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Effects of Fruit and Vegetable Wastes and Biodegradable Municipal Wastes Co-Mixed Composts on Nitrogen Dynamics in an Oxisol

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Abstract: Organic waste generation in developing countries is increasing and appropriate disposal methods are needed. An open aerobic composting using 20 L bins was carried out using 6 composts made using ratios of 3:1, 1:2 and 1:4 fruit and vegetable wastes (FVW):biodegradable municipal waste (BMW), with and without addition of homemade indigenous microorganisms (IMO), for 30 days to monitor compost quality. The nitrogen contents of the composts ranged from 1.52 to 2.76% N equivalent to 76–138 kg N ha⁻¹ at 5 t ha⁻¹ compost application rates. Heavy metals measured were below permissible levels of compost quality standards. Selected composts were incubated for 60 days to study nitrogen mineralization dynamics when applied to an Oxisol at the rates of 0, 5 and 10 t ha⁻¹. The results showed significant differences ($p \le 0.05$) in the amounts of NH₄-N, NO₃-N and cumulative NH₄-N + NO₃-N released. Ammonium nitrogen released was higher on days 3, 21 and/or 40 for composts 3:1 – IMO at 10 t ha⁻¹, 3:1 + IMO at 10 t ha⁻¹ and 3:1 – IMO at 5 t ha⁻¹. Cumulative N (NH₄ -N + NO₃ -N) released over control were 77.98, 64.09 and 64.35% higher for application of 3:1 + IMO, 1:2 – IMO and 1:2 + IMO, respectively, at an application rate of 10 t ha⁻¹. The increased nitrogen content, low heavy metals concentrations and the amount of mineralized N from the composts exhibit potential for increased nutrient availability when applied to a soil.

Keywords: composts quality; C/N ratio; co-composting; mineralizable N; ammonium; nitrate

1. Introduction

Global solid waste generation is predicted to increase from about 3.5 million tons per day in 2010 to more than 6 million tons per day by 2025 [1]. Fruit and vegetable wastes are the plant-tissue waste generated on farms, markets or homes and are highly putrescible. Municipal solid waste (MSW) is the waste that emanates from homes and is majorly composed of organics. The processing and consumption of fruits and vegetables accounts for almost 25–30% of wastes from their peels, seeds and inedible parts and when such wastes are not properly disposed of, it causes serious environmental hazards such as the emission of greenhouse gases as it decomposes [2,3]. Vegetables and fruit wastes have a low C/N ratio of >27:1 [4] and thus, combining with biodegradable municipal waste (BMW) would be a viable option for composting.

The surge in organic waste generation of biodegradable municipal waste (BMW) and fruit and vegetable wastes (FVW) has made it imperative for governments and policy makers to seek viable ways of disposing them safely without negative impacts on man and the environment. Indigenous microorganisms (IMO) are a microbial inoculant produced at home and can be produced from kitchen,



fruit or vegetable wastes all geared towards increasing speed of compost maturity or shortening the duration of composting time [5].

Composting is an environmentally friendly process involving the destruction of pathogens and the recycling of nutrients [6] to give a final stable product commonly used as a soil amendment. Compost substrate composition and ratio are important to have for optimized composting conditions that favor microbial activity. Studies have been made on co-composting municipal solid wastes and fruit and vegetable wastes for proper disposal and utilization. Tratsch et al. [7] reported that FVW can be used as source of nitrogen for plants when composted. Co-composting of municipal solid wastes including gardening wastes and food market wastes produced a better-quality compost with suitable agronomic properties for use as organic fertilizers and with no phytotoxic properties [8]. Co-composting using vegetable wastes and paper in a ratio of 4:1 (C/N 22.9) yielded a better quality compost in comparison to using vegetable wastes and carton in the ratio of 3:1 (C/N 31.8) [9], while composting FVW with yard wastes in the ratio of 2.5:1 produced a better quality compost in comparison to composting vegetable wastes or tree leaves and grass cuttings individually [10].

However, there is limited information on nitrogen transformation of tropical soils amended with composts derived using FVW and BMW made using different formulation ratios. Composts derived from organic wastes are important sources of plant nutrients [7]. Efficient mineralization of composts in soils are usually carried out by soil microorganisms and the abundance of favorable materials causes them to proliferate and increase in number to convert it to mineral nitrogen. During mineralization, organic nitrogen is transformed to ammonium ion (NH_4^+) by soil microbes and subsequently to nitrate (NO_3^-) by nitrification process [11]. The presence of urease in the soil allows for the release of nitrogen from added organic matter (compost) for the proliferation of soil microbes [12]. Compost application to agricultural soils can increase plant biomass production, nutrient uptake and soil enzymatic activities [12].

The objective of this study is aimed at understanding how co-composting FVW and BMW in different ratios can increase the quality of the obtained compost and to elucidate the quality of the compost obtained in a short-term incubation study on nitrogen dynamics in a tropical soil.

2. Materials and Methods

2.1. Co-Composting

In total, 6 composts were produced by co-composting FVW and BMW in different ratios (3:1, 1:2, 1:4) *w/w* on fresh weight basis with and without addition of indigenous microorganisms (IMO) using 20 L bins in an open composting. The composting was conducted for 30 days and the composts obtained were analyzed for selected maturity and stability parameters. The FVW were chopped up into small pieces of about less than 5 mm and laid out overnight to drain out the excess moisture. The biodegradable municipal waste (BMW) consisted of yard wastes, rice and paper wastes only. The paper waste and yard waste were shredded to sizes less than 5 cm in length for faster stabilization [13]. Biodegradable municipal waste (BMW) had a moisture content of 36.74%, while the fruit and vegetable wastes had a moisture content of 86.23%. Carbon, nitrogen and C/N ratio of FVW were 36.79, 1.16 and 31.72, respectively, and carbon, nitrogen and C/N ratio for BMW were 39.54, 1.15 and 34.38, respectively.

A total of 3 compost compositions were made with and without the addition of an indigenous microorganism (IMO) inoculant as the source of moisture were formulated. The IMO inoculant was made using FVW in the ratio of 1:3:10 of brown sugar: FVW: dechlorinated water, which was homogeneously mixed and kept in an air tight opaque container with daily opening to release suppressed carbon dioxide. It was ready for use after about 3–5 days when the pH was about 3.5 and it released a sweet-sour smell.

The composition of the wastes was based on the amount of FVW and BMW being generated at the wet fruit market, Serdang, Malaysia. and the student's residential flat, UPM. The results from a prior preliminary study carried out at the wet fruit market Serdang, Malaysia, showed that 70% of

FVW generated in the market were fruits with only 30% being vegetables by weight. At the students' residential flat, UPM, the composition of the BMW stood at 30, 50 and 20%, respectively, for paper waste, rice waste and yard wastes, respectively. Each of the composting ratios (3:1, 1:2 and 1:4) were composted with and without the addition of an indigenous microorganism (IMO) inoculant as a source of moisture (the BMW was simulated).

The physical and chemical properties of the composting materials were characterized before the composting process and some compost parameters were also measured at the beginning and the end of the composting. Compost pH and EC were measured using ratio 1:10 using a pH meter (Model Metrohm 827, Riverview, FL, USA) and electrical conductivity meter (Mettler Toledo SevenEasyTM Conductivity Meter S30, Hamilton, New Zealand). Dry ashing was employed for digestion of samples followed by using an atomic absorption spectrophotometer (AAS) for atomic adsorption spectrometry (AAnalyst 400, PerkinElmer, Waltham, MA, USA) for the determination of total P, K, Ca and Mg. Dry ashing (oxidation) is normally done by putting the sample in an open vessel (crucible) and destroying the organic (combustible) parts in the sample by heat (thermal decomposition) in a muffle furnace at a temperature of 550 °C and the ash is then dissolved in a suitable acid, as done by Chefetz et al. [14]. In this method, 1 g of oven dried sample was weighed into a crucible and placed in a muffle furnace to ash at an initial temperature of 300 °C for 1 h and then the temperature was subsequently raised to 500 °C for 4 h. After cooling in a desiccator, the samples were then placed in a fume cupboard, a few drops of distilled water were added to the ashed samples followed by 2 mL concentrated HCl and then it was allowed to evaporate to dryness on a hot plate. Subsequently, 10 mL of 20% HNO₃ (200 mL HNO₃ in 1 L distilled water) was added to the samples and were then placed in a hot bath for 1 h. The samples were then filtered using a Whatman No 2 filter paper into a 100 mL volumetric flask and made up to volume with distilled water. Compost carbon and nitrogen contents were determined using a TruSpec CHNS analyzer (Leco, Saint Joseph, MI, USA). Determination of some total micronutrients (Cu, Zn) and heavy metals (Cd, Ni, Cr, As) of composts was carried out using the aqua-regia extraction method. In this method, 3:1 HCl: HNO₃ was poured into digestion flasks containing 0.5 g composts, it was then set upon in a digestion block for 5 h. At the completion of digestion, it was poured into a flask and made up to 50 mL. It was then filtered, and the samples were sent to the AAS for determination of the required elements.

2.2. Nitrogen Mineralization Study: Soil Incubation

The soil for nitrogen mineralization experiment was preincubated for 10 days with the addition of water to field capacity (26.5%). Soil compost mixtures at the rate of 0, 5 and 10 t ha⁻¹ compost (3:1 + IMO, 3:1 – IMO, 1:2 + IMO 1:2 – IMO) were applied in 200 g soil in plastic bottles (500 cm³) covered with perforated (punctured) foil paper to incubate for 60 days at 27 ± 1 °C in the dark. The moisture content of the soil was maintained at field capacity by regular weighing of the bottles and making up for lost water with distilled water. The incubated soils were destructively sampled on the stipulated days of 0, 3, 7, 14, 21, 28, 40, 50 and 60 days. Soil samples during each sampling were divided into 3 portions and were kept at 4 °C and 18 °C while the third portion was dried, and these samples were used for respective measurements of the parameters during the course of the incubation period. For each destructive sampling conducted, the soils were measured for pH, NH₄-N and NO₃-N. Soil pH was measured using 1:2.5 soil:water ratio and the pH was subsequently measured using a pH meter (Model Metrohm 827, Riverwiew, FL, USA). The ammonium and nitrate were determined by steam distillation after extraction using 2M KCl and they were titrated using 0.01M HCl according to Keeney [15].

2.3. Statistical Analyses

All data collected were analyzed using analysis of variance (ANOVA) using SAS version 9.4. Tukey's (honestly significant difference) post-hoc test was used to compare means when significant differences were found. The main effects were considered significant at a probability level (p) of 0.05.

Pearson's correlation analysis was performed to test relationships between variables during the nitrogen mineralization experiment.

3. Results and Discussion

3.1. Co-Composting Materials

A survey was carried out at the wet market Serdang, Selangor, Malaysia, to assess the types and quantities of fruit and vegetable wastes being generated. The survey was done on three different days and the average percentage of fruit and vegetable wastes (FVW) only being generated as waste was calculated and analyzed individually. From the preliminary survey conducted, it was observed that 70% of wastes from the wet market consisted of fruits while 30% were vegetables. Table 1 shows the composition of fruit and vegetable wastes and their physical and chemical properties. The moisture content of these materials was greater than 70%. Standing water from the FVW was drained out before composting and the moisture of the comixed compost materials were kept to less than 60%. Maintaining the moisture content of the composting materials within 40–60% can significantly enhance the composting process. The FVW can be classified as high N-containing materials, especially the leafy vegetables such as spinach and mustard. The C/N ratio of vegetables was less than 20 but is higher for fruits wastes, except for watermelon and sweet melon.

Materials	MC FW	C (%) DW	N (%) DW	C/N DW	P (%) DW	K (%) DW	Ca (%) DW	Mg (%) DW
Spinach	89.26	29.82	4.73	6.31	0.22	4.06	1.95	0.24
Cabbage	87.93	35.56	2.88	12.36	0.17	2.73	0.73	0.18
Mustard	91.89	31.30	6.12	5.11	0.27	3.92	3.87	0.39
Carrot	89.93	34.99	1.91	18.35	0.13	2.59	0.23	0.10
Cucumber	96.71	34.55	2.00	16.46	0.07	2.31	0.28	0.12
Orange	81.27	35.25	0.67	53.01	0.03	0.98	0.63	0.13
Pineapple	84.31	36.37	0.78	46.75	0.06	2.35	1.57	0.26
Apple	84.60	35.91	0.39	90.92	0.07	1.80	0.22	0.07
Banana	70.99	34.33	0.56	60.97	0.05	2.10	0.05	0.24
Watermelon	89.72	30.14	2.67	11.31	0.20	3.83	0.45	0.33
Sweet melon	90.58	32.79	1.97	16.62	0.15	3.15	0.36	0.32

Table 1. Fruit and vegetable waste (FVW) used in co-composting.

A survey was also carried out around the students' residential flat of Universiti Putra Malaysia and it was observed that 50% of biodegradable municipal wastes (BMW) from homes consisted of food wastes, primarily rice with 20% yard waste and 30% paper waste. For the present study, only waste paper, waste rice and plant leaves were taken as the components of BMW. Table 2 presents the physico-chemical properties of the materials that were used as biodegradable municipal wastes during the co-composting. The moisture contents of the biodegradable municipal wastes were quite variable as shown in the table. The N content of BMW was low (<1.7%).

Table 2. Biodegradable municipal waste (BMW) used in co-composting.

Material	MC (%)	C (%)	N (%)	C/N	P (%)	K (%)	Ca (%)	Mg (%)
	70.47	37.36	1.60	23.33	0.08	0.90	0.54	0.09
	1.51	30.93	0.18	169.96	0.01	0.87	2.77	0.06
	0.93	41.25	1.35	30.60	0.05	0.42	1.06	0.09

Table 3 presents the ratios and weights of individual materials used during the co-composting of fruit and vegetable wastes and biodegradable municipal waste. The formulation ratios were obtained from the preliminary assessment of the composition of FVW and BMW. The combined weight of each composting substrate was made up to 10 kg.

Material Used	3:1	1:2	1:4
70%	5.25	2.33	1.4
30%	2.25	1.00	0.6
30%	0.75	2.00	2
50%	1.25	3.33	4
20%	0.5	1.33	1.6
	10 kg	10 kg	10 kg
	Material Used 70% 30% 30% 50% 20%	Material Used 3:1 70% 5.25 30% 2.25 30% 0.75 50% 1.25 20% 0.5 10 kg 10 kg	Material Used3:11:270%5.252.3330%2.251.0030%0.752.0050%1.253.3320%0.51.3310 kg10 kg

Table 3. Formulation ratios and weights (kg) of FVW and BMW used in composting.

3.2. Temperature Profile during Co-Composting for 30 Days

The trends for the compost temperature during the composting of FVW and BMW with and without IMO using three different ratios is presented in Figure 1. At the start of composting, there was an almost immediate increase in temperature of all the composts irrespective of the ratios used. Normally in any composting system, 4 cycles of temperature (mesophilic, thermophilic, cooling and maturation) exists [16]. An immediate increase in temperature of the composts to 42 °C in relation to the ambient temperature of 33 °C was recorded on the first day of the composting and this indicated the thermophilic stage [8], whereby, there is vigorous microbial activity due to the abundance of easily degradable substrates in composts 3:1 - IMO, 1:2 - IMO, 1:4 - IMO, 3:1 + IMO, 1:2 + IMO and 1:4 + IMO. Further increase in temperature was subsequently noticed on day 3 for all composts in relation to ambient temperature which can be an indication of an increase in the activities of microorganisms due to organic matter decomposition that results in energy release [17], whereby the microorganisms feed on carbon to obtain energy and at the same time release water and carbon dioxide, ammonia and organic acids [18]. The composts to which IMO were added, such as compost 1:4 + IMO and 1:2 + IMO, reached the higher temperatures probably because of the increased quantity of microorganisms, therein due to the composting temperature profile which was attributed to microbial activity as reported by [19]. Addition of composting enhancing additives such as indigenous microorganisms readily affect the population of the microorganisms because of the additional nutrients and carbon which can all affect compost temperature, moisture and/or aeration [20]. In the present study, the highest temperatures of 45 °C, 48 °C, 47 °C, 44 °C, 48 °C and 50 °C were recorded on individual different days for each compost between days 3 and day 7 for composts 3:1 - IMO, 1:2 - IMO, 1:4 – IMO, 3:1 + IMO, 1:2 + IMO and 1:4 + IMO, respectively. The temperature did not go higher than 50 °C due to the difficulty of conserving heat with the low volume composts. This can have a positive effect as it has also been reported that temperatures above 60 °C have the potential to kill the microorganisms needed for composting.

Sanitization of composts usually occurs at elevated temperatures during the composting process, and it is expected that the high temperature will exterminate all possible pathogens and weeds, thereby increasing the quality of composts. The fall in temperature of the composts was observed by day 28 when all 6 compost temperatures were equal to the ambient temperature of 31 °C. Compost temperature when compared to ambient temperature on day 30 had decreased to ambient temperature in all composting bins, with a plausible reason being the exhaustion of labile nutrients [20]. The differences in temperature profile of the composting treatments in the present study shows that the temperature trend in this study was similar to Rawoteea et al. [9] and Guo et al. [21], who reported that the typical variations of compost temperature was observed in their experiment and that a long thermophilic phase was not recorded probably due to the small size of reactor used.

The initial and final pH of the compost samples is presented in Figure 2. The pH of the composts increased at the end of composting and it was statistically significant ($p \le 0.05$) between the different composts. Initial pH of the 6 composts ranged between 5.74 and 6.11, which was slightly acidic, however there was an increase in the pH of the composts at the end of composting and it ranged between 7.06 and 8.23. An increase in pH was observed in all of the treatments and it can be ascribed to the presence of microorganisms that were degrading the organic matter and subsequently releasing

ammonia. In this experiment, the rise in pH of the composts at the end in relation to the initial pH was observed at the end of the composting experiment and this can be attributed as reported by Guo et al. [21] to the aerobic composting being carried out, which was responsible for the conversion of proteins and amino acids to ammonia (mineralization). Generally, pH will go down to the acidic range initially because of the formation of organic acids, and then, as the composting process proceeds, the pH will rise as the acids produced are consumed with subsequent ammonium production. In this study, the pH at the end of the composting ranged from 6.98 to 8.23 and composts + IMO recorded significantly ($p \le 0.05$) lower pH of 8.07, 7.31 and 7.06 for composts 3:1, 1:2 and 1:4, respectively, in comparison to composts – IMO that recorded 8.23, 7.46 and 6.98.



Figure 1. Ambient and composts temperature during co-composting of FVW and BMW at different ratios (3:1, 1:2 and 1:4). key T1: compost 3:1 – IMO, T2 compost 1:2 – IMO T3 compost 1:4 – IMO, T4 3:1 + IMO T5 1:2 + IMO T6 1:4 + IMO, T7 Ambient temperature.

Initial and final C/N ratio of co-composting substrates is presented in Figure 3. The C/N ratio is an indicator of the degree of decomposition of an organic matter, as carbon is lost as carbon dioxide. For active composting, the recommendation is to use materials that can give an initial C/N ratio of 25–40:1. Composting of materials at a C/N ratio greater than 40 will slow down the composting process, whereas a C/N ratio less than 25 can result in odor problems due to anaerobic conditions, release of ammonia and accelerated decomposition. A high C/N ratio at the end of composting has been attributed to lower amounts of FVW used in composting substrates reported by Tratsch et al. [7] and at lowered rates of FVW application to composting substrates, a lower C/N ratio at the end of composting should not be expected.

Awasthi et al. [22] reported that a low starting C/N ratio will imply excess nitrogen availability, which will be lost as ammonia with attendant odor, and mostly high EC that causes compost to be unfit for use on agricultural soils, while a higher initial C/N ratio implies less nitrogen for active composting by microorganisms [23] which can be overcome by the addition of indigenous microorganisms and shredding of primary substrates used in composting to smaller sizes. At the end of the composting period in the present experiment, a C/N ratio of 13:1 was obtained in composts 3:1 – IMO and 3:1 + IMO. Composts 1:2 – IMO and 1:4 – IMO both recorded a C/N ratio of 25 while composts 1:2 + IMO and 1:4 + IMO obtained a C/N ratio of 26, respectively. Compost C/N ratio cannot be assumed to be the ultimatum in deciding compost maturity. It is an important parameter, and if it can be reduced at the end of composting to values less than or equal to 25, then it can be termed a matured compost [22,24,25].

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Figure 2. Initial and final pH of composts made with and without the addition of IMO. Footnote: Similar letters on the bar chart across the treatments indicate not significantly different at p = 0.05.



Figure 3. Initial and final C/N of composts. Footnote: similar letters on the bar chart across the treatments indicate not significantly different at p = 0.05.

Some selected final compost quality parameters are presented in Table 4. Total nitrogen contents of the 6 composts produced at the end of composting were significantly different ($p \le 0.05$). Composts 3:1 + IMO and 3:1 – IMO had about the same amount of total N and were significantly higher ($p \le 0.05$) than the other 4 composts. Compost 3:1 – IMO recorded the highest nitrogen content of 2.76% while the lowest nitrogen content at the end of composting was recorded by compost 1:2 + IMO with 1.52% nitrogen. The phosphorus, potassium, calcium and magnesium contents of the 6 composts were significantly different ($p \le 0.05$) and were equivalently higher in ratios that had higher FVW. A plausible explanation can be because of the types of FVW used which had different quantities of different fruits and vegetables e.g., spinach which has a very high potassium content, which may

have likely been mineralized during the composting. In the present study, the 6 composts made ranged in nutrient contents from 0.05 to 0.17%, 1.03 to 3.23%, 2.49 to 4.02%, 0.15 to 0.36%, 6.60 to 41.23 mg kg⁻¹, and 29.2 to 93.6 mg kg⁻¹ for phosphorus, potassium, calcium, magnesium, copper and zinc, respectively, for composts 3:1 - IMO, 1:2 - IMO, 1:4 - IMO, 3:1 + IMO, 1:2 + IMO and 1:4 + IMO.

TRT	3:1 – IMO	1:2 – IMO	1:4 – IMO	3:1 + IMO	1:2 + IMO	1:4 + IMO	Standard Compost
N (%)	2.76 ^a	1.65 ^b	1.65 ^b	2.70 ^a	1.52 ^b	1.58 ^b	0.6
P (%)	0.17 ^a	0.05 ^b	0.05 ^b	0.18 ^a	0.06 ^b	0.05 ^b	0.22%
K (%)	3.23 ^a	1.48 ^b	1.15 ^{b,c}	3.04 ^a	1.50 ^b	1.03 ^c	0.25%
Ca (%)	4.02 ^a	2.66 ^c	2.54 ^c	3.76 ^{a,b}	2.88 ^{b,c}	2.49 ^c	1.42
Mg (%)	0.36 ^a	0.19 ^b	0.17 ^b	0.31 ^a	0.20 ^b	0.15 ^b	0.18
EC (mS cm)	2.29 ^a	2.33 ^a	2.30 ^a	2.32 ^a	2.37 ^a	2.28 ^a	<3
Germ (%)	68.55 ^a	87.14 ^a	86.59 ^a	96.63 ^a	80.12 ^a	75.8 ^a	>70% *
MC (%)	44.93 ^a	48.71 ^a	44.45 ^a	43.85 ^a	40.45 ^a	43.67 ^a	variable
Cu (mg kg ⁻¹)	14.40 ^a	7.27 ^a	41.23 ^a	23.47 ^a	8.13 ^a	6.60 ^a	300
Zn (mg kg ⁻¹)	71.2 ^a	44.3 ^a	93.6 ^a	29.2 ^a	53.3 ^a	41.00 ^a	1000
Cd (mg kg ^{-1})	0.02 ^c	0.02 ^d	0.01 ^e	0.07 ^a	0.06 ^b	0.07 ^a	<5 **
As $(mg kg^{-1})$	0.53 ^b	0.43 ^c	0.53 ^a	0.28 ^f	0.34 ^d	0.29 ^e	<50 **
$Cr (mg kg^{-1})$	5.88 ^d	4.68 ^e	7.15 ^c	8.13 ^b	1.23 ^f	8.95 ^a	<200 **
Ni (mg kg ^{-1})	1.19 ^e	0.73 ^f	2.29 ^d	3.53 ^b	4.25 ^a	2.71 ^c	<150 **

Table 4. Selected final compost quality parameters.

Adapted from: Council of European Communities (CEC) quality standard for composts, * adapted from [26], ** adapted from [27]. Footnote: similar letters on table across the composts indicate not significantly different at p = 0.05.

The composts produced were relatively high in nitrogen and potassium with an average amount of 138 kg nitrogen and 51.5 kg potassium at 5 t ha⁻¹ application. Horrocks et al. [28] reported that agronomically sufficient N, P, K and S were found in the composts used in their study (municipal garden and kitchen wastes composts). Heavy metal contents of final composts samples were not significantly different (p > 0.05) among the composts, and will not therefore, pose a threat when applied to the soil. Phytotoxicity of compost sampled on germination of sweet corn were not significantly different (p > 0.05) between each compost but were all greater than 50%.

3.3. Nitrogen Mineralization: Soil Incubation

Figure 4 shows the results of the soil pH during the incubation period of 60 days. The pH of the soil and compost amended soils were significantly different ($p \le 0.05$). The pH of the soils, due to compost application for all treatments, increased up to day 21, while for some of the treatments, the highest increase was observed on day 14. The compost pH increment seemed to be more at the application of 10 t ha^{-1} in comparison to the control for all treatments, irrespective of the addition of indigenous microorganisms (IMO). The trend line for the composts with respect to days of incubation was similar for all treatments, including the control treatment. Conversion of organic nitrogen by soil microorganisms to ammonium is termed ammonification. Rise in pH of soils upon addition of organic residues is most probably because of enhanced ammonification in relation to nitrification, which subsequently leads to an OH⁻ formation [29,30]. In essence, chemical mechanisms guiding pH change in soils are all related to nitrogen cycling with the conversions of organic nitrogen in the soil to ammonium releasing OH^- (consuming H^+), increasing soil pH [31,32] and the subsequent release of 2H⁺ ions that reduces the pH of soil during nitrification [33]. The subsequent conversion with time of ammonium to nitrate releasing 2H⁺ (consuming OH⁻) can be observed by the gradual decrease in soil pH which subsequently stabilized towards the end of the incubation experiment. The soil pH change during mineralization can also be related to organic acid production during decomposition, ammonification, nitrification process and/or chemical species oxidation process [34]. Decarboxylation of organic anions due to the addition of residues in soils has also been associated to soil pH increase [35]. The sequential release of organic acids is mainly related to edaphic factors such





Figure 4. The pH of soils during incubation at different rates of compost application. Key: Trt1: 3:1 – IMO at 5 t ha⁻¹, Trt2: 3:1 – IMO at 10 t ha⁻¹, Trt3: 1:2 – IMO at 5 t ha⁻¹, Trt4: 1:2 – IMO at 10 t ha⁻¹, Trt5: 3:1 + IMO at 5 t ha⁻¹, Trt6: 3:1 + IMO at 10 t ha⁻¹, Trt7: 1:2 + IMO at 5 t ha⁻¹, Trt8: 1:2 + IMO at 10 t ha⁻¹, Trt9: control.

Ammonium ion mineralization in soil during the 60 days nitrogen mineralization study is shown in Figure 5. Significant differences ($p \le 0.05$) were observed in the amounts of ammonium nitrogen released by the different treatments. An almost immediate mineralization was observed of the lower C/N ratio of the composts (3:1 composts) applied. Highest ammonium nitrogen production of 40.21 mg kg⁻¹ on day 40 was observed at the application of compost 3:1 + IMO at 10 t ha⁻¹ while the lowest quantity of 2.94 mg kg⁻¹ ammonium was observed at the control treatment to which no compost was added on day 60. Azeez and Averbeke [36] reported that ammonification is usually fast when organic nitrogen sources such as compost is added to soils, especially in the presence of moisture because the soil microorganisms will be able to convert it to ammonium. All compost-amended soils in this experiment recorded an initial increase in ammonium release during the incubation up to day 3. A similar result was also reported by Calderon et al. [37] who reported that ammonium nitrogen was dominant in terms of mineral nitrogen release at the beginning of an incubation experiment and Tratsch et al. [7] who also reported a similar result but presumed it was because of the initial higher concentration of NH₄⁺ in the composts that were used for the mineralization experiment. Subsequently, ammonium ion, released by the remaining treatments with lower FVW contents, also increased. The highest concentration of ammonium nitrogen of 41.30 mg kg⁻¹ on day 21 and 41.86 mg kg⁻¹ on day 40 were by compost 3:1 + IMO and 3:1 - IMO at 10 t ha⁻¹ (Figure 4) and were possibly due to the higher amount of easily mineralizable fruit and vegetable wastes in relation to the control which could lead to a higher proliferation of soil microorganisms. The ammonium nitrogen mineralized during incubation can however be temporarily immobilized by soil microorganisms [36] before subsequently being released later. As the incubation progressed with time, the rate of ammonium nitrogen transformation

gradually reduced, which led to the gradual change of the ammonium ion formed into nitrate with a subsequent reduction in the ammonification rate (Figure 6).



Figure 5. Ammonium nitrogen released in soils during incubation at different rates of compost application. Key: Trt1: 3:1 – IMO at 5 t ha⁻¹, Trt2: 3:1 – IMO at 10 t ha⁻¹, Trt3: 1:2 – IMO at 5 t ha⁻¹, Trt4: 1:2 – IMO at 10 t ha⁻¹, Trt5: 3:1 + IMO at 5 t ha⁻¹, Trt6: 3:1 + IMO at 10 t ha⁻¹, Trt7: 1:2 + IMO at 5 t ha⁻¹, Trt8: 1:2 + IMO at 10 t ha⁻¹, Trt9: control.



Figure 6. Nitrate released in soils during incubation at different rates of compost application. Key: Table 1. 3:1 – IMO at 5 t ha⁻¹, Trt2: 3:1 – IMO at 10 t ha⁻¹, Trt3: 1:2 – IMO at 5 t ha⁻¹, Trt4: 1:2 – IMO at 10 t ha⁻¹, Trt5 3:1 + IMO at 5 t ha⁻¹, Trt6: 3:1 + IMO at 10 t ha⁻¹, Trt7: 1:2 + IMO at 5 t ha⁻¹, Trt8: 1:2 + IMO at 10 t ha⁻¹, Trt9: Control.

Nitrate production was higher in compost 3:1 + IMO at 10 t ha⁻¹ at 27.98 mg kg⁻¹ on day 60 and was lowest in the control plot at 3.69 mg kg⁻¹ production on day 14. At the beginning of the

incubation, the rate of nitrate release was very low, and it ranged between 6.09 and 14.96 mg kg⁻¹ on day 1 to 16.1–27.98 mg kg⁻¹ on day 60 probably because of the initial increase in ammonification. The nitrate released was still higher in the treatments that received higher FVW (compost 3:1 + and – IMO) possibly because of the lower C/N ratio exhibited by these composts due to the inclusion of fruit and vegetable wastes in their composition. In addition, however, high moisture content of soils may cause leaching of nitrates, leading to the creation of a microsite that may associate with carbon to increase denitrification losses of composts applied. The rate of nitrate production from the control soil was lower in comparison to the other treatments because of the low organic matter content throughout the 60-day incubation period. Towards the end of the incubation there was an increase in nitrate released because of the conversion of ammonium to nitrate through nitrification (33) from the added composts. Ammonium is oxidized to NO₂⁻ by Nitrobacter and then to NO₃⁻ by Nitrosomonas, thereby increasing the concentration of NO₃⁻ towards the end of the incubation [7]. Highest peak NO₃⁻ release of 27.98 mg kg⁻¹ N was attained by compost 3:1 + IMO at 10 t ha⁻¹ on day 60.

Mineralizable nitrogen (sum of NH₄-N and NO₃-N) content of the soil in relation to the addition of composts made with and without IMO is presented in Figure 7. The results were significantly different ($p \le 0.05$) between the different treatments. The mineralizable nitrogen released was lower in the control in comparison to other treatments. Total mineralizable nitrogen release pattern was similar to that of total ammonium release possibly because the ammonification process was more dominant than the nitrification process. On days 7, 14, 21 and 60 of the experiment, compost 3:1 + IMO recorded higher mineralizable nitrogen released in comparison to the control soil. Higher mineralizable nitrogen was recorded in treatments with higher amounts of FVW during the composting, a similar result as reported by Tratsch et al. [7].



Figure 7. The NH₄-N + NO₃-N (mineralizable N) released in soils during incubation at different rates of compost application. Key: Trt1: 3:1 - IMO at 5 t ha⁻¹, Trt2: 3:1 - IMO at 10 t ha⁻¹, Trt3: 1:2 - IMO at 5 t ha⁻¹, Trt4: 1:2 - IMO at 10 t ha⁻¹, Trt5: 3:1 + IMO at 5 t ha⁻¹, Trt6: 3:1 + IMO at10 t ha⁻¹, Trt7: 1:2 + IMO at 5 t ha⁻¹, Trt8: 1:2 + IMO at 10 t ha⁻¹, Trt9: control.

Cumulative NH_4 -N + NO₃-N nitrogen of soils during incubation studies at the application of 0, 5 and 10 t ha⁻¹ compost application is presented in Figure 8. The results showed that cumulative nitrogen released was lowest in the control treatment and were highest in the treatments to which compost was

added at the rate of 10 t ha⁻¹ irrespective of the addition of indigenous microorganisms. The results from the cumulative nitrogen mineralization of organic residue amended soils were consistent with the results of Masunga et al. [38]. They ascribed the high mineralization from *Gliricidia* and organic residues with similar C/N-amended soils to the large pool of labile organic nitrogen that was released into the soil solution. The cumulative nitrogen increased with the increase in incubation duration time probably because of the continuous mineralization of the composts with time. Cumulative nitrogen released over control of 77.98, 64.09 and 64.35% were recorded for application rates of 3:1 - IMO, 1:2 - IMO and 1:2 + IMO at 10 t ha⁻¹ respectively.



Figure 8. The cumulative NH₄ -N and NO₃ -N nitrogen in soils during incubation at different rates of compost application. Key: Trt1: 3:1 – IMO at 5 t ha⁻¹, Trt2: 3:1 – IMO at 10 t ha⁻¹, Trt3: 1:2 – IMO at 5 t ha⁻¹, Trt4: 1:2 – IMO at 10 t ha⁻¹, Trt5 3:1 + IMO at 5 t ha⁻¹, Trt6: 3:1 + IMO at 10 t ha⁻¹, Trt7: 1:2 + IMO at 5 t ha⁻¹, Trt8: 1:2 + IMO at 10 t ha⁻¹, Trt9: control.

Pearson correlation was carried out to determine the relationship that existed between the parameters measured in the nitrogen mineralization study (Table 5). From the correlation table, it was observed that a highly significant ($p \le 0.001$) positive correlation existed between ammonium production and pH of the soils. An increase in ammonium can cause an increase in soil pH and vice versa which affirms the results of [11] who reported that a significantly positive correlation exists between mineral nitrogen released as well as pH. A highly significant (p < 0.01) negative correlation existed between nitrate production in the soils and soil pH. A decrease in nitrate production should be expected with an increase in soil pH and the opposite holds true. A highly significant ($p \le 0.01$) negative correlation also existed between ammonium and nitrate production, which infers that generally it can be assumed that production rates of ammonium is inversely related to nitrate production. Meanwhile a positive correlation existed between mineralizable nitrogen and ammonium.

	pН	NH ₄ -N	NO ₃ -N	NH_4 -N + NO_3 -N
pН	1			
NH ₄ -N	0.3349	1		
	< 0.0001			
NO ₃ -N	-0.2596	-0.3801	1	
	< 0.0001	< 0.0001		
$NH_4-N + NO_3-N$	0.2278	0.88168	0.1013	1
	0.0003	< 0.0001	0.1152	

Table 5. Correlation coefficients for soil parameters in the incubation study.

4. Conclusions

The composts produced by co-composting fruit and vegetable wastes and biodegradable municipal wastes had good agronomic potentials in terms of nitrogen and potassium contents. Composts 3:1+IMO and 3:1-IMO showed superiority in mineral nutrient contents probably because of the lower C/N contents as a result of the combination and ratio of substrates used in the co-composting. Understanding mineral nutrient release from the application of composts in tropical soils is important to be synchronized with plant nutrient demand for more effective nutrient use from applied composts. The different ratios used during the composting process yielded different composts with different nutrient status and waste management abilities. From the results obtained, composting using ratio 3:1 and 1:2 aided in complementing the lapses of the primary substrates used during the composting. Nitrogen release dynamics is paramount for effective nitrogen use to avoid environmental pollution and/or leaching losses. The laboratory incubation experiments showed the release rates of these composts when applied to an Oxisol at the rates of 0, 5 and 10 t ha^{-1} . An in-depth knowledge and understanding of the results obtained will help policy makers charter new guidelines with regards to organic waste disposition. Compost users will have an option of getting a better compost with more nutrients and the government and individuals can manage the wastes effectively. Recycling of fruit and vegetable wastes and biodegradable municipal wastes into composts is a sustainable waste management option.

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