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Nutrient Dynamics in Recycled Organic Amended Alkaline Soil

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Abstract

A variety of wastes are generated due to human activities. Organic waste usage in agriculture plays a significant role in the steady supply of plant nutrients through improving soil quality. An *in vitro* incubation study was conducted to measure the release of the major nutrients viz. available nitrogen (N), phosphorus (P), and potassium (K) in alkaline soil amended by recycled organic soil conditioners. The soil was amended by compost (Cm) and vermicompost (VC) @ 5 tha^{-1} and a mixture of compost and vermicompost (Cm + VC) @ 2.5 tha^{-1}. Chemical fertilizers (Cf) were added @ of 98.842 $kg \cdot ha^{-1}$ of urea and 64.99 $kg \cdot ha^{-1}$ of triple superphosphate (TSP), with amended soils being incubated for 120 days maintaining 50% field moisture holding capacity. Due to the sufficient content of potassium in experimental soil for plant growth, extra potassium was not added. Available soil N, P, and K were determined at every 0, 15, 30, 45, 60, 90, and 120 days of incubation. The highest available N and K release was found in VC treated soils at the incubation period of 45 days. On the other hand, the highest P release was recorded in Cm treated soils at the incubation period of 45 days. In this experiment, the addition of Cm, VC and Cm + VC showed better release of cumulative plant available N, P and K than either control (C) or Cf and were arranged as VC > Cm > Cm + VC > Cf > C, Cm > Cm + VC > VC > Cf > C and Cm + VC > VC > Cm > C > Cf for N, P and K, respectively. The results of this experiment revealed that the addition of compost and/or vermicompost is predominant over chemical fertilizer in supplying of major nutrients for crops in alkaline soil.

Keywords

Compost, Vermicompost, Incubation Study, Nitrogen, Phosphorus and Potassium

1. Introduction

Crops require nutrients for growth and development. Crop production depends on supplying nutrients through fertilizer, and it is almost impossible to produce crops at a predictable level without the addition of fertilizer [1]. In modern agriculture, the use of fertilizers increased 30% - 50% of crop production [2]. Growers use conventional fertilizer in a frequent manner for crop production, but about 40% - 70% of nitrogen and 80% - 90% of phosphorus in applied fertilizers are lost into the environment through ionic or gaseous forms like leaching, volatilization, denitrification, fixation, and absorption [3], which cannot be absorbed by crops, thus not only causing large economic and resource losses but also very serious environmental pollution [4].

At present, the world produces a huge amount of waste every day and creates an unhygienic environment [5]. The municipal solid waste generated by household waste contributes 11% of global CH_4 emissions [6]. So, it is urgent to take proper waste management practices to improve environmental quality [7]. Recycling perishable waste materials into valuable organic fertilizers like compost and vermicompost is important for both environment and crop production [8]. Applications of these organic manures in the agricultural field increase crop productions, enhance nutrient availability [9], moisture holding capacity [10], aggregate formation [11], and carbon sequestration [12] [13]. The addition of slurry in marginal soils to grow forage mixtures has been proved to be profitable in the northern part of Japan in terms of forage quality viz. nutrients requirement and digestibility components [14]. On the other hand, Rahman and Saiga [15] investigated the impact of the application of dairy manure on mineral nutrient uptake patterns by orchard grass grown in Andisol of Japan. They observed that the uptake of grass tetany potential related mineral nutrients (K, Ca, and Mg) was higher in the application of dairy manure compared to chemical fertilizer. Higher uptake of those mineral nutrients exhibited higher grass tetany potentiality. Sabreen *et al.* [16] observed that the nutrient release depends on the C/N ration of the amendments. The application of biochar as a soil conditioner changed the soil's physical and hydrological properties [17], which was responsible to release available nutrients for plant growth. All this concluded that soil amended by organic products must be done with care as those components may increase not only grass tetany potentiality and oxygen demand in soil, but also simultaneously impede gas exchange logging soil pores. Various gases like CH_4, H_2S, N_2O, C_2H_2, and H_2 may generate in soil air due to insufficient oxygenation. Production of methane gas indicates the decomposition of organic matter and the generation of nitrous oxide as a product of denitrification due to insufficient oxygen in the soil. All these gases then deplete the stratospheric ozone layer and are accountable for the greenhouse effect. Therefore, it is important for the proper use of organic amendments which would improve plant yields in a desirable direction through restoring soil health and by inspiring farmers to utilize more balanced agricultural practices [18].

The addition of compost and/or vermicompost in plant growth media may release slowly available nutrients for plants as well as protect nutrient losses by minimizing the economic loss and by increasing nutrient use efficiency. Most agricultural soils of the southern part of Bangladesh are dominated by alkaline in nature and the use of compost and vermicompost is becoming more popular to grow crops as the department of agriculture extension (DAE) is attaching more importance to changing the nutrient supplying pattern of those soils. It is important that the composting concept of recycling waste, nutrients, and organic matter back to agricultural land should be tested in terms of nutrient release. We hypothesized that the addition of compost and vermicompost may behave in a different direction in nutrient release in the alkaline soil. The aim of the experiment is to elucidate the rate of major nutrient (N, P, and K) releases and the efficacy of recycled organic amendments (compost and vermicompost) in alkaline soil against chemical fertilizer.

2. Materials and Methods

2.1. Sample Collection and Preparation

The experiment was conducted in the Soil Chemistry Laboratory of the Department of Soil and Environmental Sciences, The University of Barishal during 2018-2019. For *in vitro* incubation study, alkaline soil was collected from an agricultural field in the Mirganj village (22˚48'56"N; 90˚20'27.9"E) under Rahamatpur Union which is situated at Babuganj Upazila in Barishal district, Barishal, Bangladesh. The soil sample was air-dried and crushed by using a wooden hammer and sieved through 2 mm of openings.

2.2. Collection of Compost, Vermicompost

The soil amendments viz. compost and vermicompost were collected with the help of the department of agriculture extension (DAE), Barishal zone as they have been introducing those components to the farmers for their upland crops grown in alkaline and saline soils.

2.3. Experimental Setup

The plastic pot of 1.5 L volume was taken and 1.0 kg soil and/or soils amended with recommended organic or chemical fertilizers were prepared for incubation with amended by compost (Cm) and vermicompost (VC) @ 5 tha^{-1} and a mixture of compost and vermicompost (Cm + VC) @ 2.5 tha^{-1}. Urea (98.8 $kg \cdot ha^{-1}$) and triple superphosphate (TSP: 64.99 $kg \cdot ha^{-1}$) were used for conventional treatments (Cf) according to the standard recommended dose for the crops grown in alkaline soil in Bangladesh and as the soil had enough potassium, *i.e.*, potassium fertilizer was not applied in the soil for conventional treatment (BARC: Bangladesh Agriculture Research Council; https://agris.fao.org/agris-search/search.do?recordID=BD8525107). No fertilizers were applied in the control treatment (C). The treatments were replicated three times. The pots were arranged in a completely randomized design and kept for 120 days of incubation at laboratory temperature (@25˚C/20˚C; day/night temperature). The incubation periods were 0, 15, 30, 45, 60, 90 and 120 days.

The pots were watered as inundated at each time after the collection of soil samples throughout the experiment.

2.4. Chemical Analysis

Initial nutritional quality of soil, as well as compost and vermicompost, were assessed before the incubation study based on standard soil analytical methods. The initial amount of N concentration was 650, 1080, and 3540 ppm, P concentration was 4.1, 1730, and 820 ppm and K concentration was 5.6, 230, and 179 meq100 g·soil^{-1} for soil, compost and vermicompost, respectively (**Table 1**).

At every incubation period, three major nutrients, e.g., available nitrogen [19], available phosphorus [20], and available potassium Cox *et al.* [21] contents were determined, and data were presented at dry weight basis (oven dried at 105˚C for 24 hrs).

2.5. Statistical Analysis of Data

All the data were statistically analyzed using Microsoft Excel (MS Office 2007) and Statistical Package for the Social Sciences (SPSS, version 24) Packages.

3. Results and Discussion

3.1. Nitrogen Concentration

Data in **Table 2** and **Figure 1** show the effects of the application of different treatments on available and cumulative nitrogen concentration, respectively.

The highest N concentration was observed in Cf and VC treatments at 0 day of incubation. The result is justified for Cf treatment as urea fertilizer was added for the N source. The concentration of N released by all treatments decreased largely from 0 to 15 days of incubation and then increases substantially up to 45 days of incubation and then decreases again predominantly up to the end of the incubation period.

Table 1. Some physicochemical properties of the soil, compost and vermicompost.

Properties	Unit	Soil	Compost	Vermicompost
pH		8.14	6.92	6.02
Moisture Content	%	27.23	-	-
Sand	%	43.65	-	-
Silt	%	43.85	-	-
Clay	%	12.5	-	-
Texture	%	Loamy	-	-
Organic Carbon	%	1.084	15.94	15.29
Available N	Ppm	650	1080	3540
Available P	Ppm	4.1	1730	820
Available K	meq 100 g·soil^{-1}	5.6	230	179

Table 2. Concentration of available nitrogen ($\mu g \cdot g^{-1}$) in amended alkaline soil.

Incubation period (day)	Treatment[1]				
	C	Cf	Cm	VC	Cm + VC
0	616aB[2]	693aA	616bB	693bA	539aC
15	146dC	173dB	193dA	154dC	192cA
30	274cC	360cB	172dD	240dC	215aA
45	511bC	520bC	924aB	1117aA	539aC
60	269cE	336cD	673bA	605bBC	538aC
90	154dC	173dC	519cB	605bA	471abB
120	114dC	129dC	507cA	481cBC	327bB

[1]C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost. [2]Values within the rows and parameters for each variable with the same letters (upper case) are not significantly different at $P < 0.05$; values within the columns and parameters for each variable with the same letters (lower case) are not significantly different at $P < 0.05$.

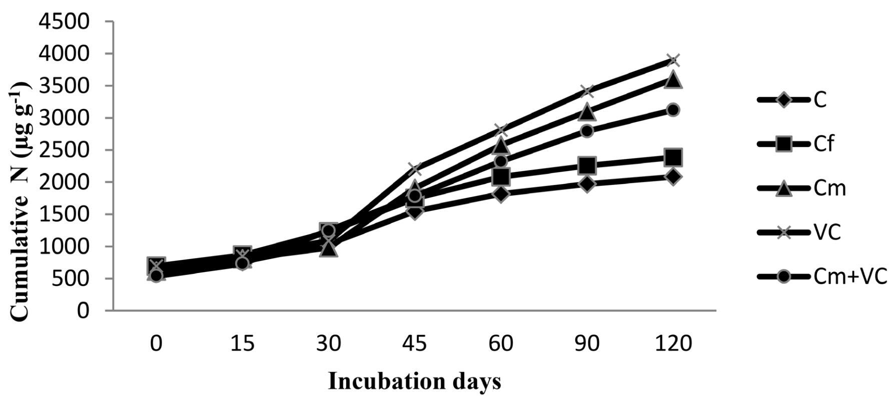

Figure 1. Cumulative N release of alkaline soil amended by compost and vermicompost (C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost).

The highest N release (1117 $\mu g \cdot g^{-1}$) was observed under VC treatment at the 45 days of incubation and the lowest N release was recorded in control treatment after 120 days of the incubation period. The cumulative N release was almost identical until 30 days of incubation and after that, the release rate tremendously differed among the treatments. Many scientists [22] [23] [24] reported similar types of results for compost and vermicompost application. Sarig *et al.* [25] claimed that the slightly alkaline nature of soil could increase the accumulation of C and N in microbial biomass, but also decreases the rate of C and N mineralization. After 30 days of incubation, nitrogen mineralization increased by NO_3^--N due to the high activity of nitrifying bacteria [26]. With time increasing, reduction of organic manure and of increasing ammonia volatilization rate by microbial activity declined nitrogen mineralization [18].

3.2. Phosphorus Concentration

The significantly highest P concentration was observed at 15 days of incubation in C and Cf treatment and at 30 days of incubation in Cm + VC and at 45 days of incubation in Cm and VC treatments (Table 3). Regardless of treatments and incubation periods, the highest P release was recorded Cm amendment at the 45th day of incubation.

The P release increased initially up to 15 days in C, Cf, and Cm + VC treated soils and then decreased linearly. In the case of Cm and VC treated soils, P release increased up to 45 days of incubation and then decreased slowly for the rest of the days. The compost treated (Cm) soil showed the best release of cumulative phosphorus (Figure 2) than any other treatments. The results of the experiment corroborate the observation of Biswas and Narayanasamy [27] for compost application in alkaline soil. Vermicompost application increases available phosphorus in soil and the results support the findings of Busato *et al.* [28]. According to MKhabela and Warman [29], compost application in soil decreases phosphorus fixation in treated soil and thereby increases the availability of P in soil.

Table 3. Concentration of available phosphorus ($\mu g \cdot g^{-1}$) in amended alkaline soil.

Incubation period (day)	Treatment[1]				
	C	Cf	Cm	VC	Cm + VC
0	3.97cB[2]	6.39bA	4.62cB	4.56bcB	4.64dB
15	6.98aA	7.71aA	7.05bAB	5.48bB	6.95bAB
30	6.05aB	7.64aB	8.83abA	8.04aA	8.27aA
45	5.12bC	5.03cC	9.05aA	8.26aAB	7.54abB
60	3.21cB	3.79dB	5.12cA	4.94AB	5.43cA
90	3.25cB	3.61dB	4.94cA	4.64bcA	4.61dA
120	3.18cB	3.38dB	4.91cA	4.15cAB	4.54dAB

[1]C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost. [2]Values within the rows and parameters for each variable with the same letters (upper case) are not significantly different at $P < 0.05$; values within the columns and parameters for each variable with the same letters (lower case) are not significantly different at $P < 0.05$.

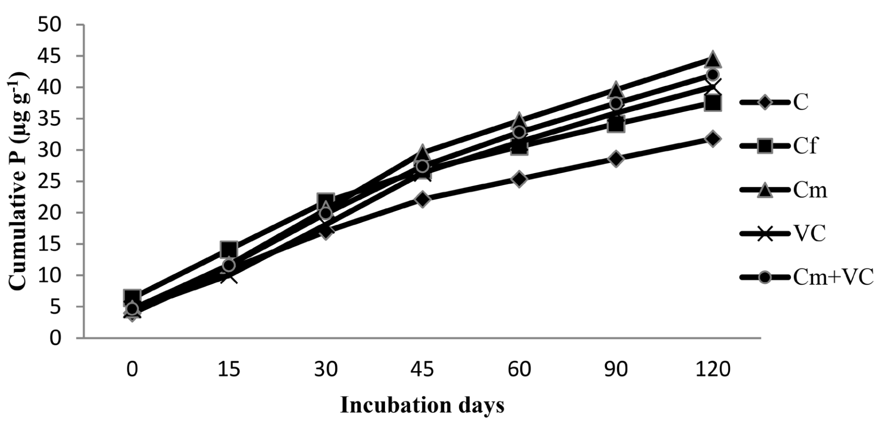

Figure 2. Cumulative P release of alkaline soil amended by compost and vermicompost (C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost).

During the decomposition of organic matter, various organic acids are produced and increase phosphatase activity which lowers pH in amended soil and increases the availability of phosphorus in soil [30]. Phosphorus availability decreased with the time of incubation due to the increasing rate of phosphorus fixation [31].

3.3. Potassium Concentration

Table 4 shows the available K release in alkaline soil amended by compost and vermicompost at different incubation periods. Initially, all treatments had a similar amount of available potassium (≈5.74 meq 100 g^{-1}). The K release decreased up to 15 days of incubation and then started to increase and reached the highest level at 45 days of incubation and then decreased slowly for the rest of the time. Among all amendments, Cm + VC showed the highest cumulative potassium release (**Figure 3**).

The compost, VC, and Cm + VC treated soils showed a slowly release pattern than the control soil, keeping the soil rich in potassium than the control soil throughout the experiment. Tazeh *et al.* [32] found similar trends for the release of potassium in alkaline soil for compost and organic manure (cow manure) application. The initial decrease of potassium may be caused by the higher growth of microorganisms in soil due to the addition of compost and vermicompost [33]. During decomposition of organic manure, it helps in the release of potassium due to the action of organic acids, from the highly residual potassium compost that was bounded by clay minerals and organic matter [34] [35]. Moreover, compost and vermicompost application in soil increased CEC that is responsible for higher available potassium for plants [36].

3.4. Efficacy of Nutrient Release

The efficacy of organic amendments on major nutrient (N, P, and K) release in

Table 4. Concentration of available potassium (meq 100 g·$soil^{-1}$) in amended alkaline soil.

Incubation period (day)	Treatment[1]				
	C	Cf	Cm	VC	Cm + VC
0	5.741bcA[2]	5.741bcA	5.792bA	5.741cA	5.741cA
15	3.661cA	3.962cA	3.961cA	3.66dA	3.962dA
30	13.54aA	10.814aB	11.674aAB	12.918abA	13.333aA
45	12.695aA	10.66aB	13.673aA	14.064aA	13.477aA
60	8.012bB	9.012AB	11.197aA	10.574bAB	10.797abAB
90	8.766bA	9.884bA	10.035abA	9.824bA	10.247abA
120	8.491bA	8.491bA	9.819abA	9.487bA	9.653bA

[1]C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost. [2]Values within the rows and parameters for each variable with the same letters (upper case) are not significantly different at $P < 0.05$; values within the columns and parameters for each variable with the same letters (lower case) are not significantly different at $P < 0.05$.

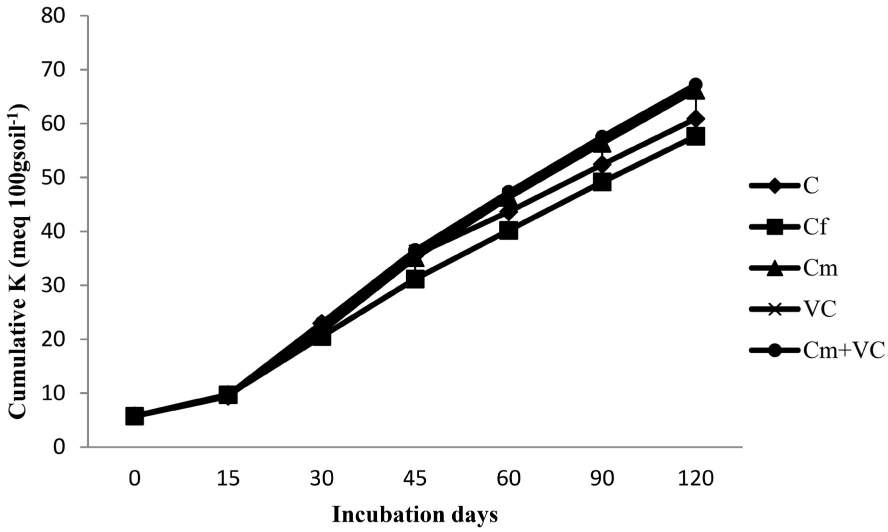

Figure 3. Cumulative K release of alkaline soil amended by compost and vermicompost. (C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost)

Table 5. Linear regression relationship between cumulative nutrient release and incubation periods.

Treatment*	Nutrient		
	N	P	K
C	y = 13.317x + 720.25	y = 0.2225x + 8.5226	y = 4.8565x + 79.794
	R^2 = 0.8878	R^2 = 0.8961	R^2 = 0.9458
Cf	y = 15.248x + 823.58	y =0.2491 + 9.6538	y = 4.5697x + 70.921
	R^2 = 0.8913	R^2 = 0.8890	R^2 = 0.9640
Cm	y = 27.408x + 531.18	y = 0.3340x + 9.2703	y = 5.3726x + 67.778
	R^2 = 0.9526	R^2 = 0.9161	R^2 = 0.9607
VC	y = 29.710x + 607.67	y = 0.3021 + 8.2164	y = 5.3903x + 71.148
	R^2 = 0.9445	R^2 = 0.9195	R^2 = 0.9542
Cm + VC	y = 23.210x + 597.79	y = 0.3113 + 9.0982	y = 5.4558x + 72.373
	R^2 = 0.9565	R^2 = 0.9195	R^2 = 0.9571

*C = Control; Cf = Chemical fertilizer; Cm = Compost; VC = Vermicompost.

alkaline soil was assessed by establishing a linear regression relationship between cumulative nutrient release vs incubation periods. Results are shown in Table 5. Data showed that the highest cumulative N release observed in VC (slope 29.710) lowest was in the control (slope 13.317) and the results can be arranged as VC > Cm > Cm + VC > Cf > C. The Cm + VC treatment showed the best consistent supply of N than other treatments. The highest cumulative P release was observed in Cm (slope 0.3340), but lowest was in control (slope 0.2225), and the treatment and results can be arranged as Cm > Cm + VC > VC > Cf > C. In the case of K cumulative release, the lowest value (slope, 4.8565) was recorded with Cf treatment, and the highest was recorded in Cm + VC (slope, 5.4558) and can be ranked as Cm + VC > VC > Cm > C > Cf. The Cm + VC treatment showed an more excellent steady supply of N and P than other treatments. On the other hand, Cm showed the most consistent supply of K than other treatments.

The changes in soil quality parameters corresponded with crop management practices as well as soil biotic and abiotic factors [37]. The nutrients release and/or supply evolved differently. For example, organic managed kiwifruit soil showed more P availability in the organic management systems; however, higher N and K availability was observed in the conventional management systems than organic or biological kiwifruit management systems in Andisol [38]. Significantly, higher cumulative N, P, and K release were recorded from all the compost-vermicompost amended soils over control or chemically fertilized soils. Organic acids are released when organic amendments are used which may have prevented nutrient sorption onto the clay surfaces [39] [40] [41]. Numerous scientists reported earlier that most plant-based soil amendments have the potential to improve soil properties as well as nutrient release [42] [43] [44].

4. Conclusion

The soil amended with compost and/or vermicompost always had higher available N, P, and K releasing capacity than the soils without or chemical fertilizer amendment, *i.e.*, in addition of recycled organic components to alkaline soil may be beneficial for economic crop production. The Cm and VC treatments showed a higher release of nutrients than any other treatments. Both Cm and VC released nutrients for a long time while Cf released nutrients for a short time, indicating the legacy consequence of recycling organic amendments. Vermicompost is more stable than compost and then in the degradation processes of compost more energy is consumed as part of microbial activities involved and *i.e.*, the concentration of available nutrients is more in soil solution continually in vermicompost amended soil. Recycled organic amendments showed significantly higher cumulative nutrients release in alkaline soil which would be beneficial for crop growth. Alam and Rahman [45] and Alam *et al.* [46] conducted experiments in calcareous soils on the growth of ornamental plants and vegetable crops, respectively, and observed better performance with vermicompost application compared to chemical fertilizer. The study concludes that recycled organic amendments are the preferable fertilizer to conventional fertilizers in agricultural practices. Further experiments with these amendments should be performed with crops grown under different types of alkaline soils in field conditions to justify the nutrient use efficiency of crops.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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