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Response of potato to different soils and fecal matter fertilizers

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Potato (*Solanum tuberosum* L.) is an important food and cash crop in Kenya. However, its production has declined over the years due to extensive nutrient mining without adequate replacement. A study was conducted to evaluate the response of potato grown under three soil types (Planosol, Andosol and Acrisol) using three fecal matter fertilizers (FMFs). This included vermicompost, normal compost and dried sludge. In addition, common fertilizer (urea and cow manure) was also used. Two greenhouse trials were laid out in a randomized complete block design with four replicates per treatment. Data collected on soil nutrient status, plant growth and yield variables were subjected to analysis of variance using Statistical Analysis Software v.9.1 and treatment means separated using Tukey's test. Results showed that fecal matter fertilizers (FMF) , vermicompost and dried sludge, were equally effective in increasing (39.2-46.5%) the potato growth compared to untreated control. Fecal matter fertilizers also contributed to high yields, where vermicompost produced (12.3 t ha^{-1}) 3 times more than untreated control (4.2 t ha^{-1}) but the difference was not significant at P≤0.05 from urea, normal compost and sludge. The interaction between fertilizers and soil types was not significant at P≤0.05. Fecal matter fertilizers are thus ecologically viable alternative source of mineral nutrients for sustainable potato production.

Key words: Acrisol, andosol, planosol, *Solanum tuberosum,* sludge, vermicompost.

INTRODUCTION

Potato is the second most important food and cash crop after maize in Kenya. It is grown both as a horticultural crop and a food security crop. In Kenya, potato plays an important role as a food staple among small scale farmers and also contributes to poverty alleviation through income generation. Approximately one million farmers grow potato in Kenya, while over 2.5 million Kenyans are employed along the potato value chain either directly or indirectly (Okello et al., 2017). Most farmers in Kenya dedicate more than a third of their arable land to the crop (Peter et al., 2009). Despite its importance, potato production is constrained by soil degradation, lack of quality seeds, as well as pest and disease management among other factors (Were et al.,

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2013).

Soil fertility and crop management practices are not only key components of sustainable crop production in potato based cropping systems but also decisive factors for increased productivity and crop quality (Scott et al., 2000). Soil fertility management also stimulates microbial soil life and decomposition processes, which in turn reduce the incidence of soil and seed borne diseases such as bacterial wilt. According to Amon et al. (2014), degradation of the soil causes up to 8% decline in potato yields. Apart from soil degradation, rainfall is the only source of water for potato production in Kenya, hence the main source of variations in yields. It is possible that the problem of low soil pH has led to imbalances in nutrient content leading to further decline of potato yields (Janssens et al., 2013). The Fecal matter fertilizers (FMFs) can be used to replenish nutrients in the soil since they contain up to 0.7% N (Nitrogen) as a percentage of wet weight (Rose et al., 2015) which is about 5 to 11 g per day (Hakan et al., 2015); where waste water from sludge has been used for irrigation it raised N, P, and K contents in potato plants and tubers. Irrigation by wastewater could reduce the fertilizer requirement of potato by 10-15%. About 11% N, 25% P (Phosphorous) and 21% K (Potassium) can also be recycled from feces (Vinnerås et al., 2006). Furthermore, approximately 80% of N, 50% of P and nearly 60% of K are found in household waste water, which can be recycled so that these nutrients can be availed for crop use. The objective of this study is to evaluate the effect of fecal matter fertilizers on potato crop grown under different soil types, Andosols, Planosols and Acrisols.

The selected soils are the major three soil types found in abundance in Nakuru County (FAO, 2006). Acrisols are soils that originate from variety of parent materials ranging from weathering of acid rocks for highly weathered clays that are undergoing further degradation and are usually found in old land surfaces that are hilly with natural vegetation. Andosol originate from volcanic glasses or other silicate-rich material and is dominant in undulating to mountainous, humid, and arctic to tropical regions with an extensive range of different vegetation. Finally, Planosols are soils that have a coarse-textured surface horizon with a finer textured subsoil that are prone to logging in flat lands formed from clayey alluvial and colluvial deposits. Furthermore, they contain light forest or grass Vegetation (Jaetzold et al., 1982). This research is aimed at using feacal matter fertilizers (FMFs) to help in making these soils productive by improving their physical, chemical and biological properties.

MATERIALS AND METHODS

Greenhouse experiments were set up at the Domestic Water Treatment Plant (0°19'22"N and 36°3'46"E) of Nakuru Water and Sanitation Services Company (NAWASSCO) located in Nakuru National Park, Kenya. The site lies in Lower Highland III (LH_3) Agro Ecological Zone with an altitude of 1850 m.a.s.l (Jaetzold et al., 2012). The average maximum and minimum temperatures range from 19 to 22 and 5 to 8°C, respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well drained, deep to very deep dark brown to grayish brown friable and smeary clay loam, with thick humic topsoil (Mollic Andosols) (Mainuri and Owino, 2013).

Preparation of fecal matter based fertilizer products

Composting materials (composite market waste) were collected from the Municipal Market, Nakuru town and NAWASSCO waste water treatment plant (sludge). Proper sorting was done to ensure only degradable materials were composted and coarse/ large materials like banana stalks were chopped into smaller pieces. The pieces were then placed in the in wooden boxes and mixed in the ratio of 3:1 (market waste: sludge) in the greenhouse. For normal compost, the materials were allowed to compost for 5 months with weekly turning and addition of water as maintenance practices. On the other hand vermicompost, worms were introduced after one month and favorable conditions (Temperature: 15-25°C, Moisture: 75% and pH: 5.7) for their survival maintained. Finally, the vermicompost was maintained in aerobic environment. Dry sludge was prepared by sun drying the sludge directly on drying beds lined with black plastic sheet in a greenhouse at 40-60°C for one month.

Collection and characterization of test soils

Three different soils, representing Planosol, Acrisol and Andosol, were collected from Nessuit (Latitude: -0°23'25.99"S, Longitude: 35°52'52.32"E), Egerton University (Latitude: 0°22'11.0"S, Longitude: 35°55'58.0"E) and Molo (Latitude: 0.2488°S, Longitude: 35.7324°E), respectively in Nakuru County, Kenya. The soils used are the dominant soils in Nakuru County and some parts of the central Highlands of Kenya where potato crop is extensively grown. The sites where the soils were collected were cleared to remove vegetation cover and the soils were dug to a depth of 30 cm. Each soil sample comprised of a combination of the top soil and the subsoil. The soils were then put into sample bags (size: 240 kg soil) per soil type and was enough for the entire experiment. Characterization of the soil was partly done in the field and the laboratory where samples were taken for analysis to determine the physical and chemical properties. The properties analyzed were pH (electrometric), N (Kjeidahl), P (Mehlich), K (Flame photometer) and bulk density (core).

Nitrogen (Kjeldahl method)

A soil sample weighing 0.3 g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, Se and $CuSO_4$. The temperatures in the heating block was maintained at 360°C for two hours after which the samples were let to cool and transferred to 50 ml volumetric flasks and the volume made to the mark. It was then allowed to settle and 5ml of the aliquot was put in to the distillation bottle where 10ml of 40% NaOH was added. It was then steam distilled into 5ml 1% Boric acid containing 4 drops of mixed indicator for 2 min, from the time the indicator turned green. The distillate was titrated using HCl and the end point was reached when the indicator turned green through grey to definite pink. A blank experiment was prepared using the same procedure (Kirk, 1950).

Bulk density (Core method)

A core ring of 5 cm diameter with known weight (W1) and volume

Table 1. Chemical and physical properties (Mean ±SE) of three soil types.

Soil type	pH	Chemical properties			Physical property
		N (%)	P (mg/kg)	K (mg/kg)	BD (g cm^{-3})
Andosol	6.23±0.07	0.19±0.08	43.0±0.61	68.2±1.25	1.26±0.04
Planosol	6.72±0.1	0.23±0.03	35.0±0.64	62.4±1.02	1.37±0.62
Acrisol	5.75±0.21	0.36±0.02	58.0±0.82	93.5±1.28	1.24±0.07

N= Nitrogen, P= Phosphorus, K= Potassium; BD= Bulk density; Means in a column whose SE values do not overlap are significantly different at α=0.05 by Tukey's HSE test.

Table 2. Nutrient composition (Mean±SE) of test organic fertilizers.

Organic fertilizer	N (%)	P (%)	K (%)
Vermicompost	2.3±0.07	0.4±0.02	0.4±0.06
Normal compost	1.8±0.24	0.3±0.12	0.4±0.03
Sludge	1.5±0.07	0.2±0.04	0.2±0.04
Cow manure	0.6±0.15	0.3±0.08	0.4±0.08

N= Nitrogen, P= Phosphorus, K= Potassium; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSE test.

(V) was inserted 5cm in the soil. It was the removed from the soil and soil around the core was wiped and trimmed at the bottom and top using a knife. They were then placed in an oven at 105°C for 2 days after which they were allowed to cool and weighed (W2).

Potassium

A soil sample weighing 0.3 g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, HF and $H_3 BO_3$. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50 ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analysed using Varian spectra AA10 AAS machine.

Phosphorous

0.3 g sample was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, Se and $CuSO_4$. The temperatures in the heating block maintained at 360°C for two hours after which the samples were let to cool and transferred to 50ml volumetric flasks and volume made to the mark. 5 ml of the aliquot was transferred in to the sample bottles with 1 ml of developing colour solution (Ammonium Vanadate and Ammonium Molybdate in the ratio of 1:1). The samples were left to stand for 30 min after which they were transferred to cuvates. Readings (absorbance) were taken using a spectrophotometer at 430 wavelength. Calibration was done using certified standards. The chemical composition of the soils used in the study are presented in Table 1 while the nutrient composition of the FMFs are presented in Table 2.

Experimental design and layout

Two pot experiments were conducted in a plastic greenhouse. The plastic containers (pots), with a size of 10 l, were filled with 10 kg of soil each and a total of 18 pots randomized per block in 4 blocks. The treatments were set up in a Randomized Complete Block Design (RCBD) with factorial arrangement of two factors, soil type and fecal matter fertilizers. The treatments included three levels of soil types (Acrisol, Andosol and Planosol) and three fecal matter fertilizers (vermicompost, normal compost and sludge) and positive inorganic fertilizer control, urea and organic fertilizer cow manure, replicated four times and arranged 30 cm between the pots and 75 cm between the blocks .

Crop establishment

Healthy and sprouted seed potato tubers were sliced into pieces each weighing 25 to 30 g and having 2 to 3 eyes (buds). Every pot was planted with one sliced piece of tuber at a depth of 5 cm. The various amendments were applied at different rates as follows: vermicompost, 3.9 t/ha; normal compost, 4.9 t/ha; Urea, 0.2 t/ha; dried sludge, 6 t/ha; and cow manure 15 t/ha.

Data collection

Data were collected on a weekly basis for four weeks after germination on growth variables. The number of branches was determined by counting well-developed branches with leaves. Plant height measurements (cm) were taken from the base of each crop to the top of the main plant stem using a ruler. Numbers of leaves were counted on well-developed branches and yield was obtained by weighing (grams) the tubers using electronic balance (SF-400) and later converted to t ha^{-1}.

Data analysis

Data were subjected to analysis of variance (ANOVA) using Proc GLM, SAS software v.9.1 (*SAS INC*., 2001). Where ANOVA revealed existence of significant differences among treatments, means were separated using Tukey's HSD test at P≤0.05.

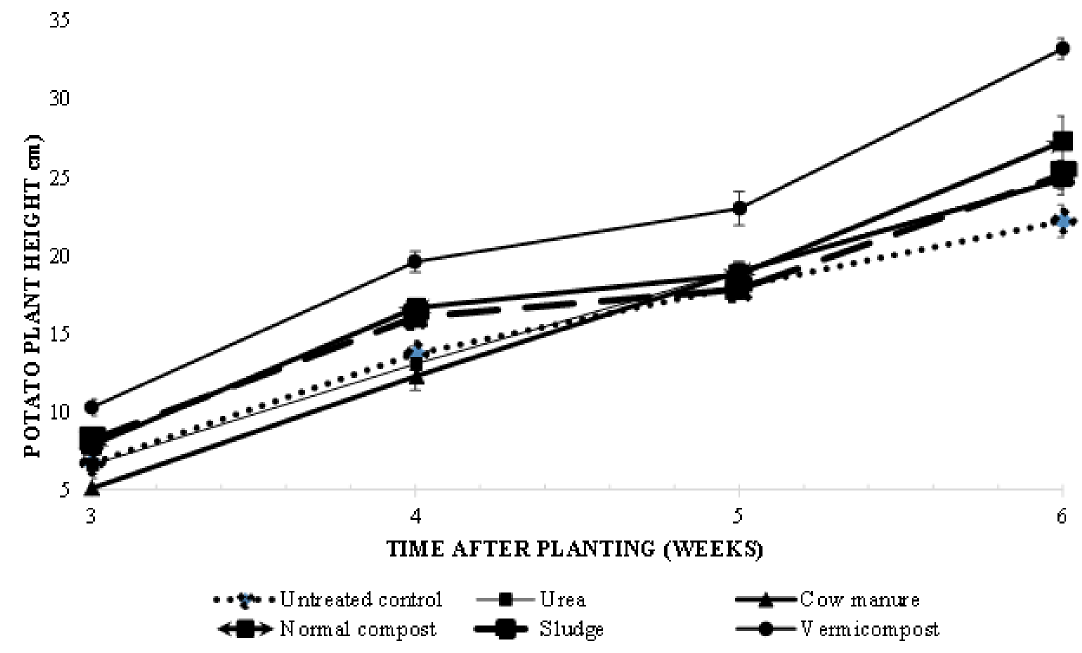

Figure 1. Potato plant height (Mean ± SE) response to fecal matter fertilizer under Andosols.

RESULTS AND DISCUSSION

Effect of fecal matter fertilizers (FMFs) on potato height

Under Andosol soil, results showed that vermicompost produced significantly ($P \leq 0.05$) better potato height response compared to other fertilizers at all the growth stages. The potato crop had same level of height response to normal compost and sludge at all growth stages. The other treatments, urea, cow manure and untreated control equally produced the lowest height response and there were no differences during the period of week 3, 4 and 5 (Figure 1).

According to figures obtained from Planosol, however, vermicompost, normal compost, cow manure and urea treatments were different during week 3, 5 and 6. Untreated control had the lowest performance in all the growth stages (Figure 2). The FMFs produced comparable height responses under Acrisol soil in which sludge, urea and vermicompost recording equally taller plants at all the growth stages. The latter fertilizers produced results that were superior to cow manure, normal compost, and untreated control (Figure 3). FMFs vermicompost, normal compost and sludge were able to supply enough nitrogen that contributed significantly to potato plant height under Andosol and Acrisol. This is because they have the benefit of being slower-acting and gentler than urea as a chemical fertilizer. These products were in a form which did not allow them to be absorbed immediately by plants but had to be broken down first by soil bacteria and fungi into forms that plants can absorb which is in agreement with the findings of Borah et al. (2007). This means that, unlike in inorganic fertilizer, they were not easily leached, and that the potato crop got the benefit of nutrients for growth more evenly over a period of time during the vegetative stage. When it came to Planosol, the response was low; although the performance of sludge, vermicompost, cow manure and urea had no significant difference in week 3, 5 and 6. This is attributed to the soil characteristic of Planosol that restricts root development, thus low water and nutrient absorption.

Effect of FMF on a number of branches and leaves of potato

Results showed clear plant age-dependent increase in a number of branches and leaves in response to fecal matter fertilizers application. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications in a potato crop, under the Andosol soil, produced significantly ($P \leq 0.05$) 5.8 to 24.0% more number of branches compared to the untreated control. Similarly potato grown under Acrisol produced 22.6 to 38.7% number of branches more compared to the untreated control (Table 3). The cow manure, urea and the untreated control equally recorded the lowest number of branches and leaves over the growth period. Furthermore, results showed significant ($P \leq 0.05$) age and soil type-dependent response of a number of plant

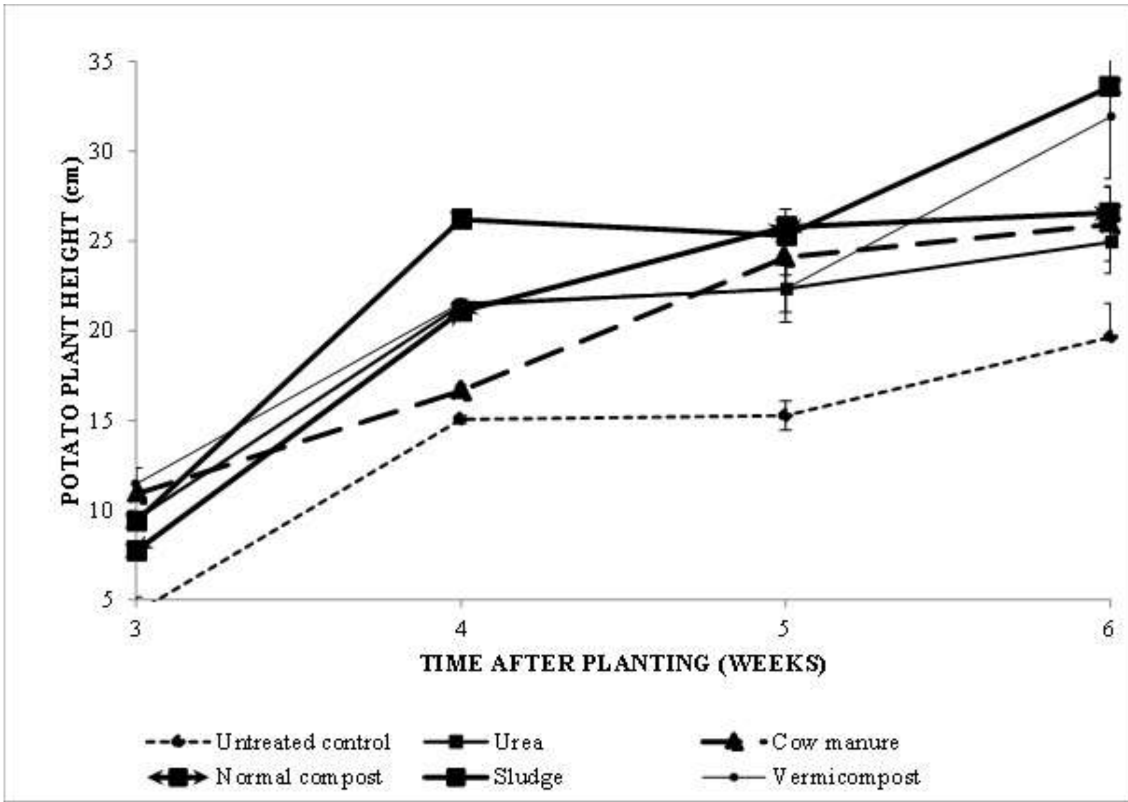

Figure 2. Potato plant height (Mean ± SD) response to fecal matter fertilizer under planosol.

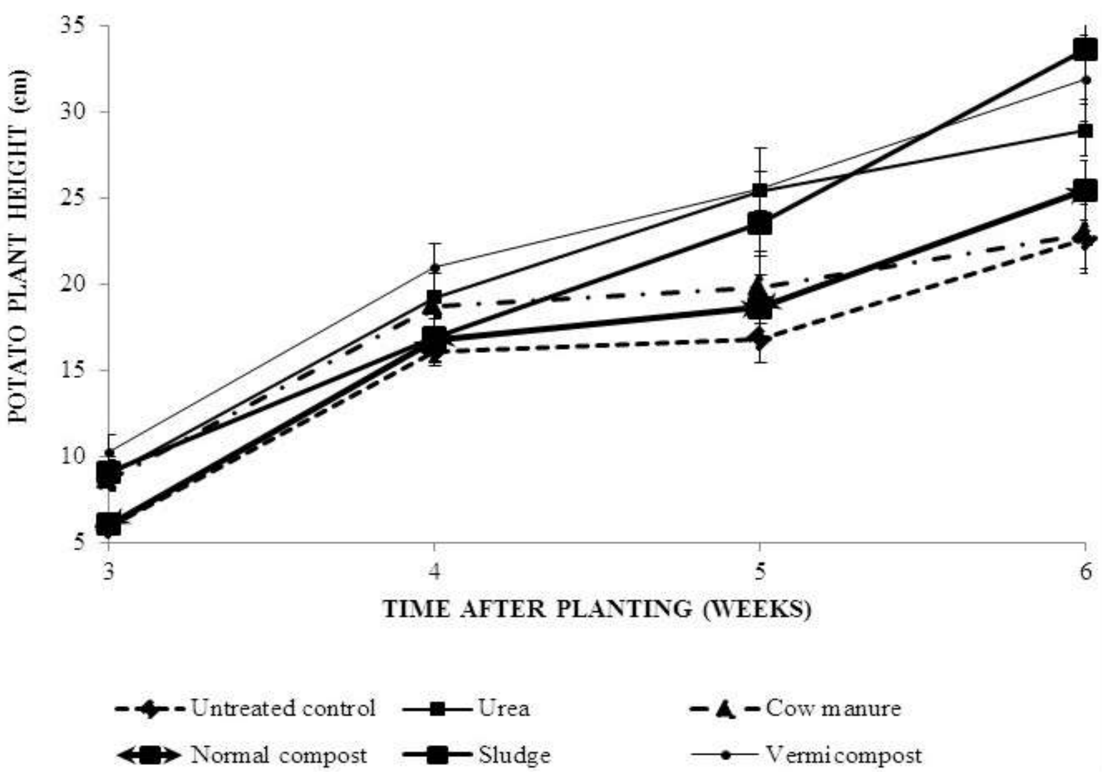

Figure 3. Potato plant height (Mean ± SD) response to fecal matter fertilizer under acrisol.

Table 3. Growth response of potato to faecal matter fertilizers under different soil types.

WAP fertilizers	Andosols		Planosols		Acrisol	
	NB	NL	NB	NL	NB	NL
Untreated control	2.9±0.1	10.7±0.9	4.6±0.4	9.9±0.4	3.0±0.6	13.4±0.3
Urea	3.5±0.7	19.0±0.3	3.3±0.3	26.3±0.6	3.0±0.0	18.8±0.7
Cow manure	4.0±0.0	12.0±1.0	3±0.1	20.8±0.5	3.5±0.4	17.4±0.6
Normal compost	5.0±0.1	17.6±0.1	3.5±0.1	19.8±0.4	4.0±0.0	19.3±0.7
Sludge	4.3±0.2	22.6±0.2	4.3±0.5	17±0.3	4.0±0.4	17.2±0.5
Vermicompost	5.3±0.3	19.5±0.6	4 ±0.0	17.5±0.4	4.3±0.1	17.0±0.6
Untreated control	4.4±0.1	34.7±0.5	5.2±0.4	30.0±0.3	3.6±0.3	36.2±0.5
Urea	5±1.8	34.0±0.6	4.7±0.6	53.5±0.2	6.0±0.3	57.5±0.4
Cow manure	4.3±0.2	34.5±1.3	4.5±0.3	57.2±0.6	3.7±0.3	57.8±0.6
Normal compost	6.7±0.1	64.3±0.8	6.0±0.4	50.0±0.5	5.7±0.5	55.0±0.6
Sludge	5.3±0.4	62.3±0.8	5.4±0.8	53.5±1.2	5.0±0.1	53.1±0.4
Vermicompost	6.3±0.3	51.5±0.8	6.0±0.4	61.7±0.4	6.3±0.1	50.0±0.4
Untreated control	8.7±0.1	46.9±0.54	7.5±0.1	43.9±0.4	6.7±0.4	67.3±0.5
Urea	6.7±1.8	54.3±0.7	9.3±0.2	79.2±0.8	8.7±0.2	74.4±0.8
Cow manure	6.3±0.5	54.5±1.1	8±0.01	87.8±1.0	7.0±0.4	80.2±0.3
Normal compost	10.7±0.4	69.5±0.6	9.5±0.1	83.6±1.0	9.3±0.3	86.0±1.2
Sludge	8.3±0.1	62.3±0.6	7.5±1.9	65.5±0.8	9.3±1	76.8±0.8
Vermicompost	10.8±0.1	68.2±0.6	10.3±0.1	69±0.7	10.5±0.3	96.2±0.6
Untreated control	10.4±0.1	51.6±0.77	12.6±0.1	46.6±0.7	10.6±0.1	67.8±0.6
Urea	11.8±0.5	60.8±0.4	13.7±0.4	83.3±0.6	14.3±0.3	84±0.6
Cow manure	11.8±0.1	61.8±0.4	9.3±0.6	88±0.4	11.3±0.2	88.5±1.2
Normal compost	12.7±0.4	71±0.3	12.0±0.3	94±0.8	14.7±0.1	86±0.9
Sludge	11±0.4	66.5±0.3	12.6±1.6	72.9±0.7	13.0±0.6	79.4±0.7
Vermicompost	12.9±0.3	68.2±0.4	13±0.8	75.5±0.7	13.5±0.1	101±0.6

NB = Number of branches, NL= Number of leaves, WAP= Weeks after planting; Means in a column whose SE values do not overlap are significantly different at P≤0.05 by Tukey's HSD test.

leaves. At the end-point response, 6 WAP, the normal compost, sludge and vermicompost fertilizer applications produced 28.9-37.6, 56.4-101.8 and 30.5-49.0% more potato leaves under Andosol, Planosol and Acrisol, respectively (Table 3).

For number of branches, the two composts had same ability to supply nitrogen throughout the growth stages and their performance was way better than the other fertilizers applied under Andosol. Andosols are soils that have been cultivated for long and their nutrients have been depleted, especially the level of N, as shown in Table 1. When compost is applied, it improves the soil physical and chemical properties that enabled the fertilizers applied to supply the needed nitrogen to the crop as shown in Table 3. The situation was different under Planosol where low potato response was recorded due to high bulk density (1.37±0.072 g cm^{-3}) across the growth stages (Table 3). Such soils with high bulk density restricted root growth as it increased compaction; thus the crop was not able to absorb water and nutrients from the soil and also tuber growth was limited. This is in agreement with the findings in (Usman et al., 2015). Under Acrisol, the best performance was observed where urea, vermicompost and sludge were applied. This type of soil has properties that favor good water and nutrient absorption and as a result, there was extensive root development. The contribution of cow manure to potato nitrogen supply was limited when compared to FMFs. This is probably due to the slow rate at which cow manure releases nutrients. This is consistent with the findings of Souza et al. (2008), that slower nutrient releasing organic fertilizers hinder growth and production of potato.

For a number of leaves, the performance of all the fertilizers was more or less the same with no significant difference in week 3 under Andosol. This may be due to the stage of the crops where they did not have well developed roots that could absorb nutrients and also the

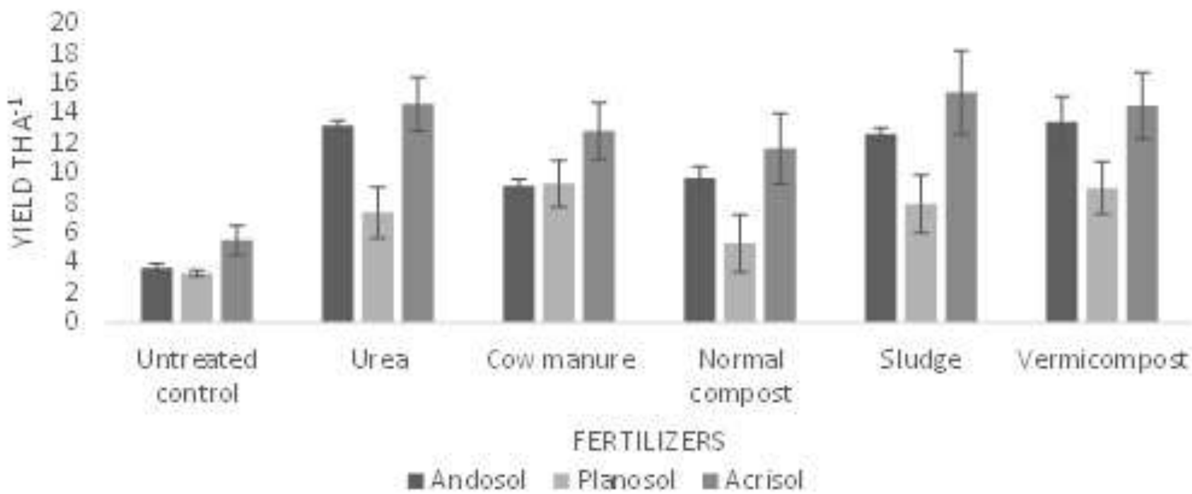

Figure 4. Potato yield (t ha^{-1} Mean ± SD) under different soil types and fecal matter fertilizer application.

products applied. The subsequent weeks exhibited positive response where vermicompost, sludge and normal compost interaction with all the soil types was high as shown in week 4, 5 and 6. This is because vermicompost had two characteristics that favored crop growth; first it had been broken down by worms making it finer and the increase in nutrient content. It is also in organic form, thus it boosts the soil physical properties. Andosols are always fertile soils, but if leached the levels of nutrients decline; consequently leading to use of organic fertilizers. This in line with findings filed in FAO report (2014). There was no significant difference between all the fertilizers across all the growth stages. This means that all the fertilizers applied had same ability to supply nitrogen for vegetative growth.

Effect of FMF on potato yield

Results showed significant ($P \leq 0.05$) FMFs and soil type-dependent potato yield responses (Figure 4). Sludge and vermicompost applications equally produced the highest potato yield of 15.4 t ha^{-1} and 14.5 t ha^{-1} under Acrisol soils respectively. These yield levels were comparable to the positive control, urea. Potato crop had the lowest yield response to the different FMFs under the Planosol soils. There was insignificant soil type by FMF interaction effect on potato crop yield. The effect of FMF was felt on yield where fertilizer applied was significant at $P \leq 0.05$. The chemical properties of the products applied contributed greatly to increased yield. Vermicompost recorded highest yields of 15.5 t ha^{-1} under Acrisol but the difference was not significant from sludge, urea and cow manure. Acrisols have low levels of nutrients in general, so any addition of nutrients will give a positive response. In this case, acrisols had the highest content of K (93.5 mg/kg) and also N (0.36%). Though acrisols have the ability to fix P, this may have been compensated by substantial amounts in the soil, which may have been taken up by the plant. The low yields from planosols could be attributed to the low nutrient status and poor aeration due to its high clay content. This may have restricted root development. The differences noted among soils were directly proportional to the results obtained from the characterization of the soils in terms of N, P, K and bulk density level. Acrisol had the best properties which meant that it had more ability in making available the nutrients for root absorption. This is explained by the fact that application of nutrients in the soil does not guarantee availability of the same nutrients to the crop due to some processes taking place such as phosphorous fixation. For example, andosols have a tendency to fix phosphorous; any addition from the amendments may be partially fixed in the soil. Suitable soil properties like bulk density of 1 to 1.3g cm^{-3} ensure better tuber formation in the soil, while a high bulk density restricts tuber formation through compaction leading to low yields. These results are in line with the findings of Amara and Mourad (2013).

Among the FMFs, it is evident that vermicompost promoted plant growth and production by 30% more than chemical fertilizers which is in agreement with the findings of Sinha et al., (2010) who found that the use of vermicopmost in production of wheat and corn crops promoted growth by 30 -40% higher as compared to chemical fertilizers. This result may be due to the provision of organic matter by vermicompost to the soil, which helped with the retention of water and nutrients for a healthy root system. Vermicompost has been found to be more superior in protecting the soil and promoting crop growth than any other organic material (Munroe, 2007). The difference in performance demonstrated variation in their capability to constantly supply the required nutrient quantity which they contain when necessary, as shown in Table 2. The effect of interaction between soil types and fertilizers was not significantly different at P≤0.05. This shows that both soil types and fertilizers acted independently to some extent.

Conclusions

Treated Fecal matter fertilizers are an important source of plant nutrients when used in crop production. They improved growth parameters and yield three times more than the untreated control. The performance was also better than cow manure. Potato crop showed positive response to these products particularly vermicompost and their performance was similar to that observed with commonly used inorganic fertilizer urea.

Acrisols amended with sludge had the highest potato yield closely followed by amendment with vermicompost on the same soil. However, planosols had the least potato yield irrespective of the FMFs added.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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