability of certified seeds, increased pests, diseases, decreased SOM, and microbial biomass (Faridvand et al., 2021; Nyawade et al., 2019c). Most soils within the production areas have been reported to have low levels of organic carbon, zinc, potassium, nitrogen, and phosphorus, which has affected the productivity and sustenance of soil fertility (Chappa et al., 2022; Otieno et al., 2021). Due to global warming, precipitation rates are anticipated to lessen in Kenya with a forecast increase in evapotranspiration levels (Nyawade et al., 2021). Such changes would result in a decrease in available soil moisture and increased SOM decomposition, mostly close to the soil surface thus affecting soil water retention and carbon sequestration (Raza et al., 2021, 2022; Seleiman et al., 2021). Regarding agricultural intensification, the use of ISFM strategies to manage low nutrient holding capacity is long overdue in tropical and subtropical soils due to high SOM turnover.

The absolute and food poverty in Kenya stands at 57 and 48%, respectively, implying that the country is far from being food self-sufficient (GoK, 2014). Therefore, in this regard, there are no complete recommendations for the mutual application of bioslurry and inorganic fertilizer to enhance potato crop productivity in the area. There is inadequate information on potato response to the utilization of combined organic and inorganic fertilizers hence resulting in over-dependence on the use of chemical fertilizers at high rates, which have resultantly remained a barrier for small-scale farmers to wade through improved potato production techniques. The current production rate is on the extreme, very low and we can presuppose that also the environmental performance of the potato farming system to yield could be lower. Regarding these drawbacks, this research considers shedding more light on the effect of combining inorganic fertilizer (diammonium phosphate) and organic fertilizer (bioslurry) on potato productivity and correlated parameters of growth and tuber yield.

Taita Taveta County is one of the potential potato production areas with suitable soil and climatic conditions besides having standard farm sizes for smallholder farmers in the highlands, midlands, and lowlands, of about 0.4, 1.3, and 4.8 ha, respectively. Crop husbandry is the foremost job in the County, and the dominant origin of sustenance for families which also supply raw materials to agro-based industries and creation of employment with approximately 80% of the nation's workforce (GoK, 2014). The agricultural sector is comprised of both subsistence and large-scale commercial farming with the entire acreage under horticulture being 3296 ha compared to the 18,125 ha that is under other food crops (GoK, 2013). Smallholder irrigation facilities are now in place in the area under study during off-season production which makes it possible for farmers to venture into potato production for purposes of both gaining income and food not only under irrigation but also in rain-fed conditions.

However, to obtain higher yields and quality crop production, farmers rush to use inorganic fertilizers (Mugo et al., 2021; Nasar et al., 2022). With the increase in environmental concerns, there is an urgent need to relook at the research priorities to focus on developing alternative sustainable crop production systems to be achieved through the providence of non-pollutant, non-conventional and cultural techniques. In Kenya, majority of households have now appreciated the use of renewable energy and installed biogas digesters where they produce clean energy using available animal waste and use it in lighting, room warming, cooking, and running farm errands such as irrigation among others.

Different studies have shown that prolonged usage of inorganic fertilizers without topping up organic matter has resulted in reduced soil fertility and land productivity (Faridvand et al., 2021; Mugo et al., 2021; Nasar et al., 2022). This predisposes the land to soil acidity making it unsuitable for crop production. The use of bioslurry for potato production has shown better yields compared to using chemical fertilizers, therefore, proved to be the best alternative for use in the fertilization of potato plants (Groot & Bogdanski, 2013; Warnars, 2012; Zelalem et al., 2009). There is limited literature available on the use of slurry fertilizer as organic manure particularly in potato production; hence, the need for this study which on its success would also open up opportunities for agricultural experts to adopt and use bioslurry in supplementing the costly inorganic fertilizers for crop production.

Bioslurry is an organic material, anaerobically digested and produced as a byproduct of biogas plants after methane gas combustion (Warnars, 2012). According to Warnars (2012), bioslurry can be applied as foliar to plants to enable them get adequate amount of the recommended nutrients. Use of biogas is gaining popularity owing to the increasing demand for clean energy and has been a fundamental aspect to lessen environmental pollution and replace the consumption of fossil fuels, which plays a critical role in sustainable development. The use of bioslurry in combination with inorganic fertilizer has great potential of increasing crop production including potatoes. However, despite their great importance, the synergistic use of bioslurry and inorganic fertilizers has not been embraced fully by farmers. Therefore, based on this background this study, was carried out to explore the potential of the two aforementioned amendments with aim of boosting potato production in Taita Taveta County, Kenya. The main crops cultivated in the area are cereals and horticultural crops such as potatoes. The farming systems are comprised largely of small-scale, and farmers engage in both dairy and crop farming to meet the economic needs of their families (GoK, 2014).

Bioslurry is a byproduct of already digested animal waste and a source of water, organic carbon (OC), phosphorus (P), nitrogen (N), and micronutrients such as magnesium, zinc, calcium, and copper among others. Compared to manure, nutrients from bioslurry are freely available for uptake by the plant because it is already digested in the biodigesters (Muindi et al., 2020). The application of bioslurry has been documented to contribute to the enhancement of soil fertility by improving the biological and physicochemical properties of soil (Muindi et al., 2020; Warnars, 2012). Use of such slurry saves farmers' time and resources and hence reduces the negative impact of climate change brought about by deforestation and greenhouse gas emissions. The byproduct of biodigesters is also utilized as an organic fertilizer to promote soil and crop productivity hence reducing the overdependency on chemical fertilizers for crop production. Bioslurry nutrients are readily mineralized and taken up directly by plants compared to other organic sources such as manure which has to be mineralized before use. It can be most effective when applied as compost, therefore, reducing dependence on inorganic fertilizers which can also help farmers focus on pure organic farming. Therefore, the study was carried out to assess the knowledge base of smallholder farmers on the use of bioslurry as a soil fertility amendment for potato production in Kenya.

## 2 | RESEARCH METHODOLOGY

### 2.1 | Study site description

The study was carried out at Werugha and Wusi-Kishamba Wards located in Taita Taveta County. Werugha Ward is situated in the Taita sub-County between Iyale Valley (3°24′40.01″S, 38°20′2.36″E) (2104 m asl) and Ngangao Mountains (3°21′45.32″S, 38°20′26.07″E (1952 m.a.s.l)) (Figure 1). The northern part of Werugha extends to the foothills of Taita as far down as [3°25′4.22″S, 38°22′1.45″E (1200 m asl]. On the other hand, the Wusi-Kishamba Ward covers an area of 359.1 km$^2$ and is located approximately 8.7 km north of Mwatate Town bordering the Rong'e Ward (3°22′19.57″ S, 38°25′37.38″E) to the east, Bura Ward to the west (3°27′24.76″ S, 38°18′44.67″E), Wundanyi/Mbale Ward (3°24′17.17″S. 38°22′2.28″E) to the north, Mwatate (3°47′23.18″S, 38°29′4.54″E) and Chawia (3°28′43.5″S, 38°20′58.56″E) wards to the south. The study region comprised mainly shallow, well-drained, and black to very dark brown, very friable loam soils, with acid humic cambisols (TTCG, 2013).

The average annual rainfall received in the region varies from 500 to 1500 mm. The rainfall pattern is bimodal with long-season rainfall occurring from March to mid-June, whereas short rainfall sets in from October to the end of the year. The main crops cultivated in the area are cereals and horticultural crops such as potatoes. The farming systems are comprised largely of small-scale, and farmers engage in both dairy and crop farming to meet the economic needs of their families (GoK, 2014).

### 2.2 | Methodology

#### 2.2.1 | Data collection and respondent selection

A total of 120 smallholder farmers were randomly selected from Werugha and Wusi-Kishamba Wards. The respondents were drawn from 73 households capturing both those who had biogas digesters and ones without. The sample was representative of the small-scale farmers who adopted and non-adopters.

A multistage sampling technique was employed in this study. Out of four sub-counties of Taita Taveta County, Mwatate and Taita were selected. In the second stage, two wards namely Werugha and Wusi-Kishamba were selected out of nine wards in Mwatate and Taita sub-counties. The purposive selection was done from these wards constituting 99% of small-scale farmers that are dependent on crop and dairy farming. The ward's favorable climatic conditions were suitable for potato growth and development. Data were obtained from sampled farmers through structured questionnaires and interviews. The farmers' survey was carried out in September/December 2020, using a single-visit survey approach as described by Thompson and Stout

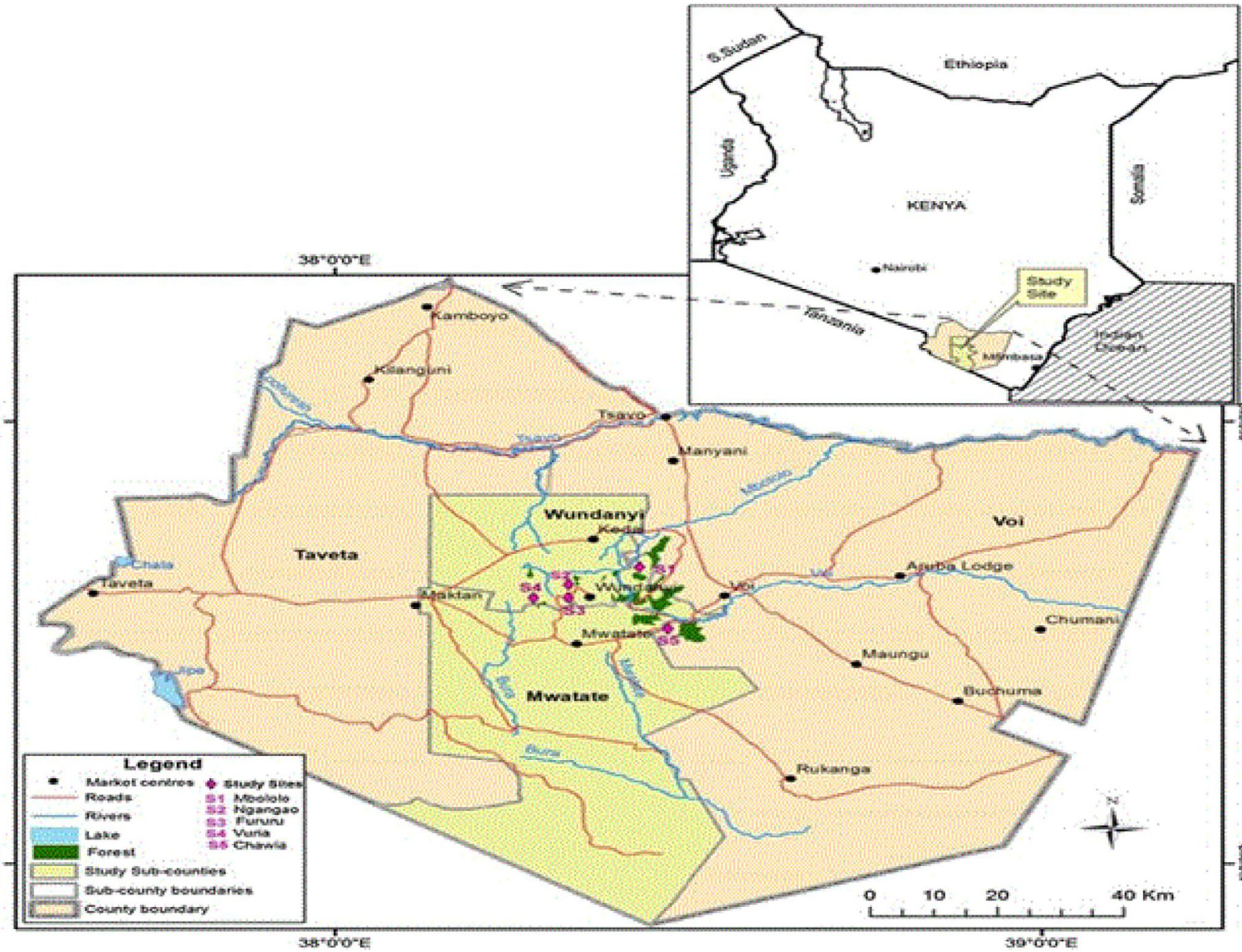


FIGURE 1 Map of Kenya showing the study sites in Werugha and Wusi-Kishamba wards (highlighted in yellow). [Colour figure can be viewed at wileyonlinelibrary.com]

(1997). The data collected included: the socio-demographic profile information, types of crops grown in the area and their productivity, knowledge of soil characteristics, soil fertility management, and bio-slurry technologies.

Mugenda and Mugenda (2003) recommended that to determine the actual sample size, consideration of three major factors is paramount. These are the estimated prevalence of the variable of interest, desired level of accuracy (in this study confidence level was set at 95%), and the acceptable margin of error (5%). Therefore, the sample size was computed as shown in Equation (1) (Mugenda & Mugenda, 2003).

$$n=\frac{Z^2pq}{e^2} \tag{1}$$

*Where:*

$N$ = Desired sample size.

$z$ = is the standard normal deviation (1.96 confidence level at 95%).

$p$ = Estimated number of potato farmers (0.05 population unknown).

$q = 1 - p\,(1 - 0.05)$.

$e$ = Precision desired/ error margin at 5% (standard value of 0.05).

Using the standard values in Equation (1), the required sample size became: $n=\frac{1.96^2(0.05)(0.95)}{0.05^2}$ $n = 73$ farmers. Working out the above equation gave an approximated sample size of 73. However, to take care of the deficient, spoilt, and non-response questionnaires, the data were collected from 120 small-scale farmers.

### 2.2.2 | Data processing and analysis

Survey data were subjected to analysis of variance using the Statistical Package for the Social Sciences (SPSS) software version 25. Binary logistic regression (BLR) was carried out to show the influence of selected factors on the use or non-usage of bioslurry among the respondent farmers. Gender, age, level of education, and farm size were entered into the model as covariates while bio-slurry use or nonuse was entered as the binary dependent variables. The Hosmer and Lemeshow statistic (Hosmer &

Lemeshow, 1980) was set at 0.793, which was larger than 0.05; hence, the model was appropriate for data description and binary logistics (Table 1).

# 3 | RESULTS

## 3.1 | Assessing the knowledge base of farmers on the use of bioslurry in the management of soil fertility

### 3.1.1 | Respondents' demographics

More than 50% of the respondents were female across the two wards (Wusi-Kishamba and Werugha) (Table 2). Respondents' age ranged from 19 to 79 years, with the majority aged above 36 years with an average mean of 50 years. The education level of respondents varied across the wards with 31 and 33% having no formal education in Wusi-Kishamba and Werugha Wards, respectively. Additionally, only 22 and 23% of respondents had attained college and graduate/postgraduate education levels in Werugha and Wusi-Kishamba Wards, respectively.

### 3.1.2 | Respondents' farm size, potato farm size, and size of the farm where fertilizer was applied

Most farmers had small-sized pieces of land with the majority (≤8adopter) owning ≤2 ha. (Table 3). Only 5% and 4% of the respondents in the Wusi-Kishamba and Werugha wards, respectively, possessed ≥4 ha. More than 64% and 69% of these respondents had dedicated less than 0.3 ha of their farms for potato production in the Wusi-Kishamba and Werugha wards, respectively, with none of them had cultivated more than 1 ha in either ward. Although none of the respondents had applied fertilizer in more than 1 ha of their farms, at least the majority (≥57%) across the wards reported having applied the input on at least between 0.1 and 0.3 ha of their farms.

**TABLE 1** Hosmer and Lemeshow test

| Step | Chi-square | df | Sig. |
|---|---|---|---|
| 1 | 4.666 | 8 | 0.793 |

*Source*: Hosmer and Lemeshow (1980).

### 3.1.3 | Farmers growing potatoes, type of fertilizer applied on the farm, reason for application of the specified type of fertilizer, and type of fertilizer used for top dressing

Over 90% of the interviewed respondents were potato-growing farmers (Table 4). The criteria governing the fertilizer choice, type, quantity, and reason for its application varied across the wards and with individual respondents with the majority of the farmers using either organic manure (>28%) or DAP fertilizer (>30%) for planting and CAN (>80%) for topdressing in both wards. Fertilizer utilization was noted to be very low with 74% of the respondents applying ≤60 kg $ha^{-1}$ in both wards. The majority (≥39%) of the farmers applied fertilizers to improve crop growth and yield.

### 3.1.4 | Potato production in the last four seasons

About 40 and 38% of the respondents from Wusi-Kishamba and Werugha wards reported having harvested yields ≤20 t $ha^{-1}$ of potato with an average of four seasonal yields of 40 and 39 t $ha^{-1}$, respectively (Table 5).

**TABLE 2** Demographics of respondents in the study area

| | Description | Wusi-Kishamba Percentage (%) | Werugha |
|---|---|---|---|
| Gender | Male | 42 | 37 |
| | Female | 58 | 63 |
| Age | 0–18 | 0 | 0 |
| | 19–35 | 13 | 21 |
| | 36–45 | 20 | 21 |
| | 46–55 | 32 | 31 |
| | 56–65 | 22 | 17 |
| | > 65 | 13 | 10 |
| Education level | No formal education | 31 | 33 |
| | Primary | 25 | 20 |
| | Secondary | 22 | 24 |
| | College | 12 | 19 |
| | Graduate/Postgraduate | 10 | 4 |

**TABLE 3** Respondents' percentage response on farm size, potato farm size, and size of farm applied with fertilizer

| Total farm size (ha) | Wusi-Kishamba Respondents (%) | Werugha |
|---|---|---|
| ≤ 1 | 46 | 49 |
| 1.1–2.0 | 35 | 29 |
| 2.1–4.0 | 14 | 18 |
| Above 4.0 | 5 | 4 |
| Farm size cultivated with potatoes (ha) | | |
| 0.1–0.3 | 64 | 69 |
| 0.4–0.7 | 22 | 22 |
| 0.8–1.0 | 14 | 9 |
| Above 1.0 | 0 | 0 |
| Size of farm applied with fertilizer (ha) | | |
| 0.1–0.3 | 65 | 49 |
| 0.4–0.7 | 22 | 31 |
| 0.8–1.0 | 13 | 20 |
| Above 1.0 | 0 | 0 |

### 3.1.5 | Reason for potato yield fluctuations

At least 87 and 78% of farmers in Wusi-Kishamba and Werugha wards reported having witnessed a significant change in potato productivity over the past few years (Table 6). Although the changes were attributed to varied factors such as climate change, inadequate fertilizer application, increased rainfall, and the incidence of pests and diseases. The majority of the farmers (43%) in Wusi-Kishamba and (49%) in Werugha wards attributed the yield fluctuations to the effects of climate change while ≤22% attributed the yield fluctuations to pests and diseases. Only ≤19% associated yield fluctuation to plant nutrition (soil fertility).

## 3.2 | Knowledge of soil fertility management and bioslurry technologies

### 3.2.1 | Percentage response of farmers on knowledge of soil type and amendment(s) normally applied on their farm

More than 90% of the respondents knew the type of soil on their farms across the wards (Figure 2). Farmers preferred using a

**TABLE 4** Percentages response of farmers growing potatoes, type of fertilizer applied on the farm, reason for application of the specified type of fertilizer, and type of fertilizer used for top dressing

| Question | Response | Wusi-Kishamba % Respondents | Werugha |
|---|---|---|---|
| If they grow potatoes | Yes | 94 | 88 |
| | No | 6 | 12 |
| Type of fertilizer applied on the farm | DAP | 32 | 33 |
| | Organic manure | 32 | 28 |
| | NPK | 14 | 18 |
| | CAN | 12 | 9 |
| | NPK + CAN | 6 | 6 |
| | NPK + DAP | 3 | 4 |
| | FYM + DAP | 1 | 2 |
| Reason for applying the specified type of fertilizer | Improves yield and plant growth | 44 | 39 |
| | Availability | 26 | 24 |
| | Recommended for planting | 14 | 18 |
| | Maintains soil fertility | 10 | 12 |
| | That's what others do | 6 | 7 |
| Type of fertilizer used for topdressing | CAN | 84 | 82 |
| | NPK | 16 | 18 |
| Quantity of fertilizer applied (kg ha$^{-1}$) | 0–20 | 29 | 29 |
| | 21–40 | 25 | 25 |
| | 41–60 | 20 | 20 |
| | 61–80 | 16 | 16 |
| | 81–100 | 7 | 6 |
| | > 100 | 3 | 4 |

TABLE 5 Percentage response on average potato yield in the last four seasons

| | | Potato yield (t ha$^{-1}$) | | | | Average potato yield in last four seasons (t ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0–10 | 11–20 | 21–30 | ≥30 | 0–10 | 11–20 | 21–30 | ≥30 |
| Wusi-Kishamba | (%) | 32 | 47 | 17 | 4 | 38 | 42 | 14 | 6 |
| Werugha | | 37 | 38 | 16 | 9 | 39 | 39 | 12 | 10 |

TABLE 6 Percentage response of farmers on yield change

| Question | Response | Wusi-Kishamba % Respondents | Werugha |
|---|---|---|---|
| Is there a change in yield? | Yes | 87 | 78 |
| | No | 13 | 22 |
| Probable reason if "Yes" | Climate change | 43 | 49 |
| | Pests and diseases | 22 | 20 |
| | Inadequate fertilizer applied | 19 | 16 |
| | Adequate rains | 10 | 10 |
| | A high amount of manure application | 6 | 5 |

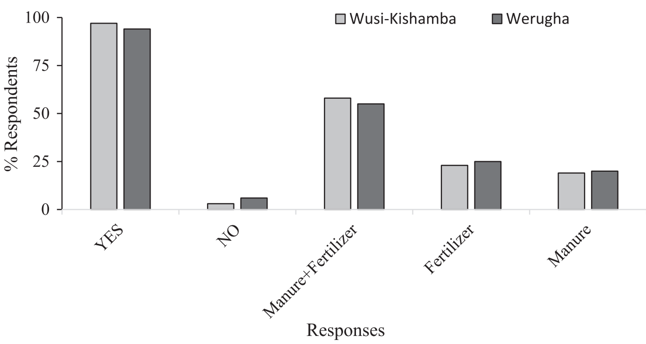


FIGURE 2 Percentage response of farmers on knowledge of soil type and the amendment(s) normally applied on their farm

combination of fertilizer and manure on their farms with ≤30% opting for the sole application of either of these two amendments across the wards.

### 3.2.2 | Manure utilization

All farmers applied manure on their farms with the majority (≥80%) using farmyard manure and ≤20% using bioslurry (Table 7). The majority in both wards (≥84%) responded to choose farmyard manure while ≥16% used bioslurry as a fertilizer of choice, based on manure availability while the rest had no accessibility to biogas with a few of them having applied it to increase and maintain soil fertility status on their farms. Further, ≥90% relied on available manure from their farms while ≥10% were buying. Also, ≥88% agreed to apply manure to all their crops while ≥12% responded not to apply manure to all crops from both wards and instead depended largely on the available soil organic matter.

### 3.2.3 | Quantity of bioslurry applied on the farm (t ha$^{-1}$)

The majority of farmers (≥47%) applied bioslurry at quantities of between 0 and 25 t ha$^{-1}$ while only ≤14% managed to use between 76 and 100 t ha$^{-1}$ across the wards (Figure 3). Furthermore, ≥31% and ≥16% of farmers from Wusi-Kishamba and Werugha wards, respectively, applied bioslurry at quantities with ranges of 26–50 t ha$^{-1}$ and 51–75 t ha$^{-1}$.

### 3.2.4 | Crops supplied with bioslurry

Both wards being good for horticultural farming, ≥42%, ≥27%, ≥16%, and ≥15% of the farmers applied bioslurry on vegetables, maize, potatoes, and beans, respectively, across the two wards of Wusi-Kishamba and Werugha (Figure 4).

### 3.2.5 | Reason for applying bioslurry on the mentioned crops and if applied alone or in combination with fertilizer

Farmers reported having applied bioslurry to named crops to maintain soil fertility and increase crop productivity (Figure 5). About 66% and 57% of farmers from Wusi-Kishamba and Werugha Wards, respectively, applied some bioslurry with 83% and 71% opting for the combined application of fertilizer and bioslurry.

TABLE 7 Percentage response of farmers on access to certified seeds

| Question | Response | Wusi-Kishamba % Respondents | Werugha |
|---|---|---|---|
| Have access to potato-certified seeds | Yes | 6 | 14 |
| | No | 94 | 86 |
| Most limiting factor if "No" | Expensive | 48 | 53 |
| | Inadequate knowledge of the importance of using certified seeds | 29 | 27 |
| | Unavailability of certified seeds | 23 | 20 |

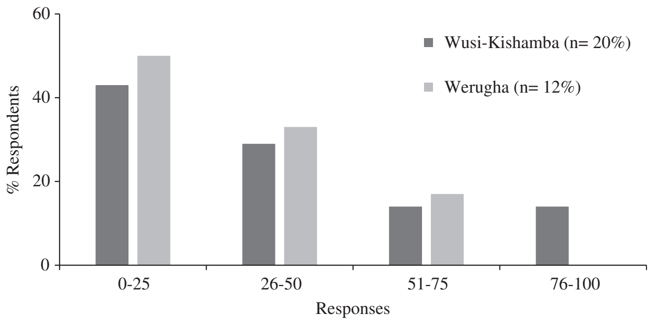


FIGURE 3 Percentage response on the quantity (t ha$^{-1}$) of bioslurry applied on the farms.

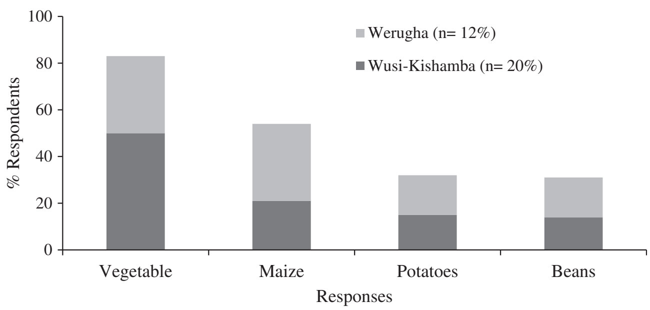


FIGURE 4 Percentage response on crops supplied with bioslurry

### 3.2.6 | Reason for the sole or combined application of bioslurry and fertilizer

The sole application of bioslurry was dictated by its availability, low cost, and its ability to maintain soil fertility (Figure 6). On the other hand, the application of bioslurry in combination with fertilizer was dictated by an urge to double up crop production and the ability of inorganic fertilizer to release nutrients faster to plants. About 67% and 57% of the farmers from Wusi-Kishamba and Werugha Wards, respectively, applied slurry solely to maintain soil fertility whereas the respective 83% and 86% of them preferred a combined application of slurry and fertilizer aiming at increasing crop production.

### 3.2.7 | Challenges faced when using bioslurry

Farmers faced numerous challenges in the usage of bioslurry across the wards, with the majority (≥50%) responding to having a major challenge in transporting it to the farms due to its bulkiness (Figure 7). About 36% and 33% of the farmers in Wusi-Kishamba and Werugha Wards, respectively, had a challenge with storage of excess slurry on their farms while respective 14% and 17% of them did not know the required quantities of slurry to apply on the farm.

### 3.2.8 | Role of researchers in making bioslurry use better

Farmers from both wards recommended that there was a need for more extension services to be offered to them especially for them to gain knowledge on how to use and store excess slurry produced in the farms (Figure 8). About ≥32%, 27%, 23%, and 18% recommended the conduction of more field education, assisting farmers in soil analysis recommended, more field trials, and provision of subsidized biodigesters across the war, respectively.

### 3.2.9 | Factors influencing farmer's decision to use or not to use bioslurry in the management of soil fertility

The results from the BLR indicated that none of the factors had a significant influence on whether farmers used or did not use bioslurry in their farms as all the *p*-values were larger than 0.05 (Table 8). This implied that the use of bioslurry was affected by other factors which were not included in the model such as the availability and cost of biogas installation.

## 4 | DISCUSSION

### 4.1 | Demographic, socioeconomic, and farm characteristics

Respondents were set apart by looking into farmer-related and farm-related characteristics. The majority of the respondents were ≥ the

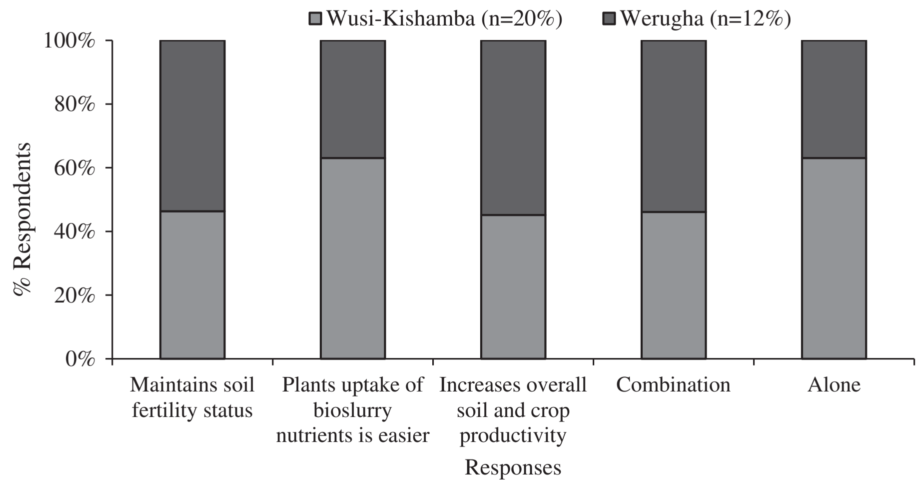


**FIGURE 5** Percentage response on the reason for applying bioslurry on mentioned crops and if applied alone or in combination with fertilizer

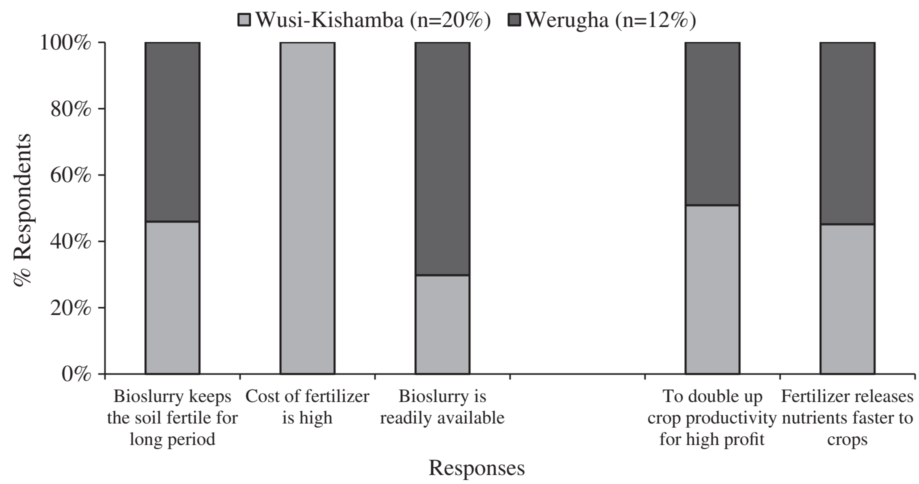


**FIGURE 6** Percentage response on the reason for sole or combined bioslurry application with fertilizer

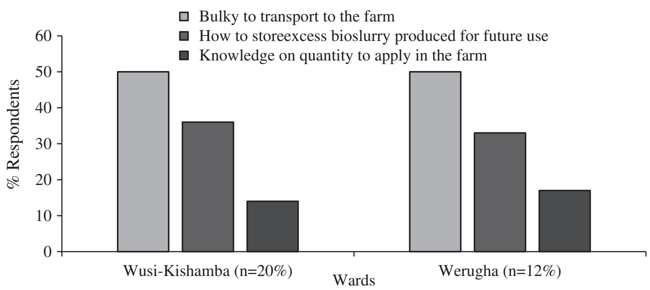


**FIGURE 7** Percentage response on challenges faced when using bioslurry

mean age of 50 years with the implication that the farmers were marginally above the optimal productive age. This finding corroborates with a study conducted by Mudibo (2006) which revealed that the older the farmers, the higher the tendency to reduction of soil productivity and yields. According to the study, less youth involvement in farming activities was exhibited, as the old generation, of farmers aged (Table 9).

In both wards, females were noted to embrace farming more than men attributed to the fact that the majority of the married women were housewives and hence had more access to land and other production factors. It was noted that according to Taita customary beliefs, that land and dairy farming were perceived as a preserve for men while women were to do domestic work and engage in crop farming. This is in line with World Bank estimates, which give the world record of women in agricultural labor between 40% and 66% (World Bank, 2014). Correspondingly, nowadays, in many parts of the country, including Taita Taveta, there is a growing trend toward what has been termed the feminization of agriculture (Onyalo, 2019).

To develop a farmer's capacity and ability to understand and obtain information, education is a key factor to be considered (Adolwa et al., 2012). From both wards, many of the respondents had attained a primary level of education while few had no formal education. Likely, respondents with low education levels or no formal education may find comprehending information daunting (Adolwa et al., 2012). We relate the high attainment of the primary level of education to the presence of a high number of primary schools strategically located and distributed in proximity to farmers' households. Also, free primary education offered by the government has led to a high number of respondents attaining a primary level of education (MoEST, 2014). According to Battese and Coelli (1995), a higher level

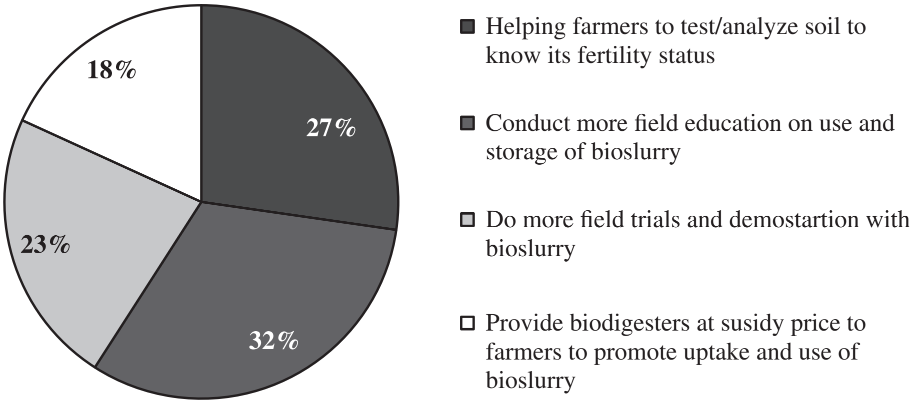


**FIGURE 8** Percentage response on the role of researchers in making bioslurry use better

**TABLE 8** Farmer's percentage response on manure application, type of manure applied, the reason for applying specified manure, source of the specified manure, and if the manure was applied to all crops on the farm

| Question | Response | Wusi-Kishamba % Response | Werugha |
|---|---|---|---|
| Do apply manure to the soil | Yes | 100 | 100 |
| Type of manure applied | Farmyard manure | 80 | 88 |
| | Bioslurry | 20 | 12 |
| Reasons for applying specified manure | Readily available from the farm | 65 | 68 |
| | Increases and maintains soil fertility | 22 | 24 |
| | Do not have biogas | 13 | 8 |
| Source of specified manure | Own source from farm | 87 | 94 |
| | Buying | 13 | 6 |
| If the manure was applied to all crops on the farm | Yes | 94 | 82 |
| | No | 6 | 18 |

**TABLE 9** Interaction of gender, age, education level, and farm size with the use or nonuse of bioslurry

| | | | | | | | 95% CI for Exp (B) | |
|---|---|---|---|---|---|---|---|---|
| Variables in the equation | B | SE | Wald | df | Sig. | Exp (B) | Lower | Upper |
| Age | −0.36 | 0.31 | 1.31 | 1 | 0.25 | 0.70 | 0.38 | 1.29 |
| Gender | −0.06 | 0.51 | 0.01 | 1 | 0.91 | 0.94 | 0.35 | 2.57 |
| Education level | −0.21 | 0.28 | 0.56 | 1 | 0.45 | 0.81 | 0.47 | 1.40 |
| Farm size | −0.22 | 0.58 | 0.14 | 1 | 0.71 | 0.81 | 0.26 | 2.50 |
| Constant | 0.57 | 1.51 | 0.14 | 1 | 0.71 | 1.76 | | |

of education among farmers' results in increased efficiency in their farming activities and hence increased productivity.

Fertilization helps replace nutrients lost from the soil after utilization by plants. Without the application of fertilizer, crop yields, and agricultural productivity, in general, diminishes (Grant et al., 2001). Diammonium phosphate (DAP) fertilizer was the most preferred fertilizer over organic manure. Fertilizers are food for plants and supplement the soil nutrient stocks with minerals easily absorbed by plants (Cheptoek et al., 2022; Mwadalu et al., 2022). We attribute the preferential application of DAP to its comparatively high nutrient content and best physical properties making it a desired alternative for farming. Being an excellent source of phosphorus and nitrogen for plant nutrition, it is relatively soluble and quickly absorbed in soil hence releasing nutrients to enhance soil and crop productivity. Grant et al. (2001) and Miriam et al. (2022) noted that phosphorus application during the early stages of plant growth until maturity helps to optimize yield production. NPK fertilizer was also embraced by farmers in their farming activities and having major nutrient components required its uptake by plants to increase with a combination of FYM applications hence increasing yield production (Mwadalu et al., 2022). In potato farming, FYM combined with DAP had a remarkable effect on both potato tuber weight and its shoot weight (Grant et al., 2001). Corroborating with results obtained by Mugo et al. (2021) and Moshileh et al. (2005), there was a substantial increase in tuber weight following the DAP application. Small-scale farmers target achieving higher crop returns at expense of the long-term effects on soil acidity, which arise as a result of overdependence on chemical fertilizers hence a decline in food production (Waithaka et al. (2007). Many farmers in both wards were only concerned with improved crop yield and plant growth, which was their main reason for applying fertilizer on their farms and not necessarily with soil health. As the study reports, organic manure was also embraced by 28% of the farmers and it was noted that it helped in improving soil fertility. Farmers applied fertilizer as they perceived that the economic returns of the crop do not outweigh the risks associated with climate change. However, on the optimistic side, organic amendments are of great benefit and help in mitigating the effects of soil acidity on both soil ecosystem and crop productivity (Ding et al., 2020; Maitra & Gitari, 2020; Soratto et al., 2022; Xu et al., 2014).

Topdressing is key in ensuring good crop growth and productivity and is majorly done to ensure that the plants receive the required nutrients (Parecido et al., 2021). Hilli et al. (2009) in their research on *Luffa acutangula* reported that the application of NPK fertilizer improved the total number of fruits per vine, and shoot growth was greatly enhanced (Maragal et al., 2018). Supplying the correct amounts of nitrogen to plants helps to increase yields as its insufficiency results in reduced productivity and leaching if applied in excess (Rahimi et al., 2022; Waithaka et al., 2007). According to Xu et al. (2014) and Ding et al. (2020), the application of topdressing fertilizer should not be done next to plant roots to avoid crop scorching and its over-application raised nitrate levels above the normal groundwater standards resulting in leaching.

Inadequate fertilization results in reduced crop productivity (Mugo et al., 2021). The majority of the farmers in both wards applied fertilizers to their farms in inadequate recommended proportions, which was most likely to affect farm productivity. Most being small-scale farmers, mixed farming was their choice of farming hence different crops require different rates of fertilizer application which is not considered as farmers were only concerned with getting increased productivity. Under fertilization or excessive fertilization was noted by Mugo et al. (2020), Guo et al. (2010), and Tilman et al. (2011). Further, the authors noted that over-fertilization does not necessarily result in increased yields given that it might as well result in low nutrient use efficiency which can also negatively affect the environment in agroecosystems.

To increase potato production, an integrated approach is required in the management of diseases and pests which includes biological control, and the use of certified seeds which the majority reported not being able to access. Development of pest and diseases resistant varieties, organic composting, and crop rotation are also paramount in the improvement of soil quality. Pests such as the Colorado potato beetle (*Leptinotarsa decemlineata*) and the potato tuber moth (*Phthorimaea operculella*) were the most damaging pests noted in the field which can also be attributed to a reduction in potato yield production. Diseases noted during the study included the late blight (*Phytophthora infestans*) which is caused by water mold. It destroys both leaves, stems, and tubers. Bacterial Wilt and Potato blackleg are bacterial infections that caused several tubers to rot on the ground were also noted. Both pests and diseases contribute to low yield productivity.

Climate change was noted to be a challenge by a majority of the farmers, and it is likely to contribute to food insecurity. The two wards depend on two rainfall seasons which are short (mid-October–December) and long rainfall (March–June) according to the data obtained from Voi meteorological station. Total rainfall received for the long rainfall season was 203 and 363 mm for the short season which is more reliable for crop production. Rain onset was late in the first dekad of November which is in comparison to a normal onset in the third dekad of October. Both Werugha and Wusi-Kishamba wards received rain showers in late October which, however, did not meet the defined threshold warranting an onset. Cumulatively the area received an annual rainfall of 794 mm for the year 2020 which farmers report to have reduced over the years. Frequent intervals of a dry spell with occasional heavy rainfall during these seasons resulted in poor temporal distribution. Wundanyi and Mwatate sub-counties received rainfall in short rainfall with ranges of 111–125 and 91–110 mm, respectively, which also continued until January 2021. Werugha ward falls in a high altitude zone compared with Wusi-Kishamba, which is in a low altitude zone. Rain shortage has resulted in low agricultural productivity hence, posing a challenge to food security.

Soil is where life on the farm starts and provides the required nutrients to plants. It is made up of different layers and particles which are of importance for farmers' knowledge in enhancing crop productivity. Each soil type has its way of improving the soil for maximum yield productivity (Waithaka et al., 2007). Each soil type has unique characteristics and hence requires a different method to be employed to improve plant productivity (Waithaka et al., 2007). Different types of soils are adapted to the loss of nutrients differently especially after harvest, however, due to inadequate resources farmers have not considered this and continually replenish their soils with nutrients (Gitari et al., 2019). They also do not know the nutrient content of their soils or fertility status as their goal is to plant and to expect a harvest without taking note that soil productivity also contributes to good crop growth and development.

Gitari et al. (2020) in their study to assess phosphorus efficacy in potatoes reported combining fertilizers and manure increases the soil carbon content, soil's total nitrogen content as well NPK availability for plant uptake. The majority of farmers in the wards combined manure and fertilizer application to achieve higher productivity. However, nutrient integration and availability of manure posed a challenge in nutrient management hence fertilizer equivalents nutrients from manure can range from 0% to 100% in the application period (Gitari et al., 2018; Gitari, Karanja, et al., 2018). To be able to utilize sources effectively, manures' nutrient availability needs to be analyzed before being applied. High-rate application of manure for long period resulted in the tippling of soil organic carbon which also led to a loss of nitrate at the highest rate compared to fertilization without the use of manure. Fertilization was noted to raise soil carbon but not to increase the loss of nitrate hence enhancing crop productivity (Gitari et al., 2018; Mugo et al., 2021; Nyawade et al., 2019b; Sanchez, 2015).

To ensure good crop productivity and also soil fertility maintenance, both soil and crops must be treated with the slurry application at a recommended rate of 5 t ha$^{-1}$ in dry farming and 10 to 20 t ha$^{-1}$ in irrigated areas to ensure significant yield increase (Gurung, 1998; Warnars, 2012). Few farmers in both wards (18%) embraced the use of slurry not only to increase crop productivity but also to maintain soil fertility status. Gurung (1998) noted that bioslurry increases crop productivity by 25%. Averagely, 65% responded that they combined the application of bioslurry with other fertilizers to double up their crop productivity to achieve high profits with only 35% responding that combined application gave a synergistic production of nutrients to plants as compared to when singly applied. The result of this study concurs with the findings of Shahabz (2011) reported an increased yield production by 25% and also an improvement of soil pH following the use of slurry on *Hibiscus esculetus*. In addition, the author reported that a combination of bioslurry with fertilizer showed a positive contribution in the soil of available nitrogen and potassium which are the plant's essential nutrients for growth and development.

## 5 | CONCLUSIONS AND RECOMMENDATIONS

Access to extension services helps to equip the farmer with adequate knowledge of crop and soil productivity hence boosting their crop production. As such, in this study, the use of bioslurry has not been well adopted by farmers from the two wards as the majority relied on chemical fertilizers and other forms of manure such as farmyard manure. Therefore, capacity-building programmes and agricultural extension services are recommended to ensure adequate knowledge use and adoption of bioslurry by smallholder farmers in the management of soil fertility and enhancing crop productivity.

## CONFLICT OF INTEREST

The co-authors have no competing interests to declare with respect to the current study.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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