Почвознание агрохимия и екология, 59, 2/2025
Bulgarian Journal of Soil Science Agrochemisty and Ecology, 59, 2/2025

DOI: https://doi.org/10.61308/TFVP1400

Liquid organic fertilizers from rabbit wastes under different feeding regimes improve soil properties, growth, yield and nutrient uptake in maize

Musibau Oyeleke Azeez*[1], Festus Adewale Oladipupo[1], Francis Tope Olatoberu[1], Akinloye Jimoh Farinde[2], Waheed Olalere Oladepo[2]

[1]*Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile Ife, Osun State, Nigeria*
[2] *Department of Agricultural Extension and Rural Development, Obafemi Awolowo University, Ile Ife, Osun State, Nigeria*

Corresponding author*: azeezmusy@gmail.com

ORCID Musibau Oyeleke Azeez https://orcid.org/0000-0001-5271-3035

Citation: Azeez, M.O., Oladipupo, F.A., Olatoberu, F. T., Farinde, A. J., & Oladepo, W.O. (2025). Liquid organic fertilizers from rabbit wastes under different feeding regimes improve soil properties, growth, yield and nutrient uptake in maize. *Bulgarian Journal of Soil Science Agrochemisty and Ecology, 59*(2), 16-31.

Abstract

The present study aimed at evaluating the effects of liquid organic fertilizers (LOF) from rabbit wastes under different feeding regimes on soil properties, growth, yield and nutrient uptake in maize. The study utilized urine and faeces collected from rabbits fed with two different feeding types (100% forage and 50% Concentrate + 50% Forage). Soil samples were collected before and after the field experiment. The maize growth parameters: chlorophyll index, plant height, number of leaves, stem girth, and leaf area index, were collected fortnightly, whereas dry matter weight, dry matter yield, grain yield, NPK uptake in maize plant, and selected soil properties were determined at the end of the field experiment. The results showed significant positive effects of LOF application on the maize growth parameters. Furthermore, maize grain yield and nutrient uptake were positively influenced in all the LOF treated plots and did not significantly different from NPK treated plot. For instance, though NPK had the highest grain yield of 6.58 ton.ha^{-1}, but not significantly different from U_fF_fRN treated plot (urine + faeces from forage fed rabbits + banana root + Neem bark) with grain yield of 6.22 ton.ha^{-1}. Selected soil properties such as pH, available P, exchangeable K increased in all LOF treated plots, whereas lower total N and C were recorded, which was attributed to high plant N uptake and high mineralization of organic matter occasioned by improved soil conditions due to LOF applications to soil. It was concluded that the LOF produced from rabbit wastes can serve as a good substitute to chemical fertilizers such as NPK for a viable maize production.

Key words: rabbit wastes, liquid organic fertilizer, NPK, maize, forage

Introduction

The declining in soil quality and nutrient losses are the main hindrance to improving agricultural productivity and food security in sub-Saharan Africa (SSA) most especially Nigeria (Dimkpa et al., 2023). Nigerian soils face numerous challenges, such as inadequate agricultural practices, land degradation, soil erosion, and the impact of climate change exacerbating the difficulties faced by farmers. Food security remains a prominent global concern, as emphasized in Sustainable Development Goal 2 (Zero Hunger) of the 2030 Agenda, by ensuring that the most vulnerable people in the society especially children have access to sufficient and nutritious food all year round (Abdi et al., 2024). The growing demand for food, animal feeds and biofuels as a result of Nigeria's exponential population growth often leads to ever-increasing demand for fertilizers for viable crop production (Apeh et al., 2024; Kihara et al. 2020). As a result, these practices are imposing an adverse influence on the fertility status of the soil, due to negative effects of chemical fertilizers on soil properties. This issue underscores the significance of transitioning towards a more sustainable agricultural approach, wherein organic fertilizers is favoured over chemical fertilizers (Thomas et al. 2019; Lawrence and Melgar, 2023).

Maize (*Zea mays*) is a cereal crop that is grown widely throughout the world in different agro ecological environments and is ranked next to wheat and rice in terms of the area being used for its cultivation (Shiferaw et al., 2011). Apart from its use for food and animal feed products, maize is also being utilized as an energy source and raw material in various industries, with its demand steadily rising each year. Despite the important role in income generation, the average yield obtained on farmers' field in Nigeria is very low (about 1.59 $t.ha^{-1}$) compared with the world average of 5.5 $t.ha^{-1}$ (Martínez-Ortiz et al., 2024). The low yield obtained by farmers was attributed to low soil fertility, pest infestation, weed and disease infection beyond the threshold level, including poor varietal potential (Ekpa et al., 2018).

Chemical fertilizers are essential for boosting plant growth and crop production because of their high nutrient content, solubility, and nutrient availability for plant uptake, but they barely sustain soil fertility (Kandpal, 2021). In addition, the processes involved with manufacturing of chemical nitrogen fertilizers contribute more than 50% of the greenhouse gas emissions attributed to the agricultural sector, which is responsible for over 10% of total greenhouse gas emissions worldwide (El-Ghamry et al., 2018). Also, the over-application of chemical fertilizers often leads to soil acidity and nutrient imbalances (Singh, 2018), pollute water resources, and destroy soil microorganisms and insects, which are very important for the soil ecosystem (Sharma et al., 2019). Therefore, the use of fertilizers from organic materials could replace chemical fertilizers, contributing to resources preservation and recycling of organic matter.

Rabbit urine and faeces are livestock wastes whose potential as biofertilizer has not been fully tapped and embraced by most local farmers in Nigeria. Previous studies had reported that liquid organic fertilizer (LOF) produced from rabbit urine contains essential nutrients such as nitrogen, phosphorus and potassium, as well as essential microorganisms which can serve as biofertilizer for plant growth (Said et al., 2018; Widayati et al., 2023; Azeez et al., 2024). The nutrient content of rabbit urine is higher than urine from other animals such as cow, goat and sheep (Mutai, 2020). The use of LOF seeks to achieve improve crop yields, livestock productivity, sustainable soil health due to improved soil fertility, enhanced soil structure due to improved soil aggregation, aeration, and water-holding capacity, and increased in soil microbial activity which is essential for nutrient cycling and plant growth (Mamatha et al., 2024). The impact of organic fertilizer, specifically made from rabbit wastes, on the growth of Arabica and Robusta coffee seedlings had been reported to enhance the plant height, leaves number, and stem diameter of both seedlings, compared with organic fertilizers from goat manure (Prajanti et al., 2023). Data on the effect of LOF produced from rabbit urine and faeces collected from different feeding types on soil properties and plant growth are very scarce.

In this study, rabbit urine and faeces collected from rabbits fed with different diets (forage only, and forage plus concentrate) were subjected to a 21-day fermentation process. The resulting LOF were applied as soil amendment and its impact was evaluated on soil properties and maize production. We hypothesized that the LOF from rabbit wastes has comparable effects as chemical fertilizers in maize production. Therefore, the objective of this study was to determine whether liquid organic fertilizers produced from rabbit wastes under different feeding regimes can be a viable substitute for chemical fertilizers such as NPK and Sulphate of Ammonia in enhancing soil properties, growth, yield and nutrient uptake in maize, while promoting environmental sustainability.

Materials and methods

The experiment was carried out at the Teaching and Research farm, Obafemi Awolowo University, Ile-Ife, Nigeria between latitude 7°33’7”N and 7°33’8” N, and longitude 4°33’2” E and 4°33’3” E. The rabbit urine and faeces were collected from three feeding regimes: forage only, concentrate only, and forage plus concentrate. Details on the various forages and concentrates used for feeding the rabbits were reported in Azeez et al. (2024). The rabbit house was constructed in such a way that allows the collection of rabbit urine and faeces separately from the three feeding regimes. The liquid organic fertilizer (LOF) was produced by fermenting rabbit wastes using a fabricated fermentation chamber for 21 days. For this field experiment, rabbit faeces and urine collected from rabbits fed with two different feeding types (100% forage and 50% Concentrate + 50% Forage) were used. The choice of these two feeding regimes was based on the previous report (Azeez et al., 2024) where high contents of plant nutrients in the wastes collected from these two feeding regimes were reported compared to rabbit wastes from rabbit fed with Concentrates only. The treatments were: (a) urine from forage fed rabbits (U_f) (b) urine from forage and concentrate fed rabbits (U_{cf}); (c) faeces from forage fed rabbits (F_f) (d) faeces from concentrate and forage fed rabbits (F_{cf}) (e) urine + faeces from forage fed rabbits + banana root + Neem bark (U_fF_fRN) (f) urine + faeces from concentrate and forage fed rabbits + banana root + Neem bark ($U_{cf}F_{cf}RN$); (g) urine from forage fed rabbits + banana root + corn cob + Neem bark (U_fC_bRN); (h) urine from concentrate and forage fed rabbits + banana root + corn cob + Neem bark ($U_{cf}C_bRN$). The field experiment was arranged in a Randomized Complete Block Design consisting of control, rabbit liquid organic fertilizer and NPK fertilizer; and replicated three (3) times, resulting to a total of thirty (30) plots. Each plot was 3 m x 3 m with 1 m spacing between plots within block and 1 m spacing between blocks. The LOF was incorporated into the soil one week before planting while NPK 15-15-15 fertilizer was applied at 120 kg.ha^{-1} N using side placement method at 2 weeks after planting. The test crop, maize, was planted during 2024 early season. Three maize seeds were sown per hole at planting distance of 0.75 m x 0.50 m and seedlings was thinned to two per stand at two weeks after planting (2 WAP). Weeds were managed with the applications of 500 g.L^{-1} of atrazine and 200 g.L^{-1} of paraquat as pre-and post-emergence herbicides, respectively, which was complemented with hand weeding at regular intervals to keep the plots weed-free. Fall army worms was managed by spraying the whole field with 2 g.L^{-1} Emamectin Benzoate.

Data collection on plant growth parameters

The following data were collected on the plant from each plot at two weeks interval: chlorophyll index using chlorophyll meter SPAD-502, plant height (cm), number of leaves, stem girth (cm), leaf length (cm), leaf width (cm) and leaf area index. Dry matter weight, dry matter yield, grain yield (15% moisture content) and nutrient removal/ uptake were also determined.

Soil and plant analysis

Before planting, composite soil sample (0-15 cm) was collected from the experimental site in order to establish the fertility status of the soil. After the crop harvest, soil samples (0–15 cm) were collected from each treated plots and control, air-dried and passed through a 2 mm sieve. The particle size analysis was determined using the modified method of Bouyoucos (1962) as described by Gee and Or (2002). Soil pH in 0.01 M $CaCl_2$ was determined using the soil-solution ratio 1:2 (Peech, 1965; Thomas, 1996). The exchangeable cations (Ca, Mg, K, Na) were determined using 1 N-NH_4OAc extraction method (Thomas, 1982; Jones, 1998). The available P was determined using Bray-1 method (Bray and Kurtz, 1945; Kuo, 1996), while total nitrogen was determined using macro-Kjeldahl digestion and distillation procedure (Bremner and Mulvaney 1982). Total carbon was determined using the chromic acid wet oxidation method (Walkley and Black, 1934; Nelson and Sommers, 1996). The nutrients in the plant samples were extracted using wet ash digestion method. Nitrogen content was determined using Kjeldahl method (Bremner, 1996). The total P content was determined using the Vanado-Molybdate method and the total K was also extracted and determined using method described by AOAC (2005).

Statistical Analysis

The data obtained were analysed using R – statistical software version 4.4.1. (R core Team, 2024). The data were checked for normality and constant variance using Shapiro and Bartlett tests, respectively. The data were fitted using a generalized linear model with fixed effects representing different treatments. Post-hoc multiple pairwise comparisons were analysed by Tukey's significant differences using the CLD function implemented in the R package emmeans. In addition, Pearson's correlation coefficient analyses were performed to determine the relationships among selected growth parameters and yield related attributes. For all analyses, the criterion used for statistical significance was $P < 0.05$.

Results and discussion

Chemical properties of the liquid organic fertilizer

Details of chemical properties of the LOF used for this study were reported in earlier publication (Azeez et al., 2024). Briefly, the pH of the LOF ranged between 5.51 to 7.92 which was mostly alkaline; electrical conductivity ranged from 4.87 to 16.28 $dS.m^{-1}$; total organic carbon (0.15 to 0.90%); total nitrogen (0.23 to 0.51%); total phosphorus (0.29 to 5.81 $mg.l^{-1}$); potassium contents ranged between 1.13 and 25.63 $mg.l^{-1}$; calcium content (0.37 to 2.5 $mg.l^{-1}$) and magnesium contents (0.06 to 0.97 $mg.l^{-1}$). The micro-nutrients contents of the LOF were moderate and the contents of heavy metals such as Pb, Cr, Cu, Cd, were very low, suggesting that the application of LOF for maize production will not pose any problem to the crop, while ensuring environmental sustainability.

Physical and Chemical properties of Soils before planting

The physical and chemical properties of the soil before planting are presented in table 1. The soil textural class was sandy loam with 786, 87, and 127 $g.kg^{-1}$ sand, silt and clay respectively. Southwestern Nigeria has soil texture mostly composed of sandy loam, sandy clay, loamy sand and clay loam (Aizebeokhai et al., 2018). The high sand content indicates a coarse soil texture, which generally results in good drainage and aeration but low water and nutrient holding capacity. The pH (0.01M $CaCl_2$) value of the soil was 5.18, which is slightly acidic. The low electrical conductivity (EC) value of 0.15 $dS.m^{-1}$ indicates a non-saline soil, which is considered suitable for most crops. The total nitrogen of the studied soil was high (0.35%) (Adepetu et al., 2014), while that of organic carbon was 1.57%. The available phosphorus (5.25 $mg.kg^{-1}$) was low (Adepetu et al., 2014), while the exchangeable potassium in the studied soil was 0.19 $cmol.kg^{-1}$. Generally, the fertility status of the studied soil was moderate.

Effects of Liquid Organic Fertilizers on Plant Growth Parameters

The results of plant height at 2, 4, 6, 8, and 10 weeks after planting (WAP) of maize (*Zea maize*) are presented in table 2. The trend in the height was consistent. The plant height in the control and treated plots increased from 2 WAP to 10 WAP. U_fF_fRN treated plot showed consistently higher values throughout the growth cycle. Treatments have more pronounced differences early in the growth phase (2 WAP). However, control and NPK-treated plots had lower values than all other plots. No significant difference among the heights of maize in all plots at 4, 6, 8 and 10 WAP was recorded. The results showed that the influence of LOF from different feeding regimes on maize height was comparable with NPK.

The results of leaf area index at 2, 4, 6, 8, and 10 WAP of maize (*Zea maize*) are presented in table 3. The trend in the leaf area index was not consistent. The leaf area index in the control and treated plots increased from 2 WAP to 6 WAP, decreased between 6 WAP and 8 WAP, and increased again from 8 WAP to 10 WAP. However, there was no significant difference in all treated plots at 2, 4, 6, 8, and 10 WAP during the growth cycle.

As observed in plant height and leaf area index, the trend in the stem girth of the maize plant was not consistent, and there were no significant differences between all treatments throughout the growth period (table 4). At 2 and 4 WAP, U_{cf} treated plot had the lowest stem girth (2.41 cm and 5.50 cm) while NPK had the highest at both periods (2.94 and 6.72, respectively). At 6 WAP, the U_fC_bRN-treated plot had the lowest stem girth; whereas at 8 and 10 WAP, the stem girth value for NPK-treated plots (8.11 cm and 7.23 cm) was the highest, followed by U_f and U_fF_{cf}RN, respectively.

The results for the number of leaves per plant at 2, 4, 6, 8, and 10 WAP of maize (*Zea mays*) are presented in table 5. No significant difference existed among the number of leaves of maize in all treated plots throughout the growth period except at 8 WAP. At 8 WAP, there was a significant difference between the number of leaves in the different plots. NPK-treated plots had the highest number of leaves, which was also significantly higher than all other plots except U_{cf} and F_{cf}-treated plots.

The results of the leaf greenness of maize (*Zea mays*) at 2, 4, 6, 8, and 10 WAP are presented in table 6. At 2 WAP, U_fF_fRN treated plot had the highest leaf greenness value of 47.76, significantly higher than all other treated plots except for U_f, F_f, F_{cf}, and $U_{cf}F_{cf}$RN treated plots. At 6 WAP, the control plot had the lowest leaf greenness value (45.8), significantly lower than the $U_{cf}F_{c-f}$RN - treated plot. $U_{cf}F_{cf}$RN treated plot had the highest leaf greenness value (52.47), which was not significantly different from that of U_fC_bRN, NPK, and Fcf treated plots, while the control plot had the lowest leaf greenness value (45.8). At 4, 8 and 10 WAP, the leaf greenness of maize plant was not significant in all the treated plots.

Similar to our study, Prajanti et al. (2023) reported that application of organic fertilizers from rabbit manure and urine, to Arabica and Robusta coffee seedlings, resulted into enhanced plant height, leaves number, and stem diameter of both seedlings, compared with organic fertilizers from goat manure. In our study, the feeding regimes play a crucial role on the results obtained from plant growth parameters, as LOf from forage fed rabbits and, combination of forage and concentrates fed rabbit improved most of the growth parameters comparable with chemical fertilizer. This is consistent with the elemental composition of these LOF as reported by Azeez et al. (2024). Liquid organic fertilizers produced from fermented rabbit urine and faeces contain nutrients that are released easily to the soil, due to microbial decomposition of the wastes during fermentation period, compared to other animal manures, where it needs time to decompose (Baitilwake et al., 2012). It could also be due to liquid organic fertilizers' abilities to supply soluble organic nutrients and biostimulants more quickly to the plant, which supported its growth.

The study on the effect of bio-fertilizer using rabbit urine on the UC82B tomato Variety in Zaria, Nigeria, showed that treatments with rabbit urine inclusive had the best performance in terms of the plant height, number of leaves and branches between 2 to 6 WAP (Indabo and Abubakar, 2022), consistent with our study.

Dry matter and grain yields

There was no significant (p>0.05) difference between the dry matter yield of maize in all treated plots (table 7), suggesting that the performance of LOF on dry matter yield is comparable with NPK. However, the control plot had the highest dry matter yield of 2.73 ton.ha^{-1}, followed by the plot treated with U_fF_fRN and NPK, which yielded 2.66 and 2.4 ton.ha^{-1}, respectively. Similar trend was also observed in grain yield, though plot treated with NPK had the highest grain yield of 6.58 ton.ha^{-1}, but not significantly different from all the LOF treated plots. Followed closely was the plot treated with U_fF_fRN with grain yields of 6.22 ton.ha^{-1}; plots treated with U_fC_bRN and $U_{cf}F_{cf}$RN had grain yields of 5.51 and 5.78 tons per hectare, respectively. The positive impact of LOF on dry matter and grain yield could also be due to the fact that LOF contains an appreciable amount of micro and macro-nutrients, including an important N source for crops (Tan et al., 2016; Liu et al., 2024). In a comparative study on the effects of fertilizer-grown lettuce and its storage ability, El-Mogy et al. (2020) reported that plots with rabbit manure fertilizer had a significant increase in yield. In a field experiment on the influence of rabbit urine as organic fertilizer on the growth and yield of two varieties of cucumber at the Vegetable Research Farm of National Horticultural Research Institute, Ibadan, Nigeria, Okonji et al. (2023) concluded that rabbit urine improved growth and yield of cucumber better than NPK. This is consistent with our study in which LOF enhanced maize dry matter and yield and its performance is comparable with NPK.

Effects of liquid organic fertilizers on nutrient uptake in maize plant

The performance of all LOF treated plots was excellent when compared with that of NPK, as there was no significant difference in the N uptake values of all treated plots (fig. 1). However, the results showed that the plots treated with NPK had the highest N uptake of 51.52 kg.ha^{-1}, followed by U_{cf} with 42.07 kg.ha^{-1} and U_fF_fRN with 39.18 kg.ha^{-1}. Plots treated with F_{cf} and F_f had N uptake of 38.21 and 37.78 kg.ha^{-1}, respectively. The control treatment had a nitrogen uptake of 34.73 kg.ha^{-1}, close to $U_{cf}F_{cf}$RN at 34.19 kg.ha^{-1}. Lower nitrogen uptake values were observed for plots treated with $U_{cf}C_b$RN and U_fC_bRN at 35.23 and 32.4 kg.ha^{-1}, respectively. The U_f treatment gave the lowest nitrogen uptake (30.51 kg.ha^{-1}).

The result of the P uptake of maize (*Zea mays*) are presented in figure 2; and it revealed significant differences across treatments, with U_fF_fRN (31.6 kg ha^{-1}) showing the highest P uptake, which was statistically higher than all other treatments except NPK treated plots. Combinations of urine and faeces from rabbit fed with forage only had the significant highest P uptake. The lowest P uptake was observed in $U_{cf}F_{cf}$RN (19.45 kg.ha^{-1}).

The trend of K uptake was similar to that of P uptake (fig. 3). There was a significant difference in the K uptake values of all plots. The result showed that the U_fF_fRN treated plot had the highest K uptake of 22.57 kg.ha^{-1}, which was statistically higher than other treated plots except for the control plot. There were no significant differences among K uptake in plots treated with U_f, U_{cf}, F_f, F_{cf}, $U_{cf}F_{cf}$RN, U_fC_bRN, and NPK.

Several authors have reported enhanced grain yields and nutrients uptake in maize crop following the applications of liquid organic manure produced from different animal manures. Sofyan et al. (2021) conducted an experiment on the effect of organic and inorganic fertilizer applications on N, P-uptake, K-uptake and yield of sweet corn (*Zea mays saccharata* Sturt) in Indonesia, reported increased in N, P and K uptakes and sweet corn grain yields, which they attributed to availability of plant nutrients in the organic fertilizers comparable with inorganic fertilizers. This is consistent with our study. The application of LOF improves soil conditions since the plant roots have more access to essential plant nutrients released by

Table 1. Physical and chemical properties of soil used for the study

Parameters	Mean values
Sand ($g.kg^{-1}$)	786±1.20
Silt ($g.kg^{-1}$)	87±1.16
Clay ($g.kg^{-1}$)	127±1.20
Textural class	Sandy Loam
pH (0.01 M $CaCl_2$)	5.18±0.01
EC ($dS.m^{-1}$)	0.15±0.01
Total Nitrogen (%)	0.35±0.01
Organic Carbon (%)	1.57±0.01
Available P ($mg.kg^{-1}$)	5.25±0.01
Exchangeable potassium ($cmol.kg^{-1}$)	0.19±0.01

± indicates standard error of the mean

Table 2. Plant height (cm) of maize

Treatments	Weeks After Planting (WAP)				
	2	4	6	8	10
U_f	24.77	72.56	176.56	257.22	269.44
U_{cf}	24.12	66.44	156.72	257.44	262.22
F_f	27.91	68.31	162.94	246.44	257.78
F_{cf}	24.49	77.02	190.55	252.33	263.67
U_fF_fRN	28.38	77.66	201.45	262	261.5
$U_{cf}F_{cf}RN$	26.25	77.96	191.66	259.89	271.22
U_fC_bRN	22.9	73.35	175.95	259	258.56
$U_{cf}C_bRN$	24.93	66.17	164.94	250	255.67
NPK	22.57	76.95	193.94	276.11	283.67
Control	21.8	66.82	170.28	230.51	253.22
$LSD_{0.05}$	**ns**	**ns**	**ns**	**ns**	**ns**

ns indicates that there is no significant difference at probability level (α) of 0.05. U_f- Urine from forage only, U_{cf}- Urine from concentrate and forage only, F_f -Fecal from forage only, F_{cf}- Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root l,+ Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage +Corn cob+ Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 3. Leaf area index of maize

Treatments	Weeks After Planting (WAP)				
	2	4	6	8	10
U_f	0.37	2.57	4.23	3.37	3.80
U_{cf}	0.35	1.68	4.00	3.12	3.12
F_f	0.40	2.20	3.84	3.55	3.70
F_{cf}	0.38	2.82	4.57	3.53	3.10
U_fF_fRN	0.33	2.48	4.55	3.73	2.46
$U_{cf}F_{cf}RN$	0.31	2.57	4.12	3.54	3.35
U_fC_bRN	0.27	2.23	4.02	3.64	3.06
$U_{cf}C_bRN$	0.24	2.21	4.12	3.38	3.37
NPK	0.26	2.93	4.57	4.04	4.20
Control	0.23	2.31	3.77	3.86	3.97
LSD $_{0.05}$	**ns**	**ns**	**ns**	**ns**	**ns**

ns indicates that there is no significant difference at a probability level (α) of 0.05, U_f - Urine from forage only, U_{cf}- Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage +Corn cob+ Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 4. Stem girth (cm) of maize

Treatments	Weeks After Planting (Wap)				
	2	4	6	8	10
U_f	2.93	6.69	6.97	6.99	6.28
U_{cf}	2.41	5.5	6.52	6.23	5.85
F_f	2.6	5.95	6.76	6.56	6.34
F_{cf}	2.83	6.46	6.55	6.91	6.48
U_fF_fRN	2.82	6.44	6.81	6.69	6.44
$U_{cf}F_{cf}RN$	2.86	6.55	6.75	6.74	6.78
U_fC_bRN	2.66	6.1	6.41	6.61	6.43
$U_{cf}C_bRN$	2.73	6.24	6.92	6.25	6.71
NPK	2.94	6.72	7.29	8.11	7.23
Control	2.54	5.81	6.57	6.72	6.51
LSD $_{0.05}$	**ns**	**ns**	**ns**	**ns**	**ns**

ns indicates that there is no significant difference at a probability level (α) of 0.05. Uf - Urine from forage only, U_{cf}- Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 5. Number of leaves per plant of maize

Treatments	Weeks After Planting (WAP)				
	2	4	6	8	10
U_f	6.33	11.00	12.00	12.67ab	11.67
U_{cf}	6.67	9.67	12.00	11.67bc	11.33
F_f	6.67	10.33	12.00	12.00bc	11.67
F_{cf}	6.33	11.33	13.00	12.67ab	11.33
U_fF_fRN	6.00	11.00	12.67	12.00bc	11.00
$U_{cf}F_{cf}RN$	6.33	11.00	11.67	12.00bc	11.67
U_fC_bRN	5.67	11.00	12.33	12.00bc	11.00
$U_{cf}C_bRN$	6.00	10.67	12.33	11.00c	11.33
NPK	6.00	11.33	12.33	13.67a	12.33
Control	6.00	11.00	12.00	12.33b	12.33
LSD $_{0.05}$	**ns**	**ns**	**ns**	*	**ns**

The symbol * indicates a significant difference at probability level (α) of 0.05. Means in columns with the same alphabet(s) are not significantly different at probability level (α) 0.05. ns indicates that there is no significant difference at probability level (α) of 0.05. U_f - Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 6. Leaf greenness of maize

Treatments	Weeks After Planting (WAP)				
	2	4	6	8	10
U_f	46.73a	44.8	48.87bcd	52.21	48.25
U_{cf}	44.83abc	42.59	46.3de	47.27	47.45
F_f	47.84a	41.43	46.57cde	52.4	51.29
F_{cf}	45.34ab	41.33	50.23ab	54.06	50.16
U_fF_fRN	47.76a	46.34	47.77bcde	52.5	49
$U_{cf}F_{cf}RN$	44.83abc	46.16	52.47a	49.48	51.65
U_fC_bRN	41.12bcd	45.21	49.9ab	54.67	55.66
$U_{cf}C_bRN$	40.66cd	42.01	49.47bc	49.1	56.06
NPK	41.66bcd	43.03	50.53ab	54.32	54.29
Control	39.95d	44.79	45.8e	50.31	50.19
LSD $_{0.05}$	*	**ns**	*	**ns**	**ns**

The symbol * indicates a significant difference at probability level (α) of 0.05. Means in columns with the same alphabet(s) are not significantly different at probability level (α) 0.05. ns indicates that there is no significant difference at probability level (α) of 0.05. U_f - Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f -Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 7. Dry matter yield and grain yield of maize

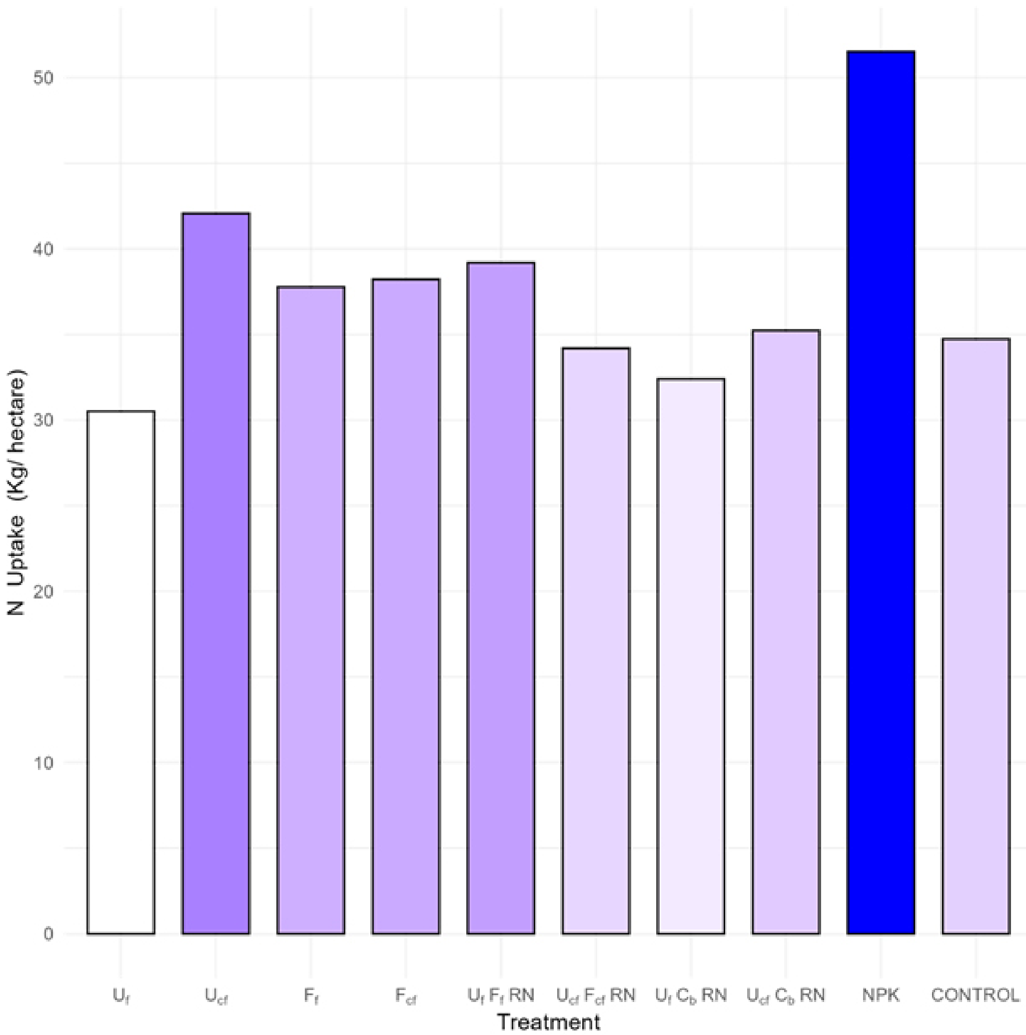
Treatments	Dry Matter Yield	Grain Yield
	(tonha^{-1})	
U_f	2.21	4.53
U_{cf}	2.31	4.44
F_f	2.28	4.18
F_{cf}	2.4	4.98
U_fF_fRN	2.66	6.22
$U_{cf}F_{cf}RN$	2.09	5.78
U_fC_bRN	2.07	5.51
$U_{cf}C_bRN$	2.24	4.35
NPK	2.4	6.58
Control	2.73	5.07
LSD $_{0.05}$	**ns**	**ns**

ns indicates no significant difference at a probability level (α) 0.05. U_f - Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Table 8. Selected soil chemical properties after crop harvesting

Treatments	pH	EC (dSm^{-1})	0C %	TN %	Avail. P (mgkg^{-1})	Exch. K (cmolkg^{-1})
U_f	5.56	0.15	0.55	0.17	10.02	0.22
U_{cf}	5.44	0.13	0.83	0.14	10.68	0.21
F_f	5.40	0.15	0.68	0.19	14.12	0.18
F_{cf}	5.37	0.12	1.29	0.20	17.02	0.18
U_fF_fRN	5.45	0.18	1.05	0.23	21.20	0.17
$U_{cf}F_{cf}RN$	5.44	0.13	0.84	0.17	18.10	0.15
U_fC_bRN	5.38	0.13	0.90	0.16	21.41	0.18
$U_{cf}C_bRN$	5.40	0.13	1.16	0.20	10.48	0.20
NPK	5.34	0.14	1.29	0.15	10.19	0.22
Control	5.33	0.20	0.84	0.19	15.45	0.20
LSD $_{0.05}$	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**

ns indicates no significant difference at a probability level (α) 0.05. U_f - Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage + Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF



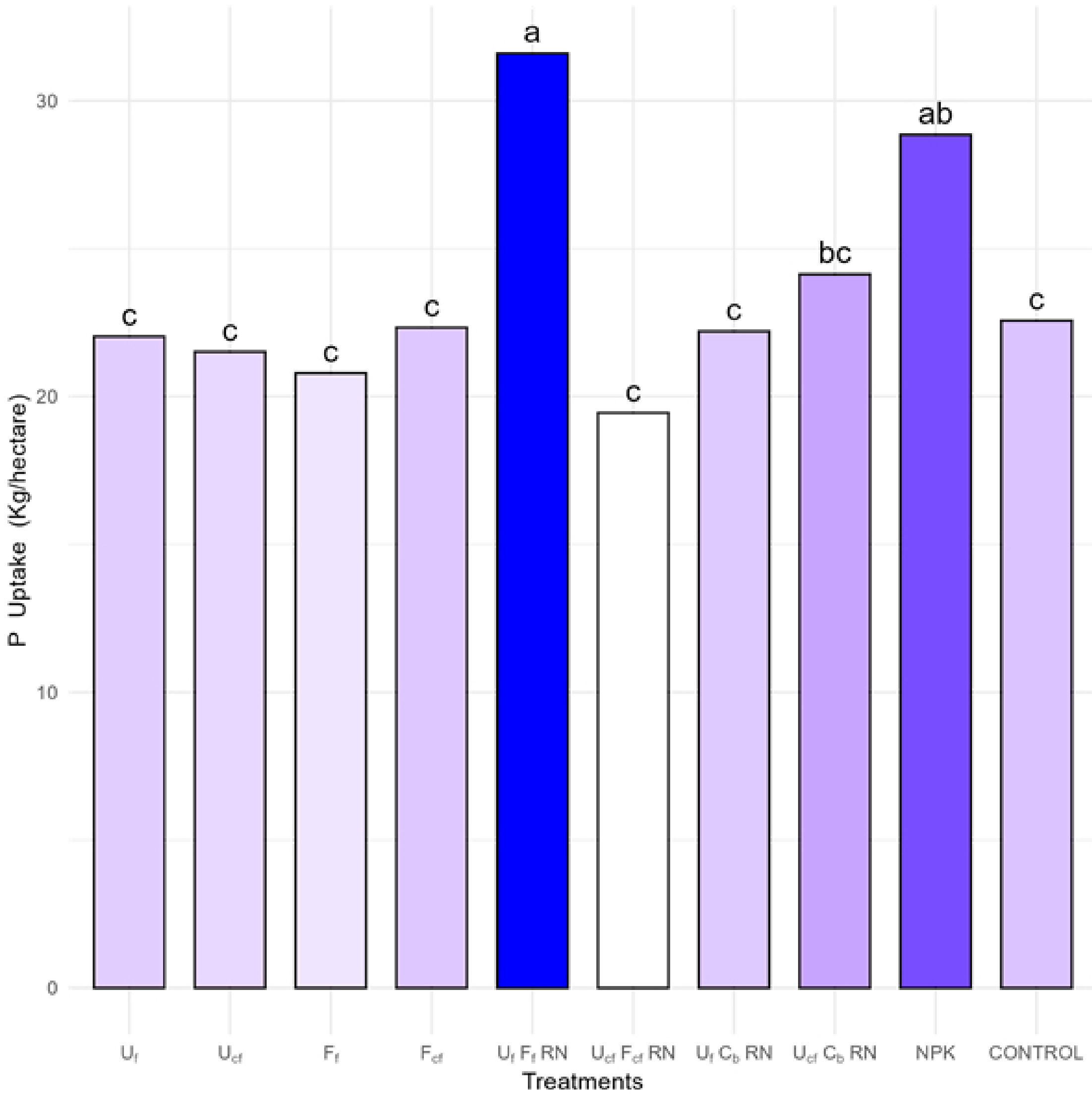
No significant difference in all treated plots at $p<0.05$. Urine from forage only, U_{cf}- Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}$RN - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_b$RN - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_b$RN - Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Fig. 1. Nitrogen uptake in maize plant

the LOF, and this enhances the recruitment of desired microbial partners for greater mutualistic benefits. In effect, the soil microorganisms around the rhizosphere soil play critical roles in nutrient cycling and soil structure maintenance, with consequent promoting nutrient cycles and plant growth (Saleem and Moe, 2014; Mmbaga et al., 2024). The above nutrient dynamics could explain the improved nutrient uptakes observed in this study following the application of LOF as compared with the chemical fertilizer.

Effects of liquid organic fertilizer on selected soil properties after crop harvesting

The results of selected soil chemical properties after crop harvesting are presented in table 8. The results showed no significant difference in the soil pH in all treated plots and control after

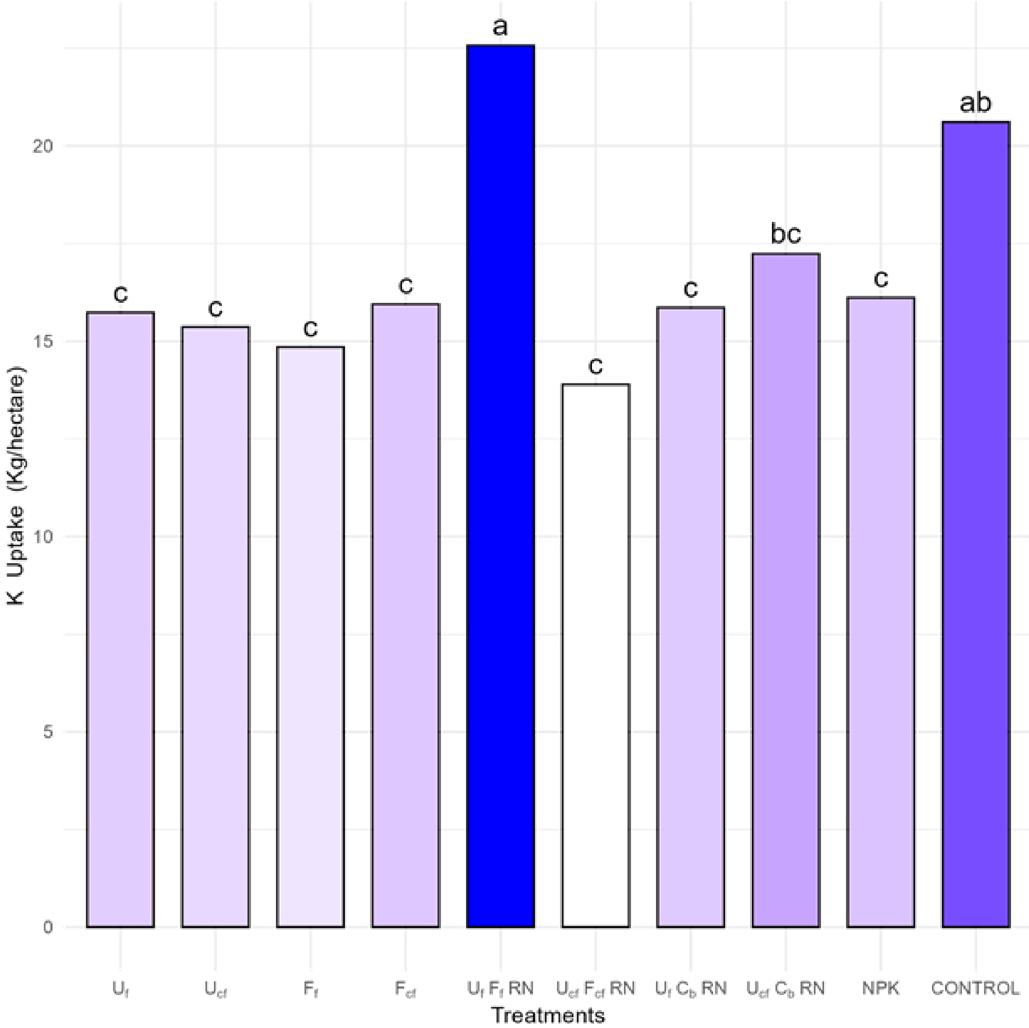


Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage +Corn cob+ Banana Root + Neem, $U_{cf}F_{cf}C_bRN$-Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Fig. 2. Phosphorus uptake in maize plant

crop harvesting. From table 1, the soil pH before planting was 5.18, indicating moderately acidic conditions. After crop harvesting, all treatments showed a slight increase in pH, with Uf-treated plots having the highest pH of 5.56, suggesting potential liming effect of added LOF. For most crops, a pH range of 6.0 to 7.5 is considered optimal (Suleiman et al., 2017), suggesting that the studied soil could be used to grow another crop due to improved soil conditions through LOF application.

Similar trend was observed in electrical conductivity of soil in all treated plots and control after crop harvesting. From table 1, the initial soil EC was 0.15 $dS.m^{-1}$, and it ranged from 0.12 to 0.20 $dS.m^{-1}$ after crop harvesting. The low electrical conductivity (EC) value indicates a non-saline soil, which is considered suitable



Urine from forage only, U_{cf} - Urine from concentrate and forage only, F_f - Fecal from forage only, F_{cf} - Fecal from concentrate and forage only, U_fF_fRN - Urine from forage + Fecal from forage + Banana Root + Neem, $U_{cf}F_{cf}RN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Banana Root + Neem, $U_fF_fC_bRN$ - Urine from forage + Fecal from forage + Corn cob + Banana Root + Neem, $U_{cf}F_{cf}C_bRN$ - Urine from concentrate and forage + Fecal from concentrate and forage+ Corn cob + Banana Root + Neem, NPK - 120 kg of N per ha, Control - no NPK, no LOF

Fig. 3. Potassium uptake in maize plant

for most crops. Soils with electrical conductivity of 4 $dS.m^{-1}$ are generally considered harmful to most crops (Wickramasinghe et al., 2021). In this study, application of LOF from rabbit urine and faeces for maize production did not result to accumulation of soluble salts which makes the LOF an environmentally sustainable fertiliser.

Soil organic carbon (SOC) showed no significant difference in all treated plots and control after crop harvesting. It was observed that the SOC decreased slightly in all treated plots after crop harvesting, though not significant. The highest SOC was observed in Fcf treated plots (1.29%), followed by NPK and $U_{cf}C_bRN$ treatments (1.29% and 1.16%, respectively). The lowest SOC was recorded in U_f-treated plots (0.55%). The organic carbon recorded after crop harvest was moderate, as the critical value for organic carbon in Nigeria soils is 2.0% (Adepetu, 1990). The LOF improves soil conditions thereby enhance microbial activities, with consequent increase in decomposition and mineralization of soil organic matter, which could explain the slight reduction of SOC recorded in this study. However, it is expected that long time LOF fertilization will increase the soil C stock level due to high increased plant productivity over time (Rambaut et al., 2022).

For soil total nitrogen, the influence of LOF was similar to other soil nutrients. No significant difference in the total nitrogen of the soil in all treated plots and control after crop harvesting. The initial soil total nitrogen concentration was 0.35%, but lower values were recorded in all the treated plots after crop harvesting, which ranged between 0.14 and 0.23%. This could be attributed to higher N uptake in maize plant observed in this study. For most agricultural crops, a total nitrogen level of 0.11% and above is considered sufficient and generally adequate for vigorous plant growth without additional nitrogen fertilization (Adepetu, 1990).

The results of soil available phosphorus after crop harvesting showed no significant difference in all treated plots and control. The soil available phosphorus increased in all plots after crop harvesting. Before planting, the soil contained 5.25 $mg.kg^{-1}$ of available phosphorus, and after crop harvest, U_fC_bRN-treated plots had the highest phosphorus content (21.41 $mg.kg^{-1}$), followed closely by U_fF_fRN (21.2 $mg.kg^{-1}$). The lowest phosphorus concentrations were observed in Ucf and NPK treated plots (10.02 $mg.kg^{-1}$ and 10.19 $mg.kg^{-1}$ respectively). The available P in control plot was higher than initial value, which was not expected, probably other factors were responsible for that increase which could not be explained by this study. The K concentration in all treated plots except those of U_f, U_{cf}, $U_{cf}C_b$RN, NPK, and control were lower than the initial values (0.19 $cmol.kg^{-1}$), though no significant difference was recorded among the treatments in all the treated plots.

The non-significant difference recorded in all the selected soil chemical properties after crop harvesting could be explained from the performance of LOF produced from rabbit urine and faeces, as compared with NPK. This result suggests that small holder farmers could embark on rabbit keeping enterprise where the wastes generated could be utilized to grow their crops, thereby reducing the cost of farm inputs with consequent increase in their income and standard of living.

Conclusion

The study evaluated the impacts of liquid organic fertilizers from rabbit wastes under different feeding regimes on soil properties, growth, yield and nutrient uptake in maize. Application of LOF produced from rabbit urine and faeces increased maize growth parameters such as plant height, leaf's areas, leaf greenness. The performance of all LOF treated plots on maize grain yield, nutrient uptake and soil chemical properties after crop harvest, was comparable to that of NPK fertilizer, suggesting that the LOF is a promising good substitute to chemical fertilizer. The study concluded that LOF produced from rabbit-fed forage only or forage plus concentrate have higher concentrations of essential plant nutrients, and could serve as a potential substitute for chemical fertilizers like NPK for viable maize production, with consequent enhancement in farmers' standard of living.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We acknowledge Tertiary Education Trust Fund NRF grant for providing financial support for this research (TETFund NRF grant, TETF/ES/DR&DCE/NRF 2021/CC/EWC/00094/VOL.1).

References

Abdi, A. H., Mohamed, A. A. & Mohamed, F. H. (2024). Enhancing food security in sub-Saharan Africa: Investigating the role of environmental degradation, food prices, and institutional quality. *Journal of Agriculture and Food Research, 17*, 101241, https://doi.org/10.1016/j.

jafr.2024.101241.

Adepetu, J. A. (1990). Soil test data interpretation in soil testing programme. In: *National Workshop on Soil Testing Service for Efficient Fertilizer Use in Nigeria. Moore Plantation, Ibadan.*

Adepetu, J. A., Adetunji, M. T. & Ige, D. V. (2014). Soil acidity and liming, In: *Soil fertility and crop nutrition, Jumak Publishers, Ringroad, Ibadan*, pp 106-115.

Aizebeokhai, A. P., Okenwa, U. N., Oyeyemi, K. D., Kayode, O. T. & Adeyemi, G. A. (2018). Soil characterization using satellite remote sensing in southwestern Nigeria: Implications for precision agriculture. In: *IOP Conference Series: Earth and Environmental Science, 173*, 012027, doi: 10.1088/1755-1315/173/1/012027, https://iopscience.iop.org/article/10.1088/1755-1315/173/1/012027/pdf (last accessed 15.12.2025).

AOAC (2005). *Official Methods of Analysis 18th edn*, Association of Official Analytical Chemists, Washington, DC, USA.

Apeh, A. C., Apeh, C. C., Ukwuaba, S. I., Agbugba, I. K., Onyeaka, H. (2024). Exploring data sources and farmers' perceptions regarding agrochemical use and food safety in Nigeria. *JSFA Reports. 4*(8), 304-315, https://doi.org/10.1002/jsf2.212.

Azeez, M. O., Oladipupo, F. A., Farinde, A. J., & Oladepo, W. O. (2024). Evaluation of elemental composition and structural analyses of liquid organic fertilizers from rabbit wastes under different feeding regimes. *African Journal of Agricultural Research, 20*(12), 1013-1022. https://doi.org/10.5897/AJAR2024.16782.

Baitilwake, M. A., De Bolle, S., Salomez, J., Mrema, J. P., De Neve, S. (2012). Effect of organic fertilizers on nitrate accumulation in vegetables and mineral nitrogen in tropical soils of Morogoro, Tanzania. *Experimental Agriculture. 48*(1), 111-126. https://doi.org/10.1017/S0014479711000810.

Bouyoucos, G. J. (1962). Hydrometer methods improved for making particle size analysis of soils. *Soil Science Society of America Proceeding, 26,* 917-925.

Bray, R. H. & Kurtz, L. T. (1945). Determination of total organic and available forms of P in soils. *Soil Science, 59*, 39-45.

Bremner, J. M. (1996). Nitrogen-Total. In: *Methods of Soil Analysis Part 3 Chemical Methods, Chap. 37, 1085-1121 (Eds. Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., &. Bremner, J. M.)*, https://doi.org/10.2136/sssabookser5.3.c37.

Bremner, J. M. & Mulvaney, C. S. (1982). Nitrogen-total, In: *Methods of Soil Analysis. Part 3. Chemical Methods, Vol. 5 of Soil Science Society of America Book Series, Ed. By Sarks D.L.* Soil Science Society of America./ American Society of Agronomy. Madison, WI, 1085-1112.

Dimkpa, C., Adzawla, W., Pandey, R., Atakora, W. K., Kouame, A. K., Jemo M. & Bindraban P. S. (2023). Fertilizers for food and nutrition security in sub-Saharan Africa: An overview of soil health implication. *Frontiers in Soil Science, 3*, 1123931, https://doi: 10.3389/fsoil.2023.1123931.

Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V. & Linnemann, A. R. (2018). Sub-Saharan African maize-based foods: Technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Global Food Security, 17*, 48-56, https://doi.org/10.1016/j.gfs.2018.03.007.

El-Ghamry, A., Mosa, A.A., Alshaal, T. & El-Ramady, H. (2018). Nanofertilizers vs. biofertilisers: New insights. *Environment, Biodiversity and Soil Security, 2*, 51-72.

El-Mogy, M., Abdelaziz, S. M., Mahmoud, A.W. M. Elsayed, T. R., Abdel-Kader, N. H. & Mohamed, M. I. A. (2020). Comparative effects of different organic and inorganic fertilizers on soil fertility, plant growth, soil microbial community, and storage ability of lettuce. *Agriculture (Poľnohospodárstvo), 66* (3), 87-107.

Gee, G. W., & Or, D. (2002). 2.4 Particle-Size Analysis. In: *Methods of Soil Analysis: Part 4 Physical Methods,* SSSA Book Series. doi:10.2136/sssabookser5.4.c12.

Indabo, S. S. & Abubakar, A. A. (2020). Effect of rabbit urine application rate as a bio-fertilizer on agro-morphological traits of UC82B tomato (Lycopersicon esculentum Mill) variety in Zaria, Nigeria. *Dutse Journal of Pure and Applied Sciences, 6*, 344-352.

Jones, J. B. (1998). Soil Test Methods: Past, Present, and Future Use of Soil Extractants. *Communications in Soil Science and Plant Analysis, 29*, 1543-1552, https://doi.org/10.1080/00103629809370048.

Kandpal, G. (2021). Review on impact of chemical fertilisers on environment. *International Journal of Modern Agriculture, 10*, 758-763.

Kihara, J., Bolo, P., Kinyua, M., Rurinda, J. & Piikki, K. (2020). Micronutrient deficiencies in African soils and the human nutritional nexus: opportunities with staple crops. *Environmental Geochemistry and Health, 42*, 3015-3033, https://doi.org/10.1007/s10653-019-00499-w.

Kuo, S. (1996). Phosphorus. In *D. L. Sparks. (ed.) Methods of Soil Analysis: Part 3 - Chemical Methods.* SSSA, Madison, WI. pp. 869-919.

Lawrence, B. T. and Melgar, J. C. (2023). Organic matter amendments on nutrient and water status within subtropical peach orchards. *Acta Horticulturae, 1375*, 197-202, https://doi.org/10.17660/ActaHortic.2023.1375.26.

Liu, Y., Lan, X., Hou, H., Ji, J., Liu, X., & Lv, Z. (2024). Multifaceted Ability of Organic Fertilizers to Improve Crop Productivity and Abiotic Stress Tolerance: Review and Perspectives. *Agronomy, 14,* 1141, https://doi.org/10.3390/agronomy14061141.

Mamatha, B., Chandana, M., Guguloth, R., Pakala, S., Nayaki, M. & Chuncha, L. P. (2024). "Enhancing Soil Health and Fertility Management for Sustainable Agriculture: A Review". *Asian Journal of Soil Science and Plant Nutrition, 10*(3), 182-190, https://doi.org/10.9734/ajsspn/2024/v10i3330.

Martínez-Ortiz, M. A., Salinas-Moreno, Y., Ramírez-

Díaz, J. L., Ledesma-Miramontes, A., & Alemán de la Torre, I. (2024). Challenges and Opportunities in the Specialization of Maize Cultivation. *Agro Productividad*, 82-92, https://doi.org/10.32854/agrop.v17i9.3037.

Mmbaga, N., Ngongolo, K. & Materu, S.T. (2024). Potential of rabbit urine as fertilizer on growth and production of Brassica carinata L. *Discover Agriculture 2*, 99, https://doi.org/10.1007/s44279-024-00106-2.

Mutai, P. A. (2020). The Potential Use of Rabbit Urine as a Bio Fertilizer Foliar Feed in Crop Production. *Africa Environmental Review Journal, 4*(1), 138-147.

Nelson, D. M & Sommers, L. E. (1996). Total carbon, organic carbon and organic matter. In: *Methods of Soil Analysis Part 3 Chemical methods (Eds Sparks, D. L., Page, A. L., Helmke, P.A., & Loeppert, R. H.)*, SSSA Book Series 5, Madison, Wisconsin, USA, pp 61-1010.

Okonji, C. J., Ajayi, E. O., Obisesan, O. I., Osundare, O. T. & Adetuyi, A. O. (2023). Effect of Rabbit Urine on Growth and Yield of Cucumber. *Badeggi Journal of Agricultural Research and Environment, 05*(01), 15-23.

Peech, M. (1965). Hydrogen-Ion Activity. In: *Methods of soil analysis. Part 2. Chemical and microbiological properties, (Ed. Norman, A. G.)*, Agronomy Monographs. American Society of Agronomy, Inc. https://doi.org/10.2134/agronmonogr9.2.c9.

Prajanti, S. D. W., Litaay, C., Widiatningrum, T., Amelia, D. R., & Daud, D. (2023). Application of Rabbit Urine and Manure Based Fertilizer on the Growth of Arabica and Robusta Coffee Seedlings. *Biosaintifika: Journal of Biology and Biology Education, 15*(3), 441-449.

Rambaut, L.E., Vayssières, J., Versini, A., Salgado, P., Lecomte, P. & Tillard, E. (2022). 15-year fertilization increased soil organic carbon stock even in systems reputed to be saturated like permanent grassland on andosols. *Geoderma, 425*, 116025.

R Core Team (2024) *R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna*. https://www.R-project.org/ (last accessed 15.12.2025).

Said, M. I., Asriany, A., Sirajuddin, N., Abustam, R., Rasyid, R. & Al-Tawaha, A.R.M. (2018). Evaluation of Liquid Organic Fertilizer from Rabbit's Urine Waste fermented using Local Microorganisms as Decomposers. *Iraqi Journal of Agricultural Science, 49*(6), 990-1003.

Saleem, M. & Moe, L. A. (2014). Multitrophic microbial interactions for eco and agro-biotechnological processes: Theory and practice. *Trends Biotechnology, 32*, 529-537.

Sharma, B., Vaish, B., Singh, U.K., Singh, P. & Singh, R.P. (2019). Recycling of organic wastes in agriculture: An environmental perspective. *International Journal of Environmental Research, 13*, 409-429.

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role of maize in global food security. *Food Security, 3*(3), 307-327, https://doi.org/10.1007/s12571-011-0140-5.

Singh, B. (2018). Are Nitrogen Fertilizers Deleterious to Soil Health? *Agronomy, 8*(4), 48, https://doi.org/10.3390/agronomy8040048.

Sofyan, E. T., Sara, D. S. & Machfud, Y. (2021). The effect of organic and inorganic fertilizer applications on N, P-uptake, K-uptake and yield of sweet corn (Zea mays), 2019. In: *IOP Conference Series: Earth and Environmental Science, 393*, 012021, https://doi.org/10.1088/1755-1315/393/1/012021.

Suleiman, R., Jimoh, I. A. & Aliyu, J. (2017). Assessment of soil physical and chemical properties under vegetable cultivation in Abuja Metropolitan Area, Nigeria. *Zaria Geographer, 24*, 89-99.

Tan, F., Wang, Z., Zhouyang, S. Y., Li, H. L., Xie, Y. P., Wang, Y. P., Zheng, Y. M. & Li, Q. B. (2016). Nitrogen and phosphorus removal coupled with carbohydrate production by five microalgae cultures cultivated in biogas slurry. *Boresource Technology, 221*, 385-393.

Thomas, G. W. (1982). *Exchangeable cations In: Methods of Soil Analysis, (Eds Page, A.L., Miller, R.H., & Keeney, D.) 22nd Edition*. Medison: America Society of Agronomy, pp. 57-164.

Thomas, G. W. (1996). Soil pH and Soil Acidity. In: *Methods of Soil Analysis Part 3 Chemical Methods (Eds Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P. N., Tabatabai, M. A., Johnston, C. T., & Sumner, M. E.)*, https://doi.org/10.2136/sssabookser5.3.c16.

Thomas, C. L., Acquah, G. E., Whitmore, A. P., McGrath, S. P. & Haefele, S. M. (2019). The Effect of Different Organic Fertilizers on Yield and Soil and Crop Nutrient Concentrations. *Agronomy, 9*(12), 776. https://doi.org/10.3390/agronomy9120776.

Walkley, A. & Black, I. A. (1934). An examination of the method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Science, 37*, 29-38.

Wickramasinghe, W.M.D.M., Devasinghe, D.A.U.D., Dissanayake, D.M.D., Benaragama, D.I.D.S., Egodawatta, W.C.P. & Suriyagoda, L.D.B. (2021). Growth physiology and crop yields of direct-seeded rice under diverse input systems in the Dry Zone of Sri Lanka. *Tropical Agricultural Research, 32*(3), 325-337.

Widayati, O., Syaefullah, B.L., Sritiasni, S., Zurahmah, N., Aswandi, A., & Irma, I. (2023). Evaluation of the Growth and Yield of Organic Corn Fodder under Various Watering Times and Concentrations of Rabbit Urine Fertilizers. *Buletin Peternakan, 47*(4), 261-266, doi:10.21059/buletinpeternak.v47i4.84194.

Received: 27th March 2025, ***Approved:*** 09th May 2025, ***Published:*** June 2025