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Availability of Nitrogen, Microbial Respiration and Bulk Density as Influenced by Faecal Matter Fertiliser in Acrisol, Andosol and Planosol

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Abstract

Crop production in Kenya has declined over the years due to nutrient mining leading to food insecurity. This research aimed at using faecal matter fertilizers as a source of Nitrogen (N) and its effect on other desirable characteristics like bulk density, soil organic carbon (SOC) in the soil. Also the ability of different types of soils to make N available for absorption by potato roots in response to application of the fertilizers was studied using Potato (*Solanum tuberosum* L.) as test crop. A greenhouse pot experiment was set up at Nakuru Water And Sanitation Services Company domestic treatment site in Nakuru County. It was in completely randomized block design, factorial arrangement with two factors: five fertilizers types (vermi compost, sludge, normal compost, cow manure and urea) and three soil types (Acrisol, Planosol and Andosol). Potato tissues were analysed for total nitrogen while soil samples were analysed for available Nitrogen, CO_2 emission (microbial respiration), organic carbon and bulk density. Results obtained showed considerable performance of feacal matter fertilizers where the level of N were significantly different at α=0.05. The three soil types had levels of N, CO_2, organic carbon significantly different. The significant levels of N in potato tissue and soil after application of fecal matter fertilizers makes these products important sources of plant nutrients and contributors to desired soil chemical, physical and biological characteristics.

Keywords

Faecal; Microbial respiration; Mining; Potato; Compost; Andosol; Acrisol; Planosol

Introduction

The soils in Nakuru region have been cultivated over years accompanied with inadequate replenishment leading to concerns raised on over reliance on inorganic fertilisers. This has affected not only biological aspect of soil but also physical and chemical properties [1]. Organic fertilisers are important in improving soil characteristics and achieving high crop yields [2]. Their addition to manage the current trend of soil physical, chemical and biological degradation has been recommended [3]. Therefore, there is need to use more of organic fertilisers and bio-fertilisers to strike a balance and limit nutrient mining. Uneven use of inorganic fertiliser in farms is amongst the inappropriate agricultural practices that have steered to primary soil degradation together with other practices like pesticide overuse, poor irrigation and use of dense machinery [4]. The soil physical properties affected directly or indirectly by organic fertilisers are aggregate stability, water holding capacity, porosity, infiltration rate, hydraulic conductivity and bulk density [5]. Level of soil bulk density is dependent on organic matter content, the texture of soils, constituent minerals and porosity. Soil bulk density is an important parameter for soil management as it is important in soil compaction. Increase in soil organic matter decreases bulk density of a soil. On the other hand, increase in organic matter also leads to change in nutrient concentration in the soil. This indicates that available nutrients in soil may play an important role in variation of bulk density of a soil. To achieve suitable soil properties, combined use of organic and inorganic fertilisers is encouraged [6]. The biological aspect of the soil helps in plant nutrition symbiosis with plants (N fixing bacteria and root mycorrhizae). Nutrients distribution (N, P, K, micronutrient) directly in plant roots depend on living soil microorganisms break down of organic matter that releases available forms of nutrients for the plants (ions). Organic fertilisers are also important sources of energy for soil ecology and nutrients for microorganisms and growing plants [7]. Use of organic fertilisers encourages macro and micro fauna activities in the soil that leads to soil acidity tolerance until pH<5, processing plant residues, forming water stable soil aggregates and incorporates organic matter in soil. It also enriches topsoil with nutrients and humus, cultivating soil by creating channels, facilitating drainage, and allowing roots to explore and grow deeper [8].

The major three soil types found in abundance in Nakuru County are Acrisol, Andosol and Planosol [9]. 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 [10]. This research 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

Site description

Greenhouse experiments were set up at the Domestic Water Treatment Plant of Nakuru Water And Sanitation Services Company (NAWASSCO) located in Nakuru National Park, Kenya. The site lies at 0°19'22"N and 36°3'46"E and in Lower Highland III Agro Ecological Zone (LH3) with an altitude of 1850 meters above sea level [11]. Average maximum and minimum temperatures ranges from 19 to 22°C and 5 to 8°C respectively. The annual rainfall ranges from 800 to 900 mm and the soils are predominantly well-drained, very deep dark brown to grayish brown friable and smeary clay loam, with thick humic topsoil (Mollic Andosols) [9].

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Preparation of faecal matter fertilisers (FMFs)

Composting materials (composite market waste) collected from the Municipal Market, Nakuru town and NAWASSCO wastewater treatment plant (sludge). Proper sorting done to ensure only degradable materials were composted and coarse / large materials like banana stalks chopped into smaller pieces. The choppings were then placed in wooden boxes and mixed in the ratio of 3:1 (market waste: sludge) in the greenhouse. For normal compost, the materials were let to compost for 5 months with weekly turning and addition of water as maintenance practices. For 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 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.

Soil collection and characterization

Three different soils, 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 sites where the soils were collected clearance was done 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 put into bags of 90 kg with a total of 240 kg per soil type that was enough for the entire experiment. Characterization of the soil was partly done in the field, while the rest of the analysis (physical and chemical was done in the laboratory a shown below in Tables 1 and 2.

Experimental design and layout

Two pot experiments were conducted in a plastic greenhouse. The pots used were 10 liter plastic containers which were filled with 10 kg of soil each and a total of 18 pots per block, and a total of four blocks. The experimental design was randomized complete block design in factorial arrangement with two factors (soil type and fertilizer that included fecal matter products). The treatments included three levels of soil types (Acrisol, Andosol and Planosol) five levels of fertilizer products (cow manure, vermicompost, normal compost, dried sludge and urea) replicated four times and arranged in a spacing of 30cm by 75 cm.

Table 1: Level of N, P, K and bulk density in the soils.

Soil Type	pH	Chemical properties		Physical property	
		N (%)	P (mg kg^{-1})	K (mg kg^{-1})	BD (g cm^{-3})
Andosol	6.23 ± 0.18	0.19 ± 0.033	43.0 ± 4.03	68.2 ± 10.31	1.26 ± 0.044
Planosol	6.72 ± 0.25	0.23 ± 0.015	35.0 ± 3.78	62.4 ± 8.06	1.37 ± 0.072
Acrisol	5.75 ± 0.51	0.36 ± 0.009	58.0 ± 6.22	93.5 ± 12.33	1.24 ± 0.077

[Note: N= Nitrogen and P= Phosphorus, K= Potassium, Means in a column whose SD values do not overlap are significantly different at α =0.05.]

Table 2: The concentration levels of N, P and K in the selected soil amendments.

Organic fertilizer	N (%)	P (%)	K (%)
Vermicompost	2.3 ± 0.11	0.4 ± 0.13	0.4 ± 0.04
Normal compost	1.8 ± 0.32	0.3 ± 0.07	0.4 ± 0.02
Sludge	1.5 ± 0.09	0.2 ± 0.02	0.2 ± 0.02
Cow manure	0.6 ± 0.1	0.3 ± 0.04	0.4 ± 0.05

[Note: N= Nitrogen and P= Phosphorus, K= Potassium, Means in a column whose SD values do not overlap are significantly different at α =0.05.]

Crop establishment

Healthy and sprouted seed potato tubers sliced into pieces each weighing 25 to 30 g and having two to three eyes (buds). Every pot planted with one sliced piece of tuber at a depth of five cm. The fertilizers applied in the rate of 3.9, 4.9, 15, 0.2 and 6 t ha^{-1} for vermicompost, normal compost, cow manure, urea and dried sludge, respectively. The faecal matter fertilizer product was applied to supply 90 kg N ha^{-1} and P was standardized at 103 kg P ha^{-1}. The crops were irrigated at the rate of one liter of water per pot per day. The crop was under intensive care and there was no disease incidence.

Soil sample collection and preparation for soil N analysis

Soil samples were taken from each pot (100g) and were put in khaki bags. Each bag labeled accordingly then transported to the laboratory the same day. In the laboratory, the samples were air dried for 1 week after which they were crashed sieved using 2.00 mm sieve.

Tissue sample collection and preparation for soil N analysis

The tissues were sampled at early bloom stage of potato growth, they were put in khaki bags labeled and transported to the lab where they were cleaned with distilled water. They were then oven dried for 2 days and crashed.

Analysis of soil samples

Nitrogen (Kjeldahl method) [12].

Bulk density (Core method)

A core ring of 5 cm diameter with known weight (W1) and volume (V) was inserted 5cm in the soil. It was then removed from the soil and soil around the core was wiped and trimmed from the bottom and top using a knife. They were then put in an oven at 105°C for 2 days after which they were allowed to cool and weighed (W2).

Microbial respiration (CO_2 evolution)

100 g of soil was weighed and put in to conical flask and 25 ml of distilled water added, stirred using a stirring rod. 15 ml of NaOH was put in a universal bottle, which was inserted inside the conical flask with soil while making sure the NaOH does not spill in to the soil. The conical flask was tied at the top tightly to prevent CO_2 from being lost from the flask and CO_2 from outside to enter the flask. The flask was incubated for one week after which the universal bottle was removed and content transferred in to 250 ml conical flask. 1ml of $BaCl_2$ was added followed by 5-6 drops of phenolphthalein indicator and titrated using 1N HCl and the titer was recorded when colour changed from pink to colourless.

Soil organic carbon (Walkley and Black method) [13].

Analysis of potato tissue samples

Nitrogen (Kjeldahl method) [14].

Data analysis

Data were subjected to analysis of variance (ANOVA) using Proc GLM, SAS software v.9.1 (SAS INC., 2001). Where significant differences was realized, mean separation was done using Tukey's HSD test.

Table 3: Soil microbial respiration (CO_2 evolution) (Mean ± SD) in terms of CO_2 in kg ha^{-1} d^{-1} under different soil types and faecal matter fertiliser application.

Soil types			
Fertilisers	**Andosol**	**Planosol**	**Acrisol**
Untreated control	5.0 ± 0.9	3.2 ± 0.4	4.2 ± 0.5
Urea	6.1 ± 0.9	5.4 ± 0.8	5.6 ± 1.3
Cow manure	5.9 ± 1.8	5.0 ± 0.3	6.3 ± 1.6
Normal compost	5.0 ± 1.1	5.6 ± 1.3	5.9 ± 1.1
Sludge	6.9 ± 0.9	5.2 ± 0.1	6.9 ± 1.3
Vermicompost	6.2 ± 1.1	5.0 ± 0.7	5.6 ± 1.3

[**Note:** Means in a column whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test.]

Table 4: Total Nitrogen (%) (Mean ± SD) under different soil types and fecal matter fertiliser application.

Soil types			
Fertilisers	**Andosol**	**Planosol**	**Acrisol**
Untreated control	2.8 ± 0.5	2.1 ± 0.6	3.3 ± 0.5
Urea	3.8 ± 0.3	3.1 ± 0.7	4.1 ± 0.2
Cow manure	4.0 ± 0.8	3.0 ± 0.7	4.0 ± 0.3
Normal compost	3.9 ± 0.6	3.6 ± 0.3	3.9 ± 0.6
Sludge	3.7 ± 0.3	3.8 ± 0.4	4.3 ± 0.2
Vermicompost	4.2 ± 0.4	3.6 ± 0.3	4.5 ± 0.1

[Note: Means in a column whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test]

Results

Soil analysis

Nitrogen: There were significant differences at P ≤ 0.05 on soil response as influenced by fertilisers on N level as shown in Figure 1 although interaction between fertiliser and soil types, trial and block showed no significantly difference. Vermicompost had better performance but the difference was not significant with sludge and normal compost. Sludge, normal compost cow manure and urea also had no significant differences between their means. Untreated control recorded lowest level of Nitrogen in the soil.

The levels of Nitrogen concentration as shown in Figure 1 indicated that the fecal matter fertilizers had substantial amount of nutrients compared to cow manure. This may be due to the content of fecal matter that has both urine and solid faeces where urine is a rich source of Nitrogen. This is agreement with findings of [15,16]. Having substantial levels of Nitrogen in the soil after harvesting which was ≥ 0.24% shows that the soil was not left deficient. Untreated control had deficient N levels an indication of nutrient mining, which may have resulted due to lack of enough replenishment of the Nitrogen supplying fertiliser in the respective soils.

Bulk density: In bulk density the effect of fertiliser application, interaction between fertiliser and soil types, trial and block were not significantly different, but the soil types alone as independent variable had significant difference at P ≤ 0.05. Planosol had high bulk density followed by Andosol and Acrisol respectively although there was no significant difference between Andosol and Acrisol (Figure 2).

The characteristics of each soil type and the human activities on the site that soils were collected played an important role on this parameter. The values obtained were within normal range of 1.25 ± 0.049 gcm^{-3} to 1.46 ± 0.063 gcm^{-3}. Acrisol had low bulk density due high levels of organic matter compared to Planosol that had high mineral component with less organic matter. The bulk density did not change significantly

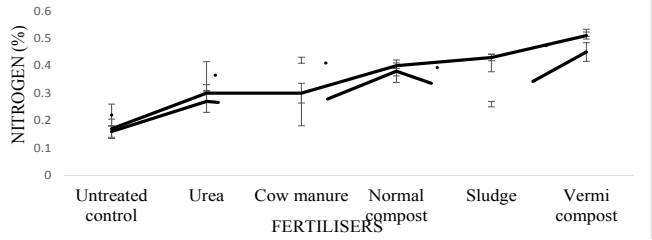

Figure 1: Soil % Nitrogen (mean ± SD) under different soil types and feacal matter fertiliser application.
[Note: Means in levels whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test].

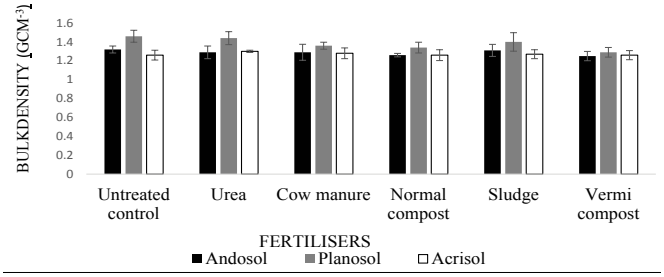

Figure 2: Soil bulk densities (Mean ± SD) under different soil types and fecal matter fertiliser application.
[Note: Means in levels whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test].

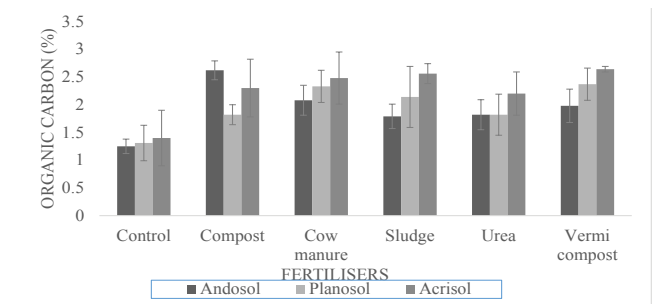

Figure 3: Soil organic carbon (Mean ± SD) under different soil types and fecal matter fertilizer application.
[Note: Means in levels whose SD values do not overlap are significantly different at P ≤ 0.05 by Tukey's HSD test].

during the two trials conducted. This is because the time that the experiment was done was not sufficient to influence bulk density. It is expected that addition of organic manures result in increased soil organic matter content. This in turn has shown to increase water holding capacity, porosity, infiltration capacity and a decrease in bulk density [17].

Soil microbial respiration: There were significant differences at P ≤ 0.05 on soil response as influenced by fertilisers and not soil types, interaction between them, trial and block in microbial respiration (CO2 evolution) as shown in Table 3. Sludge under Andosol and Acrisol had the highest evolution of 6.9 ± 0.9 and 6.9 ± 1.3 kg ha-1 d-1 respectively. There was no significant difference between urea and cow manure under Andosol and Acrisol. The lowest levels were recorded in untreated control under Planosol soil.

The level of CO_2 was high in faecal matter fertiliser products and cow manure since these products were organic and provided a substrate for the microorganisms to break down and feed on thus increasing microbial respiration. Fabrizio et al. [18] reported that when compost is used the level of microbial respiration increases thus increase in CO_2. Although the difference was not significant with inorganic fertiliser urea because it enhances vegetative growth that leads to increase in organic matter that intern act as substrate for microorganisms.

Soil organic carbon: The level of organic carbon in soil ranged from 1.3% in Andosol under control but the difference was not significant with Planosol and Acrisol under control. The highest level was 2.6% recorded in Andosol under normal compost but the difference was not significant with Acrisol under normal compost, Planosol and Acrisol under cow manure and Acrisol under sludge, urea and vermi compost..

The level of organic carbon in Andosol was 2.6% this was 2 times more when compared to same soil under control 1.3%. This shows that the compost from feacal matter waste being an organic waste can be an important source for maintaining a minimum level required organic carbon content in the soils. The contribution of other fertilizers like cow manure , sludge and urea was also evident but the properties of the soils involved contributed significantly to the levels of organic carbon as shown in (Figure 3). This study was able to depict the effect of land use in terms of different fertilizers application on soil organic carbon. The results were positive and in line with findings by [19-20].

Nitrogen in potato tissue: Tissues response to fertilizers and soil types were significantly different at $P \leq 0.05$ but the interaction between them, trial and block were not significantly different. All the fertilizers had no significant difference between them but significantly different from the untreated control as shown in Table 4.

The relationship between SOC and bulk density in Figure 4b was different from the one with microbial respiration. The relationship was a weak slope of R=-0.1778 and this was attributed to the less time that the fertilisers had to influence the relationship. For organic fertilisers to influence this relationship the experiment must have been more than the two trials conducted. A higher bulk density indicates more compactness in soil, resulting in less pore spaces and soil porosity, which leads to low organic carbon [21].

Nitrogen tissue analysis sludge, vermicompost, normal compost, urea and cow manure had Nitrogen levels that were not significantly different from each other. These demonstrated that the ability of feacal matter fertilizers to supply Nitrogen was comparable with the commonly used fertilizers urea and cow manure. The Nitrogen levels in the tissues were within sufficiency range in line with [22]. The soil type effect on Nitrogen levels in the tissues was significant at α=0.05 with Acrisol having high concentration although the difference was not significant with Andosol this is because these soils made N available in the soil which in turn led to high levels of Nitrogen in the tissues. Planosol had low level of N although it was not below the sufficient levels range of N in potato tissues.

Correlation between soil organic carbon and microbial respiration: The correlation coefficient R in (Figure 4a) between soil organic carbon and microbial respiration was moderately uphill with a figure of R=0.5879. In Figure 4b, the correlation between bulk density and soil organic carbon was a weak downhill with R= -0.1778.

The relationship between soil organic carbon and microbial biomass is directly proportional but from the results R=0.5879 shows a moderately positive correlation. This is because the quality of SOC is important to

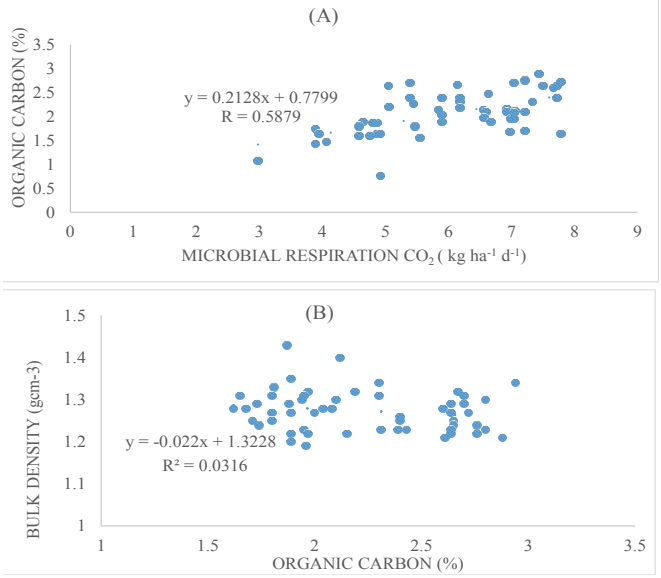

Figure 4: Correlation coefficient (R) between organic carbon and microbial biomass (A), bulk density and organic carbon (B).

the energy required by microorganisms. If the quality is low, it limits the source of energy required for microbes growth, which ultimately decreases the Carbon mineralization rate and vice versa. Landgraf et al. [23] found that carbon source that simply decomposes, such as glucose and sucrose, could make the soil microorganism swiftly propagate and proliferation of their activities. Feacal matter fertilizers decomposed easily thus the microbes increased with increase in organic carbon in the soils.

Conclusion

Faecal matter fertilizers products were able to supply enough nitrogen for potato growth and still were able to improve the soil nutrient status after harvesting. These products contributed not only to Nitrogen nutrient but also improved desirable properties like microbial respiration. To increase nutrient uptake, the nutrients have to be available whenever the crop needs them to enable optimum crop production. These products can contribute significantly to this course.

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