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Quality Analysis of Feecal Sludge and Rich Husk Co-Compost

Nicholas kojo Njada^{1*}, Bright Mayinl Laboan², Bernard Adu Gyan¹, Richard Amankwah Kuffour¹, Sabastian Samuel Kwesi¹

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ABSTRACT

Rice husk and fecal sludge are significant waste management challenges in Ghana, often leading to sanitation and environmental issues. Given their complementary nutrient profiles (rice husk: potassium, organic carbon; fecal sludge: nitrogen, phosphorus), co-composting these bio-wastes presents a promising agricultural application. These biowastes, while rich in nutrients, can contribute to pollution when improperly managed. This study aimed to mitigate these issues by co-composting rice husk and fecal sludge to produce a nutrient-rich compost suitable for agricultural applications. This study aimed to optimize rice husk compost through co-composting with fecal sludge. A Completely Randomized Design (CRD) experiment was conducted at the University of Skill Training and Entrepreneurial Development (AAMUSTED) Mampong campus. Rice husk (R) and fecal sludge (F) were mixed in varying ratios (RF 1:0.5, 1:1, and 1:2) and subjected to aerobic composting. Results indicated that raw rice husk was nutrient-deficient compared to fecal sludge. However, co-composting significantly enhanced nutrient content. The RF 1:2 ratio yielded the highest total nitrogen (21,000 mg/kg), phosphorus (9,300 mg/kg), and mineralized nutrients. Pathogen reduction was also observed, with RF 1:2 demonstrating the lowest levels of total and fecal coliforms. Based on these findings, co-composting rice husk and fecal sludge in a 1:2 ratio is recommended for producing high-quality compost that can be used to improve agricultural productivity while mitigating waste management challenges.

INTRODUCTION

Due to the global population boom, agricultural waste production has surged, with rice husk being a significant byproduct. Rice husk is abundantly generated by the rice milling industry on farms and at processing facilities (Hisham & Ramli, 2019). Globally, approximately 150 million tons of rice husk are produced annually (Madin *et al.*, 2023).

In Ghana, rice production has steadily increased, with yields fluctuating between 1.7 and 2.7 tonnes per hectare (Abebrese *et al.*, 2023). Notably, production levels have more than doubled since 2007, demonstrating an average annual growth rate of over 15% from 2005 to 2010 (Islam, 2020). This trend underscores the increasing volume of rice husk generated within the country.

Ghana's primary rice-producing regions, the Northern, Volta, and Upper East, annually generate between 45,000 and 60,000 tonnes of rice husk each. The Northern region stands out as the leading producer, with approximately 63,000 tonnes harvested in 2009 (Seglah *et al.*, 2022).

In 2012, Ghana harvested 481 metric tons of paddy rice, resulting in 332 metric tons of milled rice (Abebrese *et al.*, 2023). However, the management of rice husk remains a significant challenge in the country (Latifah *et al.*, 2015).

In rice-producing areas like the Kpong Irrigation Project, rice straw is often left in the fields after harvest, while rice bran is sold to livestock farmers. Rice husk, on the other hand, is frequently discarded near milling machines, accumulating and eventually being burned to reduce its volume (Murimi & Gbedemah, 2018). While controlled

burning can produce rice husk ash (RHA), which has potential health and environmental benefits, the process also generates harmful smoke (Hanuni Ramli, 2019).

Rice husk (RH) is a challenging material to decompose due to its high carbon-to-nitrogen ratio (C:N) and content of silica and lignin (Freitas *et al.*, 2023). This makes it unsuitable for direct agricultural use as it remains largely undecomposed in the soil (Demir & Gülser, 2021). Composting can help reduce the C:N ratio, but RH compost still persists in the soil longer than other organic wastes (Aziz *et al.*, 2022).

Fecal sludge (FS) is a slurry or semisolid waste generated from the collection, storage, or treatment of human excreta and toilet wastewater (Jain *et al.*, 2022; Samal *et al.*, 2022). FS obtained from on-site sanitation systems typically requires treatment before disposal (Samal *et al.*, 2022).

In many developing countries, fecal sludge is often disposed of improperly, including dumping in pits, drainage systems, and water bodies without treatment (Liu *et al.*, 2023). Ghana faces similar challenges in fecal matter management. However, this waste is rich in nutrients and microbes and can be effectively co-composted with rice husk for agricultural applications, closing the nutrient loop (Greff *et al.*, 2022). Composting reduces the mass and volume of organic materials through microbial degradation and the release of carbon dioxide (Kausar & Khwairakpam, 2022; Yang *et al.*, 2019; Wu *et al.*, 2019). The increasing global population has led to a surge in biowaste generation, with Africa accounting for 60% of

¹ Department of Public Health, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong-Ash, Ghana

² Soil Research Institute, Council for Scientific and Industrial Research, Accra, Ghana

* Corresponding author's e-mail: nicholaskojo14@gmail.com

the total (Emenike *et al.*, 2013). Sewage sludge production is estimated at 40-60 grams of dry matter per resident per day in both urban and industrial sewage plants, with projections for further growth (Ahmed *et al.*, 2023). Ghana's treatment plants produce approximately 350-900 cubic meters of wet sludge daily, depending on their size (Ahmed *et al.*, 2023).

The improper disposal of fecal matter and rice husk (RH) poses significant environmental concerns in developing countries. According to the Food and Agriculture Organization (FAO), agricultural waste, including RH, has increased due to rising food demand. Burning RH at landfills generates ash and smoke, contributing to water pollution and global warming (Pode, 2016). Similarly, disposing of fecal sludge in landfills can release nutrients and pathogens into surface waters, leading to eutrophication, water quality degradation, and human health risks (Cofie *et al.*, 2009).

While efforts have been made to treat sanitary waste, recycling and reuse, particularly for fecal sludge and RH, remains limited (Loiko *et al.*, 2022). Although some studies have explored the treatment and co-composting faecal sludge with cocoa pod, oil palm punch and municipal waste (Coffie *et al.*, 2016; Nartey *et al.*, 2017), further studies on faecal sludge and rice husk co-composting is yet to be explored and this study is therefore needed to inform policy direction.

Numerous technological advancements have been proposed to enhance sanitation systems through organic solid waste recycling (Tsui & Wong, 2019). Co-composting offers an effective solution for managing organic waste, particularly when combining human waste and rice husk (Majbar *et al.*, 2018). These materials complement each other, with human waste providing nitrogen and moisture, while rice husk offers carbon and bulk (Gallizzi, 2018).

Although rice husk has a high C:N ratio and low nutrient content, its waxy surface and silica content can hinder microbial decomposition (Younis *et al.*, 2022). Converting biowastes into valuable organic fertilizer resources addresses environmental concerns and provides economic benefits (Mushtaq & Khalid, 2019).

While composting and co-composting in Ghana have traditionally focused on municipal waste and sawdust, exploring other materials, such as fecal sludge and agricultural wastes, offers potential benefits (Gbenatey *et al.*, 2017). By studying the co-composting of fecal sludge and rice husk, researchers can identify optimal mixing ratios for nutrient content and pathogen reduction. Additionally, investigating the nutrient availability in the resulting compost is essential for informed decision-making and implementation.

This study aimed to enhance fecal sludge compost quality by co-composting it with rice husk. Specific objectives included: 1) characterizing the physico-chemical properties and bacterial load of fecal sludge and rice husk, 2) determining the optimal mixing ratio for NPK content and bacterial reduction, and 3) assessing the nutrient availability for plants in the co-compost.

By addressing these objectives, this study contributes to a better understanding of rice husk and fecal sludge co-composting, offering valuable insights for waste management practices and agricultural applications. The findings can inform policy decisions, improve composting processes, and provide valuable resources for future research.

MATERIALS AND METHODS

Rice husk was collected from local milling points, while fecal sludge was obtained from the Mampong Municipal faecal sludge disposal site. Both materials were transported to the composting site at AAMUSTED.

Compost Experimental Design

A windrow composting method was employed in a pilot-scale experiment. This method is economical and easy to manage for small-scale operations. The experiment utilized a complete randomized design (CRD) with four treatments (mixing ratios) and three replications.

The four treatments were:

- Treatment 1; control: 100% rice husk
- Treatment 2: 1:0.5 rice husk to fecal sludge
- Treatment 3: 1:1 rice husk to fecal sludge
- Treatment 4: 1:2 rice husk to fecal sludge

The composting heaps were turned weekly to aerate the material and promote microbial activity. Water was added periodically to maintain optimal moisture content.

Laboratory Analysis and Data Analysis

Laboratory analyses were conducted on both the raw materials and the compost samples. Parameters measured included:

- Physico-chemical properties: Organic Carbon (OC), pH, electrical conductivity (EC), moisture content (MC)
- Nutrients: Total and available nitrogen (N), phosphorus (P), and potassium (K)
- Microbial characteristics: Total coliform (TC) and fecal coliform (FC)

Data analysis was performed using the GenStat 12th edition statistical package. Analysis of variance (ANOVA) and least significant difference (LSD) tests were used to evaluate the effects of different mixing ratios on compost quality.

RESULTS AND DISCUSSIONS

Characterization of Rice Husk and Faecal Sludge

The organic carbon (OC) content of rice husk was very high with relatively high potassium (K) while that of faecal-sludge had a high potassium (K), total nitrogen (TN), and phosphorus (P) as compared to the lower levels found for rice husk (Table 4.1). Rice husk contained a high C: N ratio while that of faecal sludge was low. The pH of both rice husk and faecal sludge was rated slightly acidic. The electrical conductivity (EC) of rice husk was low while high in faecal sludge. Microbial load (total and fecal coliform) for faecal sludge was very high while that of rice husk was low.

Table 1: Characterization of raw rice husk and faecal sludge

Property	Rice Husk	Faecal Sludge	P value
OC (%)	45.03±1.68	32.66±1.16	< 0.01
N (%)	0.47±0.17	3.15±0.11	< 0.01
C: N	95 ±3.30	10.36 ±2.17	< 0.01
P (%)	0.05 ±0.19	0.79 ±0.15	< 0.01
K (%)	0.81±0.14	1.26 ±1.10	< 0.01
pH	5.5 ±0.62 ^a	6.90 ±0.18	< 0.01
EC (ds/m)	0.77±0.15	5.92 ±0.17	< 0.01
Tot. Coliform (CFUg ⁻¹)	2.3x10 ³	2.4x10 ¹⁷	< 0.01
Feacal Coliform (CFUg ⁻¹)	0	4.2x10 ¹³	< 0.01
Moisture (%)	21.1±1.16	90.24±0.10	< 0.01

(Source: field experiment)

Physiochemical Properties and Microbial Load as Affected by Compost Mixing Ratios

Temperature

The daily temperature recorded showed the same pattern for all the treatments (RF1:0-RF 1:2). It started from 30.0 °C reached maximum temperature within the first week at 55.0 °C and dropped back to 25.0 °C toward the end of the composting process. Among the RF mixing ratios, RF

(1:2) produced the highest temperatures followed by RF (1:1) and RF (1:0.5). The temperature within the first 40 days showed that all RF mixing ratio treatments recorded higher temperatures than Rice-husk only. A temperature measured for all the treatments after 40 days showed low temperature at 25.0 °C and was constant to the end of the treatment (Figure 1).

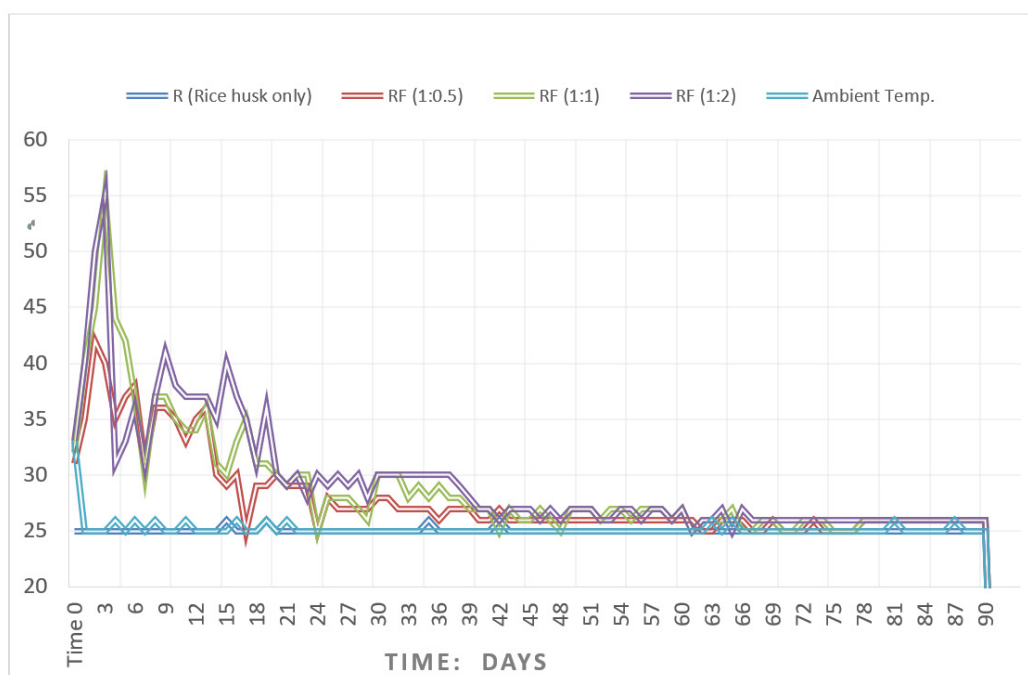


Figure 1: Temperature of mixing ratios for rice husk and faecal matter co-compost

pH and Electrical Conductivity

Rice husk and faecal sludge (RF) ratios recorded different pHs throughout the experiment except on day 30 when RF (1:0.5) was comparably the same to sole rice husk of pH 6.2 (Table 2). Also, on the 60th day R (1:0) and RF (1:1)

had the same pH of 6.8 (Table 2). Electrical conductivity values for all rice husk-faecal sludge treatments were higher ($p < 0.05$) than for sole rice husk (Table 3). The EC of RF ratios were significantly different ($p < 0.05$) with a corresponding increase in faecal sludge contents.

Table 2: Levels of pH in RF co-composting treatments

Treatments	Day (0)	Days (30)	Day (60)	Day(90)
R (Rice husk only)	5.5 ^a	6.2 ^a	6.8 ^a	6.6 ^a
RF (1:0.5)	6.1 ^b	6.2 ^a	6.7 ^a	6.9 ^b
RF (1:1)	6.2 ^c	6.4 ^b	6.8 ^a	6.8 ^b
RF (1:2w)	6.4 ^d	6.6 ^b	6.6 ^a	6.9 ^b

Different alphabets indicate significant differences among treatments (Source: field experiment)

Table 3: Levels of Electrical conductivity (ds/m) in RF co-composting treatments

Treatments	Day (0)	Days (30)	Day (60)	Day(90)
R (Rice husk only)	0.77 ^a	1.82 ^a	0.47 ^a	0.53 ^a
RF (1:0.5)	2.23 ^b	2.64 ^b	0.65 ^b	2.95 ^b
RF (1:1)	4.45 ^c	2.68 ^c	1.03 ^c	3.44 ^c
RF (1:2)	4.93 ^d	4.12 ^d	1.52 ^d	3.87 ^d

Different alphabets indicate significant differences among treatments (Source: field experiment)

Total NPK and mineralized NPK at the end of the co-composting experiment

Among all the treatments, RF (1:2) had higher total N and P (mg/kg) of (2.1% and 0.98%) respectively followed by RF (1:1) and RF (1:0.5) which had (1.40%) for N and P% RF 1:1 (0.68), RF 1:0.5 (0.42) while rice husk only recorded the lowest at the end of the study with N% of (0.5) and P% of (0.4) (Table 4.). On the contrary, higher

total K (mg/kg) was observed in sole rice husk followed by RF (1:0.5) and RF (1:1) while RF (1:2) recorded the least. Mineralized N and P were highest in RF (1:1) followed by RF (1:2) and RF (1:0.5) with the lowest recorded in sole rice husk. But mineralized K was more pronounced in RF (1:2) followed by RF (1:1) and RF (1:0.5) with sole rice husk recording the lowest (Table 4).

Table 4: Levels of total NPK, mineralized NPK, and organic NPK on (RF) co-composting at (t=90 days)

Treatment	Total (mg/kg) (%)		Mineralized (mg/kg)	(%)	Organic (mg/kg)(%)	
K R (Rice husk only)	5000	0.50	100	2	4900	98
RF (1:0.5)	14000	1.40	1260	9	12740	91
RF (1:1)	14000	1.40	2480	18	13520	82
RF (1:2)	21000	2.10	2940	14	18060	86
K R (Rice husk only)	4000	0.40	120	3	3880	97
RF (1:0.5)	4200	0.42	320	8	3880	92
RF (1:1)	6800	0.68	680	10	6120	90
RF (1:2)	9300	0.98	1581	17	7719	83
K R (Rice husk only)	12200	1.22	1220	10	10980	90
RF (1:0.5)	10000	1.00	1400	14	8600	86
RF (1:1)	9300	0.93	1581	17	7719	83
RF (1:2)	7400	0.74	2072	28	5328	72

(Source: field experiment)

Levels of OC% in rice husk and fecal sludge co-composting mixing ratios

The organic carbon (OC) percentage was determined during the composting processes and at the end of the treatment cycle. The percentage OC at t=0 was 45.03%, 42.1%, 40.5%, and 30.2% for T1, T2, T3, and T4. After

day 30 of composting, a decrease was recorded in the %OC for the treatments T1-T4 by the following (40.03%, 37.21%, 32.56%, and 29.09%) respectively. From day 60 to day 90 of the composting processes, the %OC dwindled but was not significant (Table 5).

Table 5: Levels of OC% in rice husk and faecal sludge co-composting mixing ratios

Treatment	Time 0	30 days	60 days	90 days
R(Rice husk only)	45.03 ^a	40.03 ^a	39.65 ^a	38.61 ^a
RF(1:0.5)	40.21 ^b	37.21 ^b	35.05 ^b	32.17 ^b
RF(1:1)	36.32 ^c	32.56 ^c	29.63 ^c	27.65 ^c
RF(1:2)	33.64 ^d	29.09 ^d	27.05 ^d	25.24 ^d
P value	<0.01	<0.01	<0.01	<0.01

Different alphabets indicate significant differences among treatments
(Source: field experiment)

Carbon to Nitrogen Ratio (C: N)

The C:N ratio was also a stability factor. There was a significant ($p < 0.05$) difference in C: N amongst the various treatments throughout the composting period (Table 6). The C: N for R (rice husk only) was linearly constant (95-93) throughout the composting period while that of all RF mixing ratios decreased C/N of (36.62-10.6). Carbon: Nitrogen contents in R (rice husk only)

were higher than all RF mixing ratios by 297-392 % (RF 1:0.5), 387-544 % (RF 1:1), and 495-778 % (RF 1:2). Carbon: Nitrogen (C: N) recorded in RF 1:0.5 treatments was 36.2-18.17 higher than (RF 1:1) 25.15-14.46 and (RF 1:1) obtained higher C: N than that of (RF 1:2) which recorded 20.23-10.61. The order of C: N was: RF1:2 < RF1:1 < RF1:0.5 < R (rice husk only) (Table 6).

Table 6: C:N ratio as influenced by rice husk-faecal sludge co-composting ratios

TREATMENTS	C: N ratio as influenced by rice husk-faecal sludge co-composting ratios			
TIME (DAYS)	Day= 0	30 days	60 days	90 days
R(Rice husk only)	95.12	95.08	94.4	93.17
RF(1:0.5)	36.62	27.82	23.74	18.91
RF(1:1)	25.15	19.5	16.1	14.46
RF(1:2)	20.23	15.97	12.21	10.61

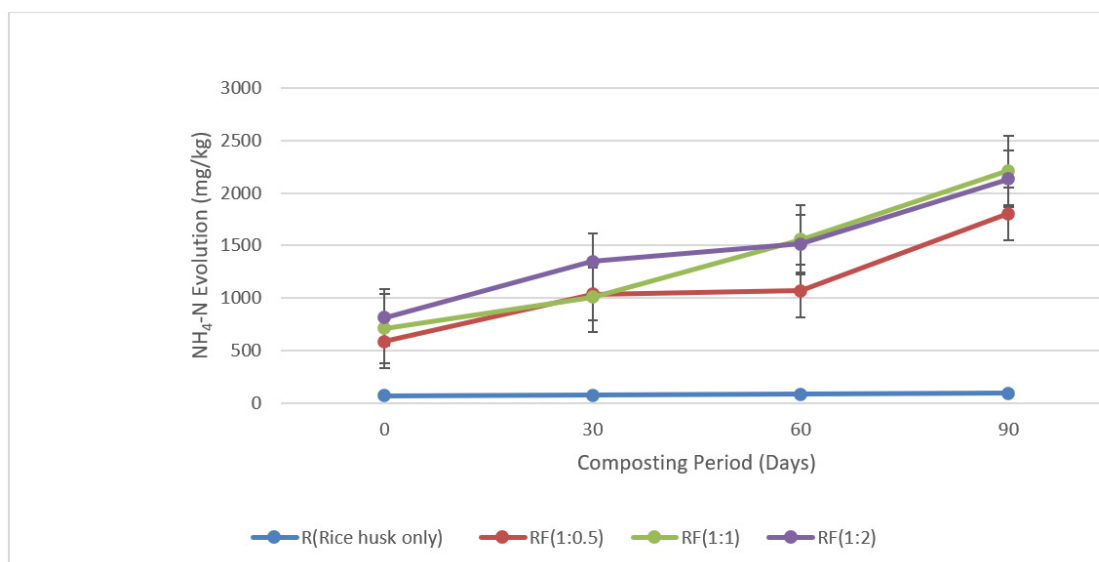
Significance* declared at 0.05
(Source: field experiment)

Ammonium-Nitrogen ($\text{NH}_4^+\text{-N}$)

The $\text{NH}_4^+\text{-N}$ trends amongst the various compost mixing ratios were significantly different ($p < 0.05$). All the rice husk-faecal sludge (RF) mixing ratios, RF (1:0.5), RF (1:1), and RF(1:2) released from $t=0$ periods of composting with values of 585 mg/kg, 712 mg/kg and 814 mg/kg concerning the mixing ratio, $t=90$ significantly higher ($p < 0.05$) with values of 1803 mg/kg, 2215 mg/kg and 2135 mg/kg than sole rice husk (R) released from the start to the end of the composting periods with 70 mg/kg and 93 mg/kg respectively. The $\text{NH}_4^+\text{-N}$ content was released from Sole Rice husk from the beginning of the composting periods with 70 mg/kg to the end of the composting periods with 93mg/kg.

The $\text{NH}_4^+\text{-N}$ content in RF (1:1) from $t=0$ periods of composting through to the end of the composting $t=90$ increased with 712 mg/kg and 2215 mg/kg and this increment was higher than sole rice husk which recorded

(70-93) from the beginning of the composting period to the end of the composting period by 13% - 40% respectively. Maximum Ammonium-Nitrogen released from RF (1:05) and RF (1:2) during the composting period was up to 1803 mg/kg and 2135 mg/kg by 40% and 42% respectively, which were higher than the maximum Ammonium-Nitrogen recorded in sole rice husk with 90mg/kg and by 29%. Ammonium-Nitrogen recorded from the beginning to the end of the composting period in RF (1:2) was higher than the Ammonium-Nitrogen recorded from the beginning to the end of the composting period in RF (1:0.5) by 14-42%, 13-40% respectively. Ammonium-Nitrogen recorded in RF (1:2) throughout the composting period was higher than Ammonium-Nitrogen levels in RF (1:1) by 14-42 % and 13-41% respectively. Ammonium-Nitrogen content was in order: RF (1:1) > RF (1:2) > RF (1:05) > R (Rice husk only) (Figure 2).



Significance *declared at p level of 0.05

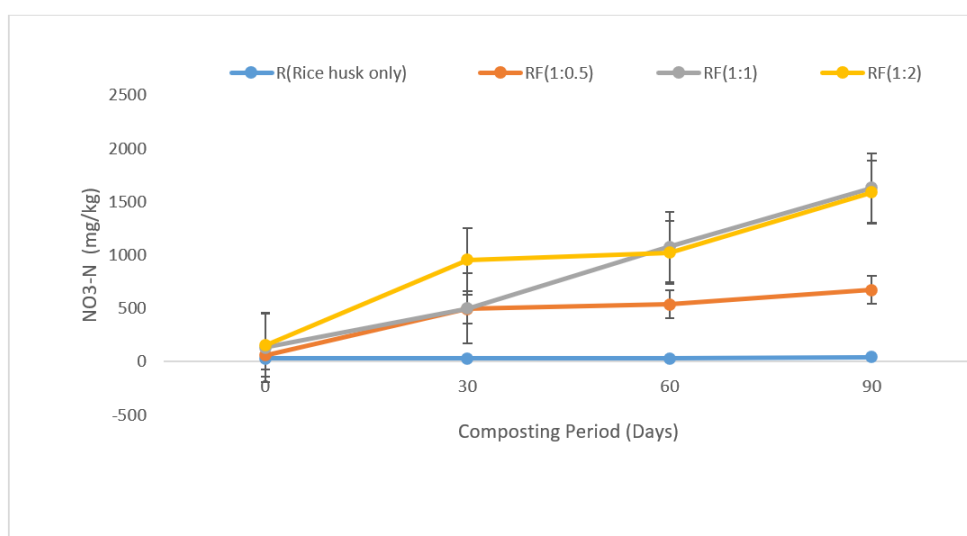
Figure 2: Effects of rice husk-feecal sludge co-composting on Ammonium-Nitrogen

Nitrate-Nitrogen ($\text{NO}_3\text{-N}$)

The study shows that there was a significant difference amongst the various compost mixing ratios at ($p < 0.05$) for Nitrate-Nitrogen ($\text{NO}_3\text{-N}$) throughout the study. Among these were RF (1:0.5), RF (1:1), and RF(1:2) the study showed $t=0$ periods composting with values of 59 mg/kg, 134 mg/kg, and 151 mg/kg for the mixing ratios. They were significantly higher at ($p < 0.05$) as compared to $t=90$ with values of 674 mg/kg, 1630 mg/kg, and 1588 mg/kg concerning the mixing ratios. Also, there was low Nitrate-Nitrogen ($\text{NO}_3\text{-N}$) for the control thus sole rice husk (R) compost from the $t=0$ to $t=90$ of the composting periods with 32 mg/kg and 44mg/kg respectively as compared to the Nitrate-Nitrogen ($\text{NO}_3\text{-N}$) for the treatments with the faecal (Figure 3). The Nitrate-Nitrogen concentrations of RF (1:1) from the early periods of composting through to the end of the

composting increased linearly with 134 mg/kg and 1630 mg/kg respectively and this increment was higher than the sole rice husk from the beginning to the end of the composting period by 24 - 49% respectively.

Maximum Nitrate-Nitrogen recorded in RF (1:0.5) and RF (1:2) during the composting period were up to 674 mg/kg and 1588 mg/kg and by 38% and 43% respectively, which were higher than the maximum Nitrate-Nitrogen released from sole rice husk with 44mg/kg and by 31%. Nitrate-Nitrogen recorded from the beginning of the compost to the end of the composting period in RF (1:2) was higher than the Nitrate-Nitrogen recorded from the beginning to the end of the composting period in RF (1:0.5) by 25-42%, 23-38% respectively. Nitrate-Nitrogen recorded from RF (1:2) throughout the composting period was higher than Nitrate-Nitrogen recorded in RF (1:1) by 25-42 % and 24-41% respectively.



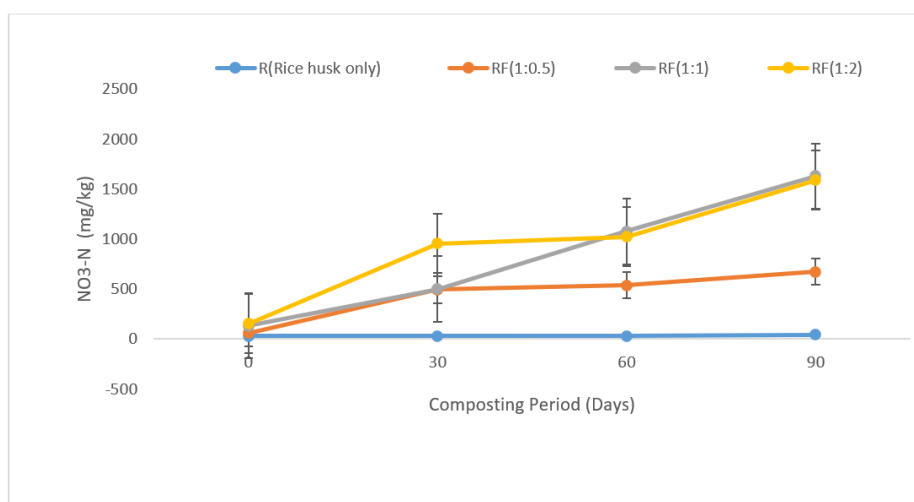
Significance *declared at the p level of 0.05

Figure 3: Nitrate-Nitrogen ($\text{NO}_3\text{-N}$) levels in rice husk-feecal sludge treatment co- composting ratios

Phosphorus

The available phosphorus content levels from the beginning to the end of the composting period were significantly ($p < 0.05$) different amongst the various treatments (Figure 4). All the rice husk-feecal sludge (RF) mixing ratios, RF (1:0.5), and RF (1:2) recorded significantly ($p < 0.05$) higher increase for Phosphorus than sole rice husk (R) throughout the composting period except for RF (1:1) which increased from $t=0$ to $t=60$ and dropped slightly at $t=90$. This was higher than the

Phosphorus content that was recorded from the early to the final stage of the composting process in sole Rice Husk (R). The Phosphorus content levels in R (Sole Rice Husk) increased slightly from the beginning to the end of the composting period 131mg/kg -173mg/kg. The Phosphorus content recorded for RF (1:2) from the beginning to the end of the study was higher than all the other treatments. The Phosphorus content was in these order: RF (1:2) > RF (1:1) > RF (1:05) > R (Rice husk only).



Significance* declared at p level of 0.05.

Figure 4: Levels of mineral P in rice husk –fecal sludge co-composting ratios

Potassium (K) study was significantly different at ($p < 0.05$) amongst the various compost mixing ratios. All the rice husk-feecal sludge (RF) treatments, RF (1:0.5), RF (1:1), and RF (1:2) produced significantly higher Potassium as compared to sole rice husk (R) during the co-composting. The Potassium levels in the rice husk-feecal sludge (RF) treatments followed a sinusoidal trend meaning it rose and dropped again or dropped while that of R (Sole Rice Husk) was linear during the experiment. The Potassium levels from the RF (1:2) compost increased from the beginning to the 60th day and decreased towards the end

of the treatments from 1617 mg/kg up to 2819 mg/kg and dropped to 2108 mg/kg, which was higher than the sole rice husk (R) (60-149 %), RF1:0.5 (33-144 %) and RF1:1 (6-23 %). Available Potassium recorded in RF (1:1) was higher than sole rice husk (R) and RF1:0.5 with (31-134 %) and 8-131%, respectively. RF1:05 recorded higher available Potassium of 21-117% than sole rice husk (R) during the experiment. Available Potassium content was in the order: RF (1:2) > RF (1:1) > RF (1:05) > R (Rice husk only) (Figure 5).

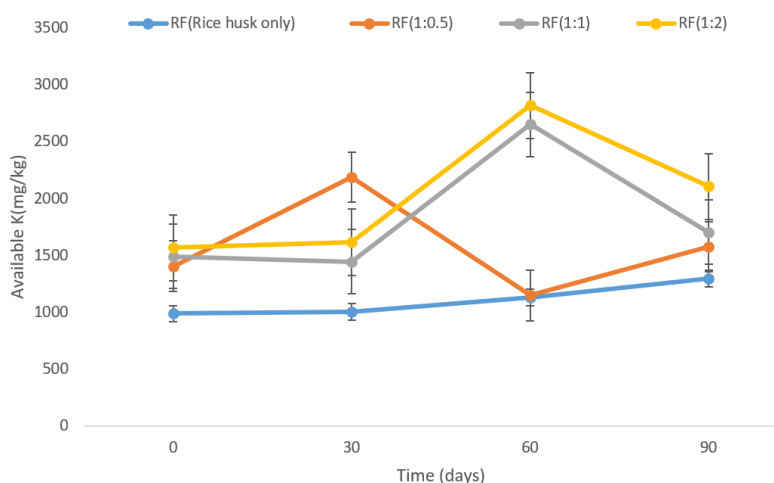


Figure 5: Levels of mineralized K in RF co-composting ratios

Microbial Load

Total coliform and faecal coliform markedly varied among the various mixing ratios at the beginning (time 0) and at the end (90 days) of the study. They were high with increasing faecal sludge content (Figure 6). The microbial load for rice husk-faecal sludge treatments (RF) at time

zero was higher than that recorded during the cycle. However, microbial load recorded for rice husk only (R) rather increased during the composting experiment. Thus, microbial content in sole rice husk treatments was higher during the co-composting period than at time zero of the study

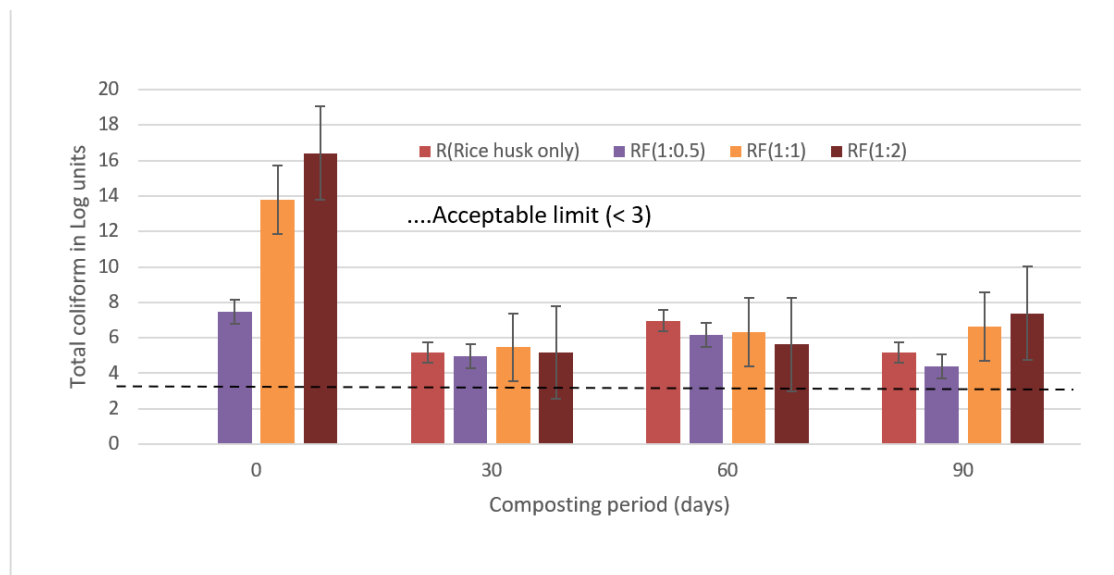


Figure 6: Impact of rice husk and faecal sludge compost mixing ratios on microbial load

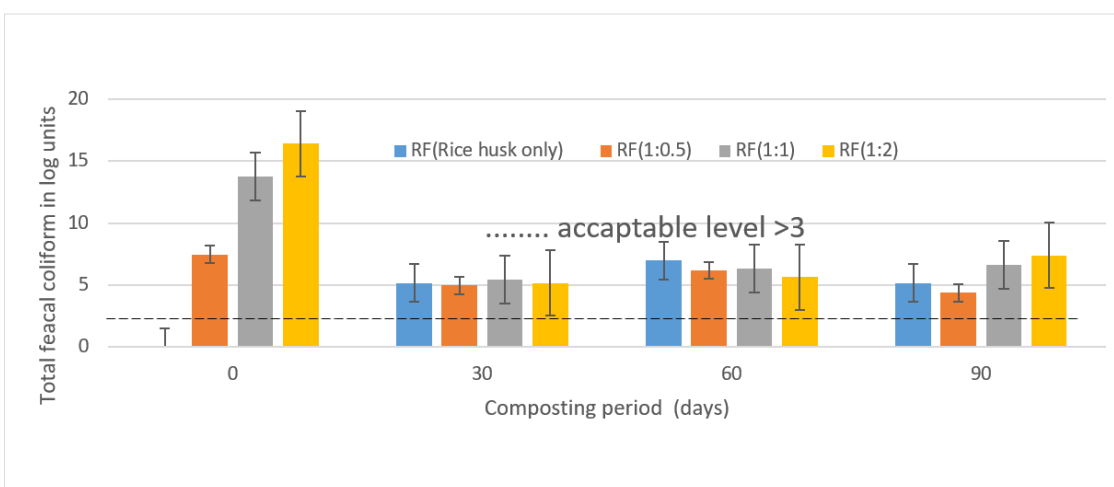


Figure 7: Microbial load defined in log units: B) Faecal coliform

Maturity determination of RF co-compost.

Several studies on rice husk composting suggested a period of 90-150 days (approximately 3-5 months) using the windrowing method has been shown to result in a mature co-compost product. The ratio of $\text{NH}_4^+\text{-N}$ to $\text{NO}_3^-\text{-N}$ was also used to determine the stability of the compost produced. Stable compost is said to have an $\text{NH}_4^+\text{-N}/\text{NO}_3^-\text{-N}$ ratio between 0.16-0.5 which gives a sense of the compost maturity depending on the feedstock. Ammonium to nitrate ratio for rice husk and

faecal sludge co-composting found in studies elsewhere after 90 days was between 1.5-3. Which is not different from the findings in this study as follow, RF (Rice husk only) 2.13, RF (1:0.5)-2.67, RF (1:1) 1.36, RF (1:2)-1.34 (Figure 3). The study showed that the ratio of $\text{NH}_4^+\text{-N}/\text{NO}_3^-\text{-N}$ at the end of the composting (day 90), all the treatments were above the 0.16-0.5 recommended ratio for stable composts, but were within the findings of other studies that used similar feedstock so it could be considered mature by the day 90.

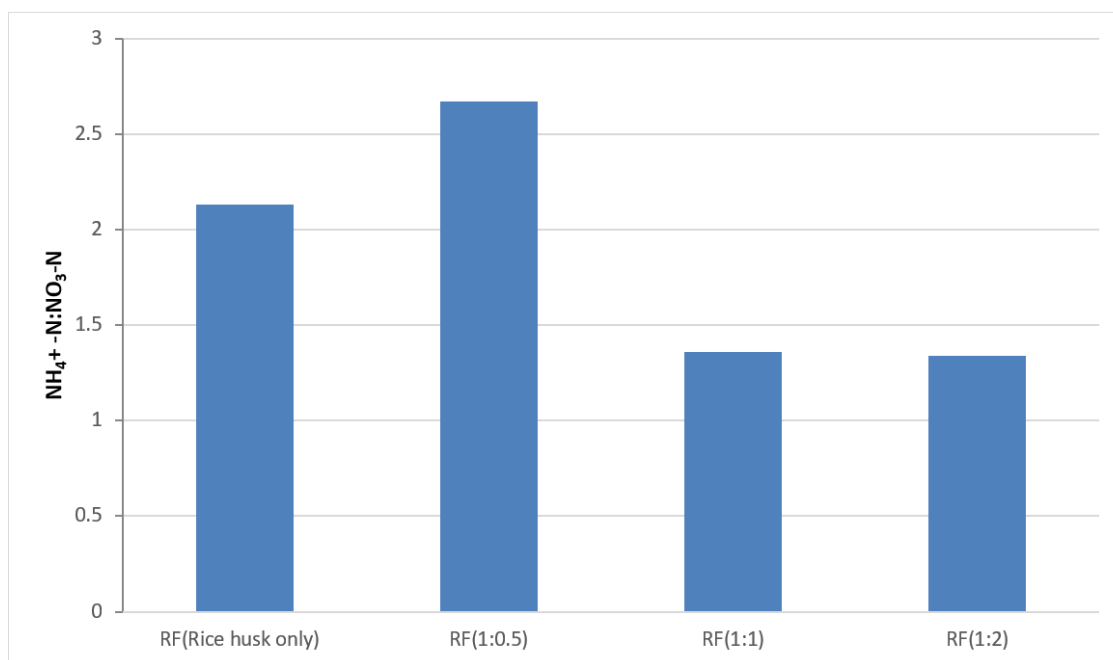


Figure 8: Maturity Determination of RF co-compost

Best Mixing Ratios Determination for Highest NPK Contents

To estimate the best mixing ratio that produced the highest quality compost, the analyses of variance on the total/mineralized NPK levels were observed in (Table 7). There was a significant difference between mixing ratios in terms of NPK content. Based on (Table 3), the mixing ratio that gave the highest NPK was RF (1:2) with total/mineralized NPK (2940 mg/kg, 1581 mg/kg, and 2072

mg/kg) respectively which was high above the other treatment. On its quality, though the microbial load of RF (1:2) was high, the treatment started on a very high microbial load of 13.58 cfu/100g to less than half by the end of the treatment at 6.38 cfu/100g based on these and other nominal values RF (1:2) performed better than the other treatments and therefore was considered the best mixing ratio for the rice husk and fecal sludge co-compost.

Table 7: Total and mineralized NPK content of compost mixing ratios at the end of the experiment

Treatments	Total (mgkg ⁻¹)	Mineralized (mgkg ⁻¹)
N		
RF(Rice husk only)	5000 ^a	100 ^a
RF (1:0.5)	14000 ^b	1260 ^b
RF (1:1)	14000 ^b	2480 ^c
RF (1:2)	21000 ^c	2940 ^d
P value	< 0.001	< 0.001
P		
RF(Rice husk only)	4000 ^a	12 ^a
RF (1:0.5)	4200 ^b	120 ^b
RF (1:1)	6800 ^c	680 ^c
RF (1:2)	9300 ^d	1581 ^d
P value	< 0.001	<0.001
K		
RF(Rice husk only)	12200 ^a	1220 ^a
RF (1:0.5)	10000 ^b	1400 ^b
RF (1:1)	9300 ^c	1581 ^c
RF (1:2)	7400 ^c	2072 ^d
P value	< 0.001	< 0.001

The mean difference is significant at 0.05. Different alphabets denote differences in treatments

Discussion

Feedstock characterization

The quality of compost depends on the feedstock. In this study rice husk and faecal sludge were used. The proximate analysis of these materials showed a low and high N content in the rice husk and faecal sludge, respectively, and high OC (%) in the rice husk and a low OC (%) in faecal sludge. This is similar to the findings of other studies done elsewhere (Rathi *et al.*, 2018; Qadwe *et al.*, 2022). High OC (%) in rice husk and the high nitrogenous base of faecal sludge make the best pair for a co-compost since it might be the reason for the quality of the compost produced. Also, the High P content in faecal sludge (Mamera *et al.*, 2022) and, high K in rice husk (Bakar *et al.*, 2016) could be the reason for the increase of P and K in the rice husk and faecal sludge co-compost. Acidic and slightly acidic rice husk and faecal sludge fall within the acceptable level agronomically and compost is assumed to balance the pH to permissible levels.

Rice husk is a byproduct of rice milling and is composed of cellulose, hemicellulose, and lignin. These compounds are all relatively resistant to decomposition, which can lead to the accumulation of organic acids in the husk (Qadwe *et al.*, 2022). In the same way, faecal sludge is a mixture of human waste, toilet paper, and other organic materials. While faecal sludge also contains potassium, its overall composition is different from rice husk. Faecal sludge undergoes microbial decomposition processes faster, and the resulting breakdown of organic matter might lead to the production of high concentrations of certain elements, including nitrogen and potassium as compared to rice husk. The electrical conductivity of rice husk (0.77 ds/m) was within the acceptable level but that of faecal sludge (5.9 ds/m) exceeded by 1.9 ds/m but that was not different from what is found in the literature (Singh *et al.*, 2022). Higher total coliform and faecal coliform (Table 4.1) could result in a level that might be above the standard threshold after co-composting since not all the microbes may be killed or destroyed during the co-composting period. The electrical conductivity and microbial content mentioned in the statement suggest that faecal sludge may have a higher level of organic matter and microbial activity compared to rice husks. This can contribute to higher electrical conductivity and potentially higher levels of total coliform and faecal coliform.

Physicochemical Properties and Microbial Load of Rice Husk and Faecal Sludge (RF) Co-Compost Mixing Ratios

Temperature

Higher temperature for all RF treatments than rice-husk only till day 40 might be due to higher oxidation of organic matter in the RF ratios relative to rice-husk only. Thus, the presence of faecal sludge in the RF treatments provided a more suitable substrate for microbes to decompose the organic matter, unlike sole rice husk. Even though RF co-compost treatments for the first few days recorded temperatures up to 55 °C it did not exceed

55 °C. To ensure the safety of composts, the temperature during the composting must exceed 55 °C, within the first 2 weeks to kill a majority of the micro-organisms and above 60 °C to destroy the presence of seeds within the compost (Hashim, 2022). The temperature recorded in this study was in line with Manga *et al.* (2022) who recorded a maximum temperature of 45 °C at the initial days of the faecal sludge –agricultural wastes co-composting study. While the temperatures obtained in the current study did not meet safety requirements, they exceeded 45 °C reported by (Gocmen *et al.*, 2022).

Lower temperatures measured in this study might be attributed to the composting methods employed (open windrows) or to the dissipation of heat due to the small volume of the piles (Oshins *et al.*, 2022) and frequent turning. This was supported by the findings of a previous study by Yu *et al.* (2022) which indicated that heap sizes affect the temperature build-up during composting. Smaller heaps heat up faster than larger heaps. This is because the smaller surface area-to-volume ratio of a smaller heap means that heat is lost faster. Larger heaps can reach higher temperatures than smaller heaps. This is because the larger volume of a larger heap means that there is more material for the microbes to decompose, which generates more heat.

Total and mineralized NPK

There was significantly higher mineralized NPK in all RF ratios than in sole rice husk. This might be due to the impact of the micro and macro-organisms on the NPK content of the raw faecal sludge in the rice husk in this study (Samal *et al.*, 2022). Total N, P, and K content at the end of the study was high with increasing faecal sludge while total K was decreasing with increasing faecal sludge and Rice husk contents, respectively. This could be linked to high N, P (3 & 0.8 %), and K (1.26 %) in faecal sludge and rice husk in the study. It was estimated by other studies that the plant's nutritional content found in the faecal proportion were in a percentage proportion of 1-2% nitrogen (N), 2-5% phosphorus (P), and 1-2% potassium (K) (Bai *et al.*, 2023; Kumar & Gupta, 2022). However, the current study unraveled that the plant nutrient content was distributed to faecal proportions: 3 % N, 0.8 % P, and 0.8 % K. This suggests that the mineralization of the faecal sludge releases richer amount of N, P, and K into the co-compost. The percentage of mineralized NPK (2-17, 3-10, and 10-28) at the end of the co-composting experiment was low for all treatments which makes organic NPK (83-98, 90-97, and 83-90 %) the major form of the total NPK in the co-compost product (Table 4). This implies that, to some extent, the compost may release NPK nutrients slowly to plants, unlike the mineral fertilizer, where all the NPK is in the plant-available form. Nevertheless, the co-compost could have a longer residual effect on the soil as the microbes continue to mineralize the organic NPK in the available form (Mensah *et al.*, 2022).

The organic carbon witnessed a reduction throughout

the composting processes but was not significant. Some factors such as temperature, and moisture content could account for the carbon decomposition. For instance, the temperature was too low throughout the treatment processes, which showed that microbes were not able to decompose the organic matter as quickly as possible. Similarly, rice husk's cellulose, hemicellulose, and lignin are complex molecular structures that make them less accessible to microbial enzymes responsible for breaking down organic matter. The presence of these compounds in rice husk makes it more resistant to microbial degradation and decomposition processes. Additionally, lignin, in particular, is highly cross-linked to low water holding. Its complex structure could be the reason that makes it difficult for microorganisms to break it down and access the other components of rice husk (Rathi *et al.*, 2018). The higher lignin content in rice husk acts as a physical barrier, making it more difficult for microorganisms to access and break down the organic matter within the co-compost. This results in a slower decomposition rate for both the rice husk and the faecal sludge. Furthermore, the carbon-to-nitrogen ratio (C/N ratio) is an important factor in composting. Rice husk typically has a higher C/N ratio compared to faecal sludge, indicating a higher carbon content relative to nitrogen. This imbalance in the C/N ratio might lead to nitrogen limitation, as microorganisms require a sufficient amount of nitrogen to efficiently decompose organic matter. The lack of readily available nitrogen in the co-composting mixture can further slowdown the decomposition process.

Generally, the treatments with faecal sludge had significantly higher mineralized NPK % than sole rice husk piles. This indicates that the increase in faecal sludge component could lead to the compost result in higher NPK content of the final co-compost (Alarefee *et al.*, 2022). The current study is supported by previous researchers (Greff *et al.*, 2022) who reported similar observations. However, RF (1:2) treatments which contain higher faecal sludge percentage recorded a higher % mineralized NPK than RF (1:1, 1:0.5, and 1:0).

Carbon to Nitrogen Ratio (C: N); Maturity Determination of RF co-compost

A significantly decreased C: N in rice husk-faecal sludge mixing ratios compared to the rice husk only might be due to the presence of faecal sludge in the RF ratios which had high N content (Samal *et al.*, 2022). The microbes used the high N content in the RF to build their tissues which enhanced the degradation of the C-rich rice husk components in the various RF mixing ratios throughout the process (Zhang *et al.*, 2022). C: N ratio in RF treatments reduced in relation to increasing faecal sludge, compared to sole rice husk. This could be as a result of the high nitrogen base of the faecal sludge. Similar results were observed in a rice husk-chicken droppings/manure co-composting study where rice husk-chicken droppings ratio treatments recorded a significantly decreased C: N ratio relative to sole rice husk (Murimi & Gbedemah,

2019). However, C: N ratio for rice husk-chicken dropping ratios decreased with increasing chicken dropping which is in support of the current study. The high C: N ratio of rice husk makes it difficult to be degraded (Wang *et al.*, 2022), thus cannot be used for agricultural applications since it can hardly be decomposed in soil (Demir & Gülsler, 2021). As such, applications of the sole rice husk would result in nutrient immobilization which depletes soil nitrogen other than supplying nutrients.

C:N had been used to determine compost stability. However, several studies on rice husk composting suggested a $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio (Siriphan *et al.*, 2017; Rathi *et al.*, 2018; Nguyen *et al.*, 2019). A period of 90-150 days (approximately 3-5 months) using the windrowing method has been shown to result in a mature co-compost product. The ratio of $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$ was also used to determine the stability of the compost produced. A stable compost is said to have an $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ ratio between 0.16-0.5 which gives a sense of the compost maturity depending on the feedstock (Bazrafshan *et al.*, 2016). Ammonium to nitrate ratio for rice husk and faecal sludge co-composting found in studies elsewhere after 90 days was between 1.5-3.0 (Siriphan *et al.*, 2017; Rathi *et al.*, 2018; Nguyen *et al.*, 2019) which is not different from the findings in this study as follow, RF (Rice husk only) 2.13, RF (1:0.5)-2.67, RF (1:1) 1.36, RF (1:2)-1.34 (Figure 3). The study showed that the ratio of $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ at the end of the composting (day 90), all the treatments were above the 0.16-0.5 recommended ratio for stable composts, but were within the findings of other studies that used similar feedstock so it can be considered mature by the day 90.

Microbial Load as Influenced by Different Compost Mixing Ratios

Composting is one of the methods employed to sanitize faecal sludge pathogenically to achieve standards acceptable for agronomic applications. To meet this standard, total and faecal coliform concentrations must be $< 1000 \text{ CFUg}^{-1}$ or $< 3 \text{ log units CFUg}^{-1}$ (Lamolinar *et al.*, 2022). The reduction in total and faecal coliform load in the co-compost treatments at the end of the study compared to time zero can be attributed to the composting process. Composting involves the controlled decomposition of organic materials under specific conditions, including temperature, moisture, and oxygen levels. These conditions create an environment that is unfavorable for the survival and growth of coliform bacteria. However, the total and faecal coliform loads were still above a critical threshold level (Figure 7) for land applications. Microbial loads above the standard threshold in the various faecal sludge ratios at the end of the composting experiment might be due to the lower temperatures recorded which could not exceed 55°C needed for microbial destruction. This could also be because at time zero (0) the microbial contents were very high (8-18.5 log units CFUg^{-1}) for the various faecal sludge to rice husk treatments.

This could not reduce the microbial content to an acceptable standard (< 3 log units) during the co-composting study. In a related study by Nartey *et al.* (2017), all mixing ratios of faecal sludge co-composted with cocoa pod husk reduced total and faecal coliform (from 4.5-5.0 log units CFUg⁻¹) to an acceptable threshold (2.5-2.9 log units CFU g⁻¹) at the end of the composting study. This could be due to moderate pathogen loads (< 5 in log units CFU g⁻¹) in all the mixing faecal sludge ratios at time zero translating into a reduction to meet the threshold limit (< 3 log units) at the end of the experiment. Moderate pathogen load in the raw faecal material observed by Levira *et al.* (2023), could be linked to dewatering of the faecal sludge (removal of the liquid fraction) before co-composting, unlike the current study where fresh faecal sludge (solid plus liquid fraction) was used. The liquid fraction of faecal sludge might contain a higher microbial load. Hence, the observed high microbial load in the current study. Dewatering the faecal sludge before co-composting could help reduce the microbial density which will result in a level that meets the standard thresholds for land applications.

Determining best mixing co-compost ratios

Determining the best mixing co-compost ratios involves assessing the nutritional content and other nominal values in a different mixing ratio of co-compost, specifically RF (1:1), RF (1:2), RF (1:0.5), and (1:0) sole rice husk using analysis of variance to find out the significant differences. The study suggested that RF (1:1) and RF (1:2) had relatively similar NPK content, indicating that they contained comparable levels of nitrogen, phosphorus, and potassium (Table 4.4). Additionally, these two mixing ratios exhibited lower microbial loads compared to RF (1:0.5) and (1:0) sole rice husk, indicating a reduced presence of microorganisms (Figure 6). However, when comparing RF (1:1) and RF (1:2) with RF (1:0.5) and (1:0) sole Rice Husk, there were significant differences in both NPK content and microbial load. This suggested that RF (1:0.5) and (1:0) sole rice husks had distinct characteristics in terms of nutrient composition and microbial levels. Based on the analysis of variance and the nominal values of the compost quality, in terms of high NPK content and low microbial load for mixing ratios RF (1:1), RF (1:2), RF (1:0.5), and (1:0). The study concluded that RF (1:2) provided the best compost mixture based on its relatively higher NPK content and lower microbial load compared to the other mixing ratios since none was below the recommended threshold.

CONCLUSIONS

Composting rice and faecal sludge rather than disposing them into the environment is an environmentally sound means of recycling rice husk which is farm residues and faecal sludge into valuable soil amendments with many uses. At the end of the study this are the key findings;

1. Raw feed stocks characterization showed that raw rice husk is low in that nutrients and microbial load while

faecal sludge is high in nutrients and microbial load. However, the faecal sludge had a high level of NPK which impacted the RF co-compost positively.

2. The mixing ratio of co-compost, specifically RF (1:1), RF (1:2), RF (1:0.5), and (1:0) sole rice husk using analysis of variance to find out the significant differences

3. The physicochemical analysis of RF co-compost revealed that RF (1:1) and RF (1:2) ratios recorded high nutrient contents compared to RF (1:0.5) and control RF (1:0).

4. In terms of microbial load, RF (1:2) recorded high total and faecal coliform density followed by RF (1:1) and RF (1:0.5).

5. The study showed that the ratio of $\text{NH}_4^+/\text{NO}_3^-$ at the end of the composting (day 90) was above the 0.16-0.5 recommended ratio for stable composts, but it was within the findings of other studies that used rice husk and faecal sludge as feedstock so it can be considered mature by the day 90.

6. The end of the composting process showed RF (1:2) mixing ratio as the best compost among the co-composting treatments based on total NPK, mineralized NPK content, C: N ratio, and microbial load at the end of the co-compost experiment.

Recommendations

The following are the recommendations made:

1. It is recommended that Rice husk be co-composted with faecal sludge in a ratio of 1:2. Farmers should be educated to mix rice husk to faecal sludge in the ratio of 1 part of rice husk to 2 parts of faecal sludge and should be composted for 90 days after which the compost would be ready for use in farming practices with maximum results.

2. Policymakers should enforce that rice husk and faecal sludge should not be disposed of into the environment but rather be recycled into fertilizer products such as compost for both agronomic and environmental benefits.

3. The government of Ghana and non-governmental organizations should organize farmers around rice farming communities and educate them on the usefulness of their farm waste especially rice husk as raw material for compost fertilizer production.

4. Further study should be conducted on the compost from best mixing ratio to tested on crops against the chemical fertilizers to ascertain its agronomic efficiency.

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