International Journal of Recycling of Organic Waste in Agriculture (2021)10: 245-256
Doi: 10.30486/IJROWA.2021.1908103.1124

ORIGINAL RESEARCH

Nitrogen, phosphorus and sulphur mineralization in soil treated with amended municipal solid waste compost under aerobic and anaerobic conditions

Marufa Sultana[1], M Jahiruddin[2*], M Rafiqul Islam[2], M Mazibur Rahman[2], Md Anwarul Abedin[2], Abdullah Al Mahmud[3]

Received: 01 September 2020 / Accepted: 22 May 2021 / Published online: 25 July 2021

Abstract

Purpose Our study had considered some organic amendments to enhance nutrient level of marketed municipal solid waste (MSW) compost for its potential use as fertilizer for growing crops in alluvial soils.

Method We prepared three types of amended compost by mixing 20% mustard oil cake (MOC), and 30% poultry manure (PM) or cowdung (CD) or sugarcane press mud (SPM) with 50% MSW compost. The nitrogen (N), phosphorus (P) and sulphur (S) mineralization study was done in soil treated with three amended and one unamended composts with three replications through an incubation experiment at a temperature of 25 ± 1°C for 82 days under aerobic (field capacity) and anaerobic (submerged) conditions. The mineralization data were fitted to the first-order kinetic model.

Results The soil NO_3^--N content was 2-3 times higher in aerobic condition than in anaerobic condition, while the NH_4^+-N was higher in anaerobic soils. The kinetic model reveals that poultry manure and sugarcane press mud had higher capability to supply N for use by the crops. The P release was the highest at day 15 with three-time higher availability in anaerobic condition. The S mineralization in soil was higher in field capacity than in submerged condition.

Conclusion The compost mixture comprising MSW, MOC and SPM in a ratio of 5:2:3 demonstrated the highest cumulative N, P and S mineralization in both aerobic and anaerobic conditions. The N and S availability decreased while the P availability increased in submerged soils which result has fertilizer management implications for wet land rice crop.

Keywords Kinetic model, N mineralization, P mineralization, S mineralization, MSW compost, Submerged soils

Introduction

Composting of municipal solid waste (MSW) is a good option of solid waste management to protect the environment and to serve as a good source of organic fertilizers. The MSW includes the residential, commercial, and institutional solid waste generated daily in a city. The benefits of using MSW compost include its impact on soil chemical, physical and biological properties that will eventually improve soil productivity. However, marketed MSW compost is reported generally poor in essential plant nutrients and the crops do not respond to its exclusive addition. Many studies are done to combine chemical fertilizers with MSW compost to obtain better crop response; the approach is called integrated nutrient management (Aktar et al. 2018; Jahiruddin et al. 2012; Kavitha and Subramanian 2007).

A good opportunity exists to improve the nutrient status of MSW compost through addition of some organic materials; literature pertaining to this type of work is highly limited. Torkashvand (2010) used molasses, office paper, sulfuric acid and paper mill sludge as mixing materials with municipal wastes

✉ M Jahiruddin
m_jahiruddin@yahoo.com

[1] Soil Science Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh
[2] Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[3] IFDC Bangladesh - USAID RFS activities, Dhaka, Bangladesh

for increasing the agronomic value of the compost. Wang et al. (2014) reported that the combined green waste compost, sedge peat and furfural residue (GSF treatment) had substantially ameliorated the saline soils in northern China, compared to individual amendment. As observed by Abideen et al. (2020), the biochar -compost mixture (1.5% biochar + 1.5% compost) better promoted nutrient uptake, water balance, and photosynthetic system efficiency compared to biochar (1.5%). Houot et al. (2012) compared four composts such as biowaste compost (BioW), municipal solid waste compost (MSW), green waste compost (GW) and co-compost of green waste and sludge (GW+S). They found no clear difference in the degrading capacity of the different composts, and the major difference was lying with the higher mineralizing capacity of the maturation microflora compared with the thermophilic microflora (e.g. bacteria).

Sustainable agriculture requires the use of organic fertilizers for steady nutrients supply and improving soil organic matter, soil physical & chemical properties and crop productivity (Hati et al. 2007; Khan et al. 2007; Liu et al. 2009).

Mineralization of nutrients from soil organic matter (SOM) is a biochemical process that is governed by many factors, such as chemical composition of SOM (Sano et al. 2006), environmental conditions (Rui et al. 2011; Pinto et al. 2020), soil properties (Xiao et al. 2013), soil microbial communities (Roth et al. 2011) and agricultural practices (Chang et al. 2014). Organic matter contains N, P and S which are present mostly in organic forms. During decomposition process, these nutrients are released as plant available forms such as NH_4^+, NO_3^-, orthophosphate ions ($H_2PO_4^-$, $HPO_4^{2-}$and PO_4^{3-}) and SO_4^{2-}. Understanding the dynamics of soil N, P and S mineralization is a prerequisite for optimizing fertilizer management and decreasing environmental risk (Rahn et al. 2003; Yin et al. 2007).

Most N assimilated by plants is derived from inorganic-N pools (mainly NH_4^+ and NO_3^-). Thus, the rate of organic-N decomposed and mineralized to inorganic-N is a key factor controlling the N supply for crops (Zhang et al. 2015). The N mineralization is also influenced by the fertilizer type (such as chemical or organic fertilizer), soil moisture content, and Temperature (Hossain et al. 2017). Using a ^{15}N tracing model, it was shown that mineral fertilizer enhanced mineralization of recalcitrant organic N, whereas the application of organic fertilizers stimulated the mineralization of labile organic N in the soil (Zhang et al. 2012). Temperature is recognized as an important factor for organic matter decomposition in soil. Klimek et al. (2020) studied the temperature sensitivity of SOM decomposition in different types of forest and concluded that the metabolic abilities of the soil microbial communities and the soil nutrient content were important controls of temperature sensitivity in taiga soils. However, mineralization of organic matter and release pattern of nutrients (N, P and S) from compost amendment is little known in alluvial soils.

The present study had considered locally available and low cost organic materials for mixing with MSW compost that the farmers commonly use as a source of organic matter in crop production. These materials were cowdung (CD), poultry manure (PM), sugarcane press mud (SPM) and mustard oil cake (MOC). It was hypothesized that MSW compost amended with organic manure such as mustard oil cake, poultry manure and cowdung would supply higher amount of nutrients to the crops. Thus, objective of the study was to examine the N, P & S mineralization behavior in soil mixed with some amended MSW composts. The expected outputs were that magnitude of nutrient availability from amended compost would be known which would help reduce the fertilizer requirement for crops.

Materials and methods

Preparation of nutrient enriched MSW compost

MSW compost was procured from the organization 'GRAMAUS' (Grameen Manobic Unnayan Sangstha) which produces and markets compost with solid wastes collected from Mymensingh City, Bangladesh. They separate plastics, glasses and metals at source point of collection. Mustard oil cake (MOC), poultry manure (PM), cowdung (CD) and sugarcane press mud (SPM) were used as amended materials in a suitable proportion to enrich the MSW nutrient level. Table 1 shows the N, P, K & S contents of the organic materials used in this study. The N, P, K & S levels in four different types of amended compost are displayed in Table 2.

Nutrient analysis

The procedure for determining nutrient contents of different organic materials and amended MSW composts was the same, as outlined below. For N

Table 1 Nutrient status of MSW compost, mustard oil cake, cowdung, poultry manure and sugarcane press mud

Organic material	N content (%)	P content (%)	K content (%)	S content (%)
MSW compost	1.14	0.23	0.87	0.27
Mustard oil cake	4.70	1.06	0.91	0.93
Cowdung	1.07	0.57	0.54	0.32
Poultry manure	1.33	0.80	0.89	0.42
Sugarcane press mud	1.59	0.091	0.64	0.51

MSW compost (mature) had 7.2 pH and 17.3 C:N ratio.

Table 2 Nutrient level of different types of compost

Types compost	N content (%)	P content (%)	K content (%)	S content (%)
Compost 1	1.41	0.33	1.01	0.41
Compost 2	3.14	0.84	0.84	0.52
Compost 3	2.91	0.62	0.77	0.45
Compost 4	3.22	0.40	0.81	0.32

Compost 1 = MSW 100%; Compost 2 = MSW 50% + MOC 20% + PM 30%; Compost 3 = MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30%.

determination, H_2SO_4 digestion (Kjeldahl method) and for P, K & S determination HNO_3-H_2O_2 digestion procedures were followed (Page et al. 1982). The amount of N, P, K and S in the acid digest was measured by the same methods used for soil analysis. Nitrogen in the digest was estimated by distillation with 10N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4 (Bremner and Mulvaney 1982). The K concentration in the acid digest was determined by flame photometer (Knudsen et al. 1982). The amount of P in the digest was determined by colorimetric method and the S was determined by turbid method, as described in the section 2.5 (quantification of N, P and S mineralization).

Set up of incubation experiment

An incubation experiment was performed in the laboratory to examine the nutrient release pattern for N, P and S from mineralization of different types of amended MSW compost. Each compost at a rate of 10 g kg^{-1} (equivalent to 20 t ha^{-1}, recommended dose for crop cultivation) was mixed with 100g soil in PVC pipes for aerobic (field capacity, 25% soil moisture) condition and plastic cup for anaerobic (1 cm standing water above soil) environment. A control soil (without compost) was run along with each set of incubation. They were incubated in the laboratory at room temperature (25 ± 1°C) for 82 days. The soil moisture level was checked weekly by weight loss and adjusted. Destructive samplings were done in this study, i.e., there was a separate set of pipe/cup for each sampling time. The first sampling was done just on the next day of incubation and this analysis was considered as initial moisture content of soil. The second measurement was done at 7 days after incubation (DAI), and thereafter measurement was done at 15-day intervals. So, there were four treatments (3 amended and 1 unamended) with three replications of each treatment, arranged in a completely randomized (CRD) design,

Basic characteristics of soil

The soil (0-15 cm) was silt loam (14% sand, 70% silt &16% clay) having 6.7 pH (water), 2.79% organic matter (Nelson and Sommer 1982), 0.17% Kjeldahl N (Bremner and Mulvaney 1982), 4.1 mg kg^{-1} Olsen P (Olsen and Sommer 1982), 0.089 cmol (+) kg^{-1} NH_4OAc extractable K (Knudsen et al. 1982) and 17.1mg kg^{-1} $CaCl_2$ extractable S (Fox et al. 1964).

Quantification of N, P and S mineralization

The available N (NH_4^+-N and NO_3^--N) content of soil was extracted by 2M KCl solution, with a 1:10 soil-extractant ratio (Keeney and Nelson 1982). The aliquot was steam distilled with MgO and Devarda alloy followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4. The available P ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}) was extracted by 0.5M $NaHCO_3$ solution, pH 8.5 and then determined colorimetrically by developing blue colour with reduction of phosphomolydate complex using NH_4-molybdate and ascorbic acid reagent (Olsen and Sommer 1982). Available S (SO_4^{2-}-S) was extracted from soil by 500 ppm P solution from $Ca(H_2PO_4)_2$, H_2O and was determined by turbidity method using $BaCl_2$ (Fox et al. 1964).

Fitting of mineralization data to the first order kinetic model

The N, P and S mineralization data were fitted to the first-order kinetic model (Stanford and Smith 1972):

$M_t = M_0\,(1-e^{-kt})$

where M_t is the net N, P and S mineralized (mg kg^{-1} soil) at time t, M_0 is the potentially mineralizable N, P and S (mg kg^{-1} soil), k is the rate constant (day^{-1}).

Results and discussion

The concentrations of N & P in the amended MSW composts had appreciably increased compared to original MSW compost.

Nitrogen mineralization

The available N content refers to the sum of NH_4^+-N and NO_3^--N contents. These inorganic forms of N are the forms that plants and microorganisms can use.

The amount of NH_4^+–N formation at day 52 became level off, the highest level being recorded at day 22. Walpola and Arunakumara (2010) reported that the NH_4^+-N content reached to the peak at day 15 followed by gradual reductions in all treatments. Unlike NH_4^+-N, the NO_3^--N concentration for all types of compost treatments was 2-3 times higher in aerobic condition compared to anaerobic condition. Aguilera et al. (2012) observed the similar result that the concentration of NH_4^+-N in flooded soils was higher than in dry soils and the reverse was true for the concentration of NO_3^--N. The NO_3^--N content under aerobic condition went to its peak at day 15; then, it decreased and finally it leveled off after 82 days for all amended soils. Ling-ling and Shu-tian (2014) found the rapid N mineralization in manure treated soil during 56-84 days of incubation.

NH_4^+-N release pattern

The release of NH_4^+-N from nutrient enriched MSW composts was significantly influenced by the added materials (cowdung, poultry manure, mustard oil cake and sugarcane press mud), soil moistures (aerobic and anaerobic conditions) and incubation days. Fig. 1 shows the extent of NH_4^+-N mineralization of different types of enriched compost under aerobic and anaerobic conditions over the period of 82 days. The soil amended with composts showed an increase in NH_4^+-N content initially presumably due to mineralization of organic matter. The amount of NH_4^+-N production reached its peak at day 22 in all the treatments and then decreased to a minimum at day 52 when it became almost stable for the rest period in aerobic condition, and under anaerobic condition, it attained the peak at day 15. Walpola and Arunakumara (2010) reported that the NH_4^+-N content reached to the peak at day 15 followed by gradual reductions in all treatments. The NH_4^+-N concentration was almost two times higher for every treatment in anaerobic condition than in aerobic condition. At the start (day 1) of the experiment, the NH_4^+-N concentration ranged from 2.80 mg kg^{-1} (T_1) - 7.47 mg kg^{-1} (T_4 & T_5) and it became level off on day 67 for both aerobic and anaerobic conditions. Treatment MSW compost + MOC + PM (T_3) had the highest release of NH_4^+-N showing a rate of 31.76 mg kg^{-1} soil under aerobic condition at day 22 and 62.74 mg kg^{-1} soil under anaerobic condition at day 15. It appeared that all compost amended soils in anaerobic condition demonstrated higher NH_4^+-N mineralization compared to aerobic condition. It appeared that the NH_4^+–N concentration became almost zero on day 67 and onwards under aerobic and anaerobic conditions (Fig. 1).

NO_3^--N release pattern

The trend of NO_3^--N release under aerobic and anaerobic conditions is presented in Fig. 2. The soils amended with different types of MSW compost showed an increase of NO_3^--N content that was presumably due to mineralization of organic matter. As opposite to NH_4^+–N concentration, the NO_3^--N concentration for all types of compost was found 2-3 times higher in aerobic environment compared to anaerobic over the treatments. With the passage of time, the NO_3^--N content under aerobic condition increased progressively up to 15 days, then it sharply decreased within 37 days and thereafter it decreased slowly and finally leveled

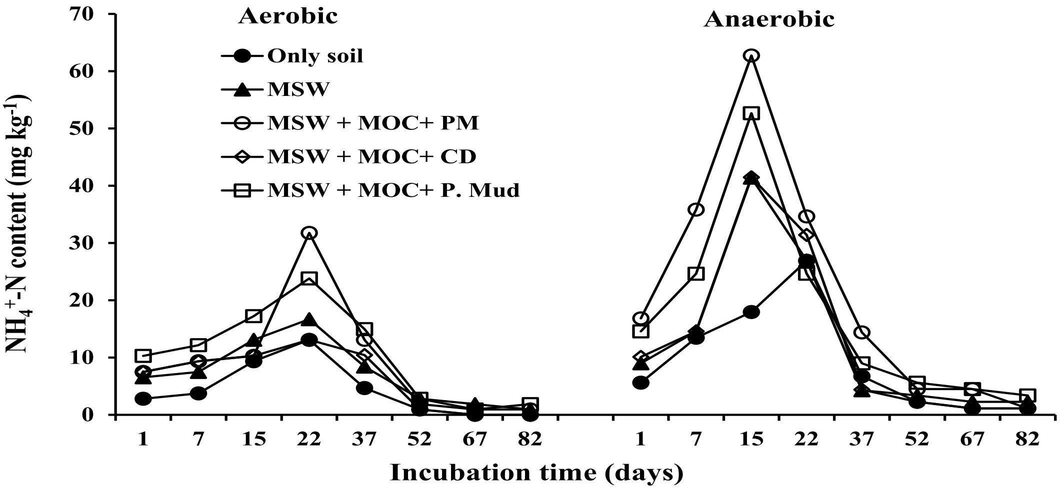

Fig. 1 Trend of NH_4^+-N release from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

off after 82 days for all amended soils. Aguilera et al. (2012) observed the similar result that the concentration of NH_4^+-N in flooded soils was higher than in dry soils and the reverse was true for the concentration of NO_3^--N. The NO_3^--N content under aerobic condition went to its peak at day 15; then, it decreased and finally it leveled off after 82 days for all amended soils. Ling-ling and Shu-tian (2014) found the rapid N mineralization in manure treated soil during 56-84 days of incubation.

Among the five amendments (treatments), the T_3 treatment, i.e., MSW compost + MOC + PM recorded the highest NO_3^--N content. Obviously, the exclusive soil (T_1) treatment demonstrated the lowest result. At the first day, the NO_3^--N concentration varied from 9.74 mg kg^{-1} (T_1) to 29.36 mg kg^{-1} (T_3) in aerobic condition against 2.87-13.34 mg kg^{-1} in anaerobic condition. At day 15, the NO_3^--N level was the highest recording 46.94 mg kg^{-1} (T_1) - 124.8 mg kg^{-1} (T_3) in aerobic condition and 19.96 (T_1) - 50.97 mg kg^{-1} in anaerobic condition.

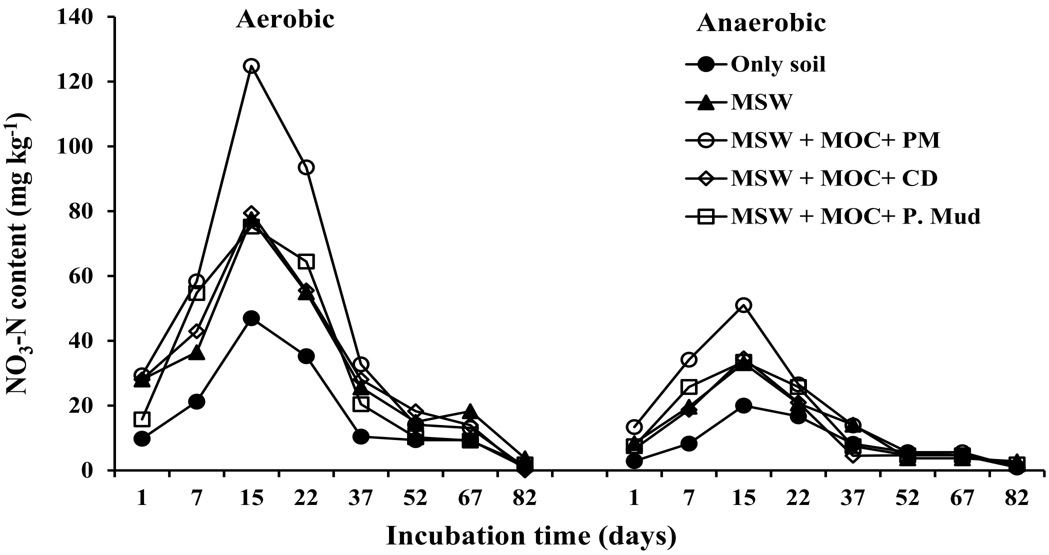

Fig. 2 Trend of NO_3^--N release from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

Cumulative N ($NH_4^+ + NO_3^-$) mineralization

The cumulative N mineralization due to different treatments and soil moisture levels across the incubation period is displayed in Fig. 3. The cumulative values of mineralization increased with incubation days, showing higher values for aerobic condition than for anaerobic condition. At the end of incubation time, the cumulative available N at field capacity soil moisture (aerobic) was found 178, 317, 442, 321 and 336 mg kg^{-1} for T_1-T_5 treatments, respectively. These values for submerged soil condition (anaerobic) were chronologically 142, 210, 326, 202 and 250 mg kg^{-1}. Then, the cumulative KCl extractable (available) soil N under both soil conditions clearly followed the order: $T_3 > T_5 > T_4 \approx T_2 > T_1$.

The labile SOM fraction can play a dominant role in N mineralization since it serves as an easily accessible energy source for microorganisms and results in greater soil N mineralization (Ros et al. 2011; Whalen et al. 2000). On the contrary, Ros (2012) reported that labile SOM fractions acted as the source of soil mineralizable N. Decreases in the soil N mineralization potential occurred when dissolved organic matter was removed (Li et al. 2010). As observed by Bu et al. (2015), POM (particulate organic matter) could have a vital role in soil N mineralization under different crop rotation systems. However, in the present study the OM fractionation was not done, thus scope is limited to compare the present results.

N mineralization kinetics

The N mineralization data for all types of compost at two soil moisture levels over the 82 days' incubation period were fitted to the first order kinetic model, $N_t = N_0\,(1- e^{-kt})$, where N_t is the net N mineralization (mg kg^{-1} soil) at time t, N_0 is the potentially mineralizable N (mg kg^{-1} soil) and k is the rate constant (day^{-1}). The data weakly to moderately fitted to the kinetic model, as shown in Table 3. The kinetic data reveal that the potential mineralization (N_0) was the maximum for T_3 treatment (poultry manure- based treatment), the values being 92.41 and 74.15 mg kg^{-1} under aerobic and anaerobic conditions, respectively. A different result was noted for 'k' value (mineralization constant), showing the highest value 1.667 for T_5 for aerobic case and 1.847 for T_4 for anaerobic case. This model analysis indicates that poultry manure and sugar press mud had higher capability to supply N for use by the crops.

Cheng and Wen (1993) from a 10-year decomposition experiment concluded that the annual mineralization rate of organic N in newly-formed humus varied with the type of original plant materials and the water regimes for decomposition. Wu et al. (2017) reported on the effect of 20-year long fertilizer application on soil N transformation in paddy soils in China that higher N nitrification was induced by manure application, which might lead to increased N losses.

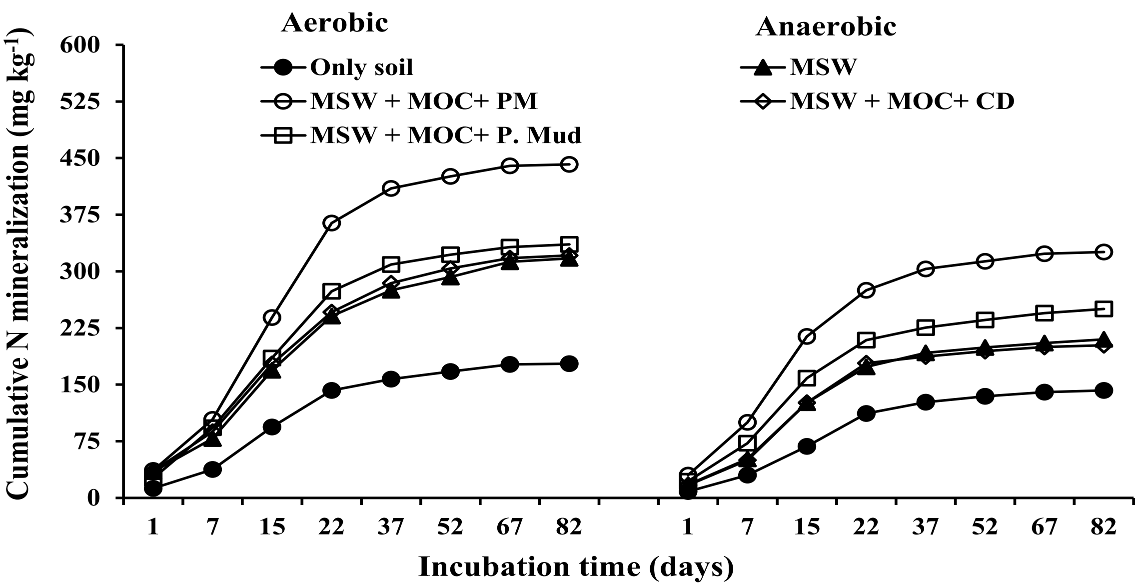

Fig. 3 Trend of cumulative N mineralization from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

Table 3 Estimated parameters of the first order kinetic model for N mineralization in soil treated with amended MSW composts

Treatments	Aerobic			Anaerobic		
	N_0	k	R^2adj*	N_0	k	R^2adj*
T_1 : Only soil	35.21	0.014	0.261	27.47	0.0135	0.244
T_2 : MSW	62.74	1.451	0.379	44.50	0.0169	0.309
T_3 : MSW + MOC + PM	92.41	1.616	0.321	74.15	0.0197	0.410
T_4 : MSW + MOC + CD	66.21	1.631	0.460	44.82	1.847	0.298
T_5 : MSW + MOC + SPM	70.89	1.667	0.380	54.93	1.841	0.370

MSW = Municipal solid waste, MOC = Mustard oil cake, PM = Poultry manure, CD = Cowdung, SPM = Sugarcane press mud.

*R^2 (adjusted) value: 0.0 to 0.2 - very weakly fit, 0.2 to 0.4 - weakly fit, 0.4 to 0.7 -moderately fit, 0.7 to 0.9 - strongly fit, 0.9 to 1.0 - very strongly fit.

N_0 = Potentially mineralizable N (mg kg^{-1} soil), k = Rate constant (day^{-1})

Phosphorus mineralization

P release pattern

The trend of P release from different types of amended MSW compost under aerobic and anaerobic conditions over the incubation period is displayed in Fig. 4. The P release was the highest at day 15 due to the T_3 treatment (MSW compost + MOC + PM) at field capacity (aerobic) condition. Next to T3, the other treatments except control demonstrated similar P availability in soil. The P level went down to about 50% for all treatments after about 12 weeks of incubation. The T_1, i.e., exclusive soil treatment (no addition of manure) showed the lowest P concentration which was 2.28 mg kg^{-1} at day 1 and 9.52 mg kg^{-1} after day 82. The P release under submerged soil (1 cm standing water) condition was the maximum at day 7 and thereafter it sharply decreased until day 22; then, it decreased steadily until incubation expiry time. The P release under anaerobic condition was about three times higher compared to aerobic condition. Naher et al. (2004) reported that the P mineralization from organic manure occurred after 15 days of application and then it increased steadily with times. They found higher P mineralization in the cowdung and poultry manure treated soils.

Cumulative P mineralization

The cumulative P mineralization, as expected, increased

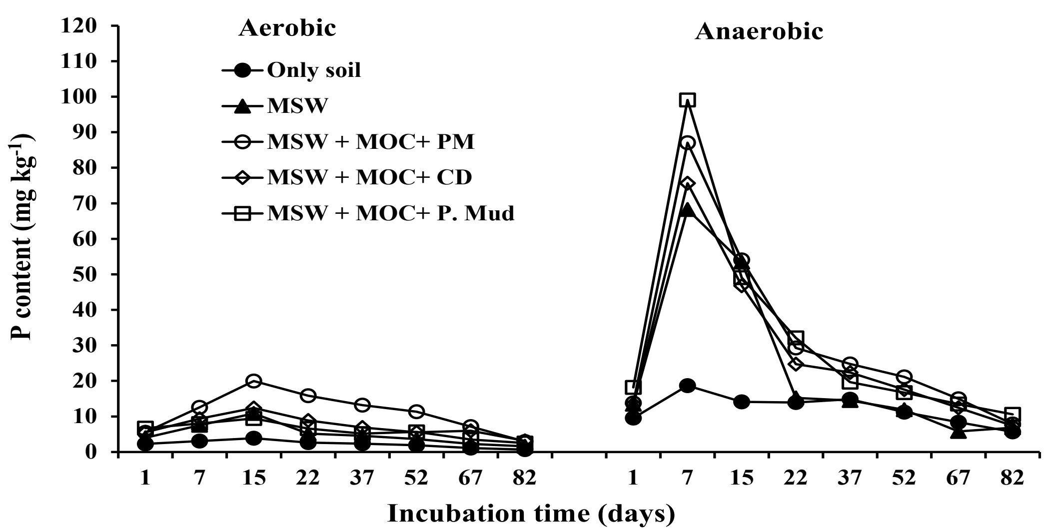

Fig. 4 Trend of P release from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

progressively with the advancement of incubation time for all treatments. The value of cumulative P mineralization at every sampling date was higher in anaerobic condition than in aerobic condition. This is not the case for N and S mineralization processes where reverse trend was noticed. The values of cumulative P at field capacity soils (aerobic) due to different treatments were as follows: T_3 (88.4 mg kg^{-1}) > T_4 (54.6 mg kg^{-1}) > T_5 (41.5 mg kg^{-1}) > T_2 (32.0 mg kg^{-1}) > T_1 (17.8 mg kg^{-1}). These values for anaerobic condition was in the order of T_5 (259 mg kg^{-1}), T_3 (253 mg kg^{-1}), T_4 (220 mg kg^{-1}), T_2 (189 mg kg^{-1}) and T_1 (96.3 mg kg^{-1}) (Fig. 5).

Ahmad et al. (2019) stated that mineralization and mobilization of biosolids (product of wastewater or MSW) P in soil have beneficial input to both environment and soil nutrient amendment. Microbial P immobilization makes soil P temporarily unavailable to plants; it eventually becomes available upon complete microbial decomposition due to the simultaneous mineralization–immobilization processes (Johnson 2012; Kirkby et al. 2014).

Zhang et al. (2020) observed that P fertilization accelerated the soil dissolved organic matter (DOM) cycle, which potentially benefited soil C sequestration in paddy fields.

P mineralization kinetics

The P mineralization data were fit to the first order kinetic model, $P_t = P_0 (1- e^{-kt})$, where P_t is the P mineralization at time t (mg kg^{-1} soil), P_0 is the potentially mineralizable P (mg kg^{-1} soil) and K is the rate constant (day^{-1}). In aerobic condition, the data fitted moderately for T_1, T_2 and T_5, weakly for T_4 and very weakly for T_3. In anaerobic condition, the data for all treatments fitted weakly to the kinetic equation. Like N mineralization, the T_3 (poultry manure based) treatment showed the highest potential P mineralization (P_0). But for the mineralization constant rate (k), the T_4 treatment (cowdung based) had the highest value under aerobic situation and in anaerobic situation, the T_1 (control, soil only) showed the highest value (Table 4)

Sulphur mineralization

S release pattern

Like N and P, the S mineralization was also significantly influenced by the compost types, soil moisture levels and incubation days. The highest S mineralization was observed with MSW + MOC + SPM (T_5) with the value of 313.48 mg kg^{-1} in aerobic condition (Fig. 6). In case of anaerobic condition, the maximum S concentration of 217.33 mg kg^{-1} was noted with the combination of MSW + MOC + CD (T_4). The S concentration ranged from 32.87 mg kg^{-1} (T_1) - 209.46 mg kg^{-1} (T_3) under aerobic condition and 21.93 - 179.11 mg kg^{-1}under anaerobic condition in the same two treatments, respectively. The

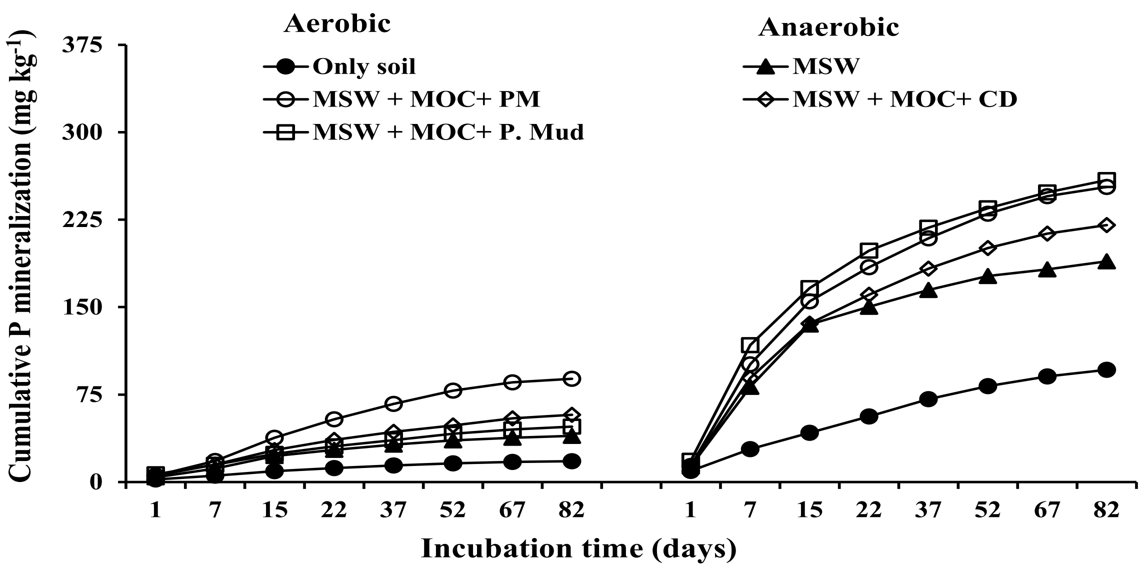

Fig. 5 Trend of cumulative P mineralization from different types of compost under aerobic and anaerobic conditions T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

Table 4 Estimated parameters of the first order kinetic model for P mineralization in soil treated with amended MSW composts

Treatments	Aerobic			Anaerobic		
	P_0	k	R^2adj*	P_0	k	R^2adj*
T_1 : Only soil	2.28	2.684	0.652	15.42	7.504	0.313
T_2 : MSW	7.72	1.335	0.413	44.27	2.159	0.357
T_3 : MSW + MOC + PM	14.08	7.217	0.189	52.26	1.653	0.318
T_4 : MSW + MOC + CD	9.46	8.273	0.357	45.98	1.694	0.336
T_5 : MSW + MOC + SPM	8.48	1.123	0.639	57.90	1.995	0.343

MSW = Municipal solid waste, MOC = Mustard oil cake, PM = Poultry manure, CD = Cowdung, SPM = Sugarcane press mud.

*R^2 (adjusted) value: 0.0 to 0.2 - very weakly fit, 0.2 to 0.4 - weakly fit, 0.4 to 0.7 -moderately fit, 0.7 to 0.9 - strongly fit, 0.9 to 1.0 - very strongly fit.

P_0 = Potentially mineralizable P (mg kg^{-1} soil), k = Rate constant (day^{-1})

S concentration of different types of compost reached its peak within a week, then came down sharply until week 3, then dropped gently until 7 weeks have passed when the S levels remained almost the same for the rest period.

Cumulative S mineralization

The cumulative S mineralization was likely to follow an increasing trend with the incubation days, showing the highest value at day 82 and the lowest at day 1 for all treatments at two moisture levels. In aerobic soil, the T_3 treatment demonstrated the highest level (1176 mg kg^{-1}), followed by T_5 (970 mg kg^{-1}), T_4 (819 mg kg^{-1}), T_2 (600 mg kg^{-1}) and T_1 (412 mg kg^{-1}) (Fig. 7). The cumulative S mineralization in anaerobic condition followed the same order, with lower values showing T_3 (807 mg kg^{-1}), followed by T_5 (633 mg kg^{-1}), T_4 (596 mg kg^{-1}), T_2 (479 mg kg^{-1}) and T_1 (330 mg kg^{-1}). It is assumed that much SO_4-S went into reduction to H_2S or S under submerged condition.

S mineralization kinetics

Unlike N and P mineralization, the S mineralization data under aerobic condition fitted strongly for all the treatments except T_1 which showed weak fit to the first order kinetic model, $S_t = S_0\ (1- e^{-kt})$, where S_t is the S mineralization at time t (mg kg^{-1} soil), S_0 is the potentially mineralizable S (mg kg^{-1} soil) and k is the rate constant (day^{-1}). In anaerobic condition, the data

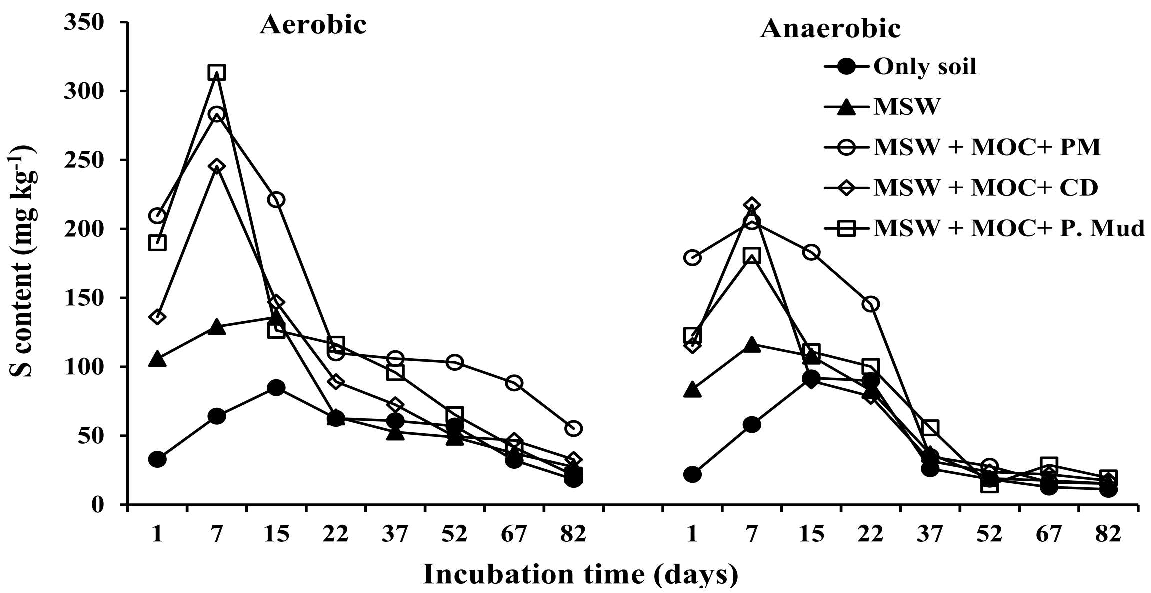

Fig. 6 Trend of S release from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM

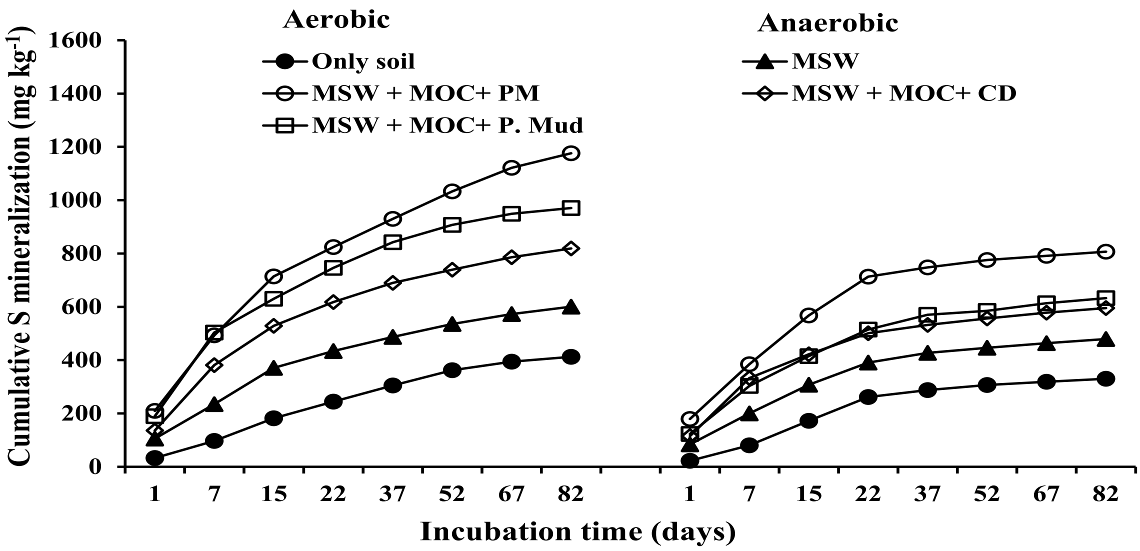

Fig. 7 Trend of S mineralization from different types of amended MSW compost under aerobic and anaerobic conditions

T_1: Only soil; T_2: MSW; T_3: MSW + MOC + PM; T_4: MSW + MOC + CD; T_5: MSW + MOC + SPM.

from treatments T_2 and T_3 fitted strongly, T_4 moderately and T_5 weakly to the kinetic model. Concerning mineralization rate constant that expressed by 'k' value, it followed the order $T_1 > T_5 > T_4 > T_2 > T_3$ under aerobic condition, while under anaerobic condition the order is opposite, showing $T_3 > T_4 > T_2 > T_5 \approx T_1$ (Table 5).

Conclusion

Use of 20% mustard oil cake and 30% sugarcane press mud or poultry manure or cowdung with 50% MSW compost (in 2:3:5 ratio) greatly increased the nutrient level of MSW compost. The highest NH_4^+-N and P release (orthophosphate ions) occurred at day 15 while the NO_3^- and SO_4^{2-} release happened at day 22 and day 7, respectively over the 82 day's incubation period. The N and S availability was reduced 2-3 times in submerged (1 cm water depth) soil conditions while the P availability much increased in this situation, the result has great implications for sustainable nutrient management in wet land rice culture. The kinetic model analysis indicates that poultry manure and sugarcane press mud had higher nutrient supplying capacity to the crops.

Table 5 Estimated parameters of the first order kinetic model for S mineralization in soil treated with amended MSW composts

Treatments	Aerobic			Anaerobic		
	S_0	k	R^2adj*	S_0	k	R^2adj*
T_1 : Only soil	65.38	7.134	0.274	65.05	1.436	0.293
T_2 : MSW	130.58	1.917	0.777	116.92	2.371	0.799
T_3 : MSW + MOC + PM	252.79	1.887	0.769	226.89	3.055	0.867
T_4 : MSW + MOC + CD	200.65	2.178	0.703	170.14	3.367	0.689
T_5 : MSW + MOC + SPM	250.55	2.730	0.733	65.05	1.436	0.293

MSW = Municipal solid waste, MOC = Mustard oil cake, PM = Poultry manure, CD = Cowdung, SPM = Sugar press mud.

*R^2 (adjusted) value: 0.0 to 0.2 - very weakly fit, 0.2 to 0.4 - weakly fit, 0.4 to 0.7 -moderately fit, 0.7 to 0.9 - strongly fit, 0.9 to 1.0 - very strongly fit.

S_0 = Potentially mineralizable S (mg kg^{-1} soil), k = Rate constant (day^{-1})

Acknowledgement This research was supported by the World Bank (WB) funded Higher Education Quality Enhancement Project (HEQEP) implemented by the University Grants Commission (UGC), Bangladesh.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

Abideen Z, Koyro HW, Huchzermeyer B, Gul B, Khan MA (2020) Impact of a biochar or a biochar-compost mixture on water relation, nutrient uptake and photosynthesis of *Phragmites karka.* Pedosphere 30(4): 466-477. https://doi.org/10.1016/S1002-0160(17)60362-X

Aguilera J, Motavalli PP, Gonzales MA, Valdivia C (2012) Initial and residual effects of organic and inorganic amendments on soil properties in a potato-based cropping system in the Bolivian Andean Highlands. Amer J Expt Agric 2(4): 641-666. https://doi.org/10.9734/AJEA/2012/2006

Ahmad AM, Ugya AY, Isah HA, Imam TS (2019) Mineralization and mobilization of biosolids phosphorus in soil: A concise review. J Appl Biol Biotech 7(05): 98-106. https://doi.org/10.7324/JABB.2019.70516

Aktar S, Islam MS, Hossain MS, Akter H, Maula S, Hossain SSF (2018) Effects of municipal solid waste compost and fertilizers on the biomass production and yield of BRRI dhan50. Prog Agric 29(2): 82-90. https://doi.org/10.3329/pa.v29i2.38291

Bremner JM, Mulvaney CS (1982) Nitrogen-Total. In: Methods of soil analysis, Part 2: Chemical and microbiological properties, Page et al. (eds.) American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp 595-624. https://doi.org/10.2134/agronmonogr9.2.2ed.c31

Bu R, Lu J, Ren T, Liu B, Li X, Cong R (2015) Particulate organic matter affects soil nitrogen mineralization under two crop rotation systems. Plos One 10(12): e0143835. https://doi.org/10.1371/journal.pone.0143835

Chang R, Jin T, Lü Y, Liu G, Fu B (2014) Soil carbon and nitrogen changes following afforestation of marginal cropland across a precipitation gradient in Loess Plateau of China. Plos One 9(1): e85426. https://doi.org/10.1371/journal.pone.0085426

Cheng LL, Wen QX (1993) Mineralization and transformation of nitrogen derived from plant materials in soils over 10 years. Pedosphere 3(2): 97-106

Fox RL, Olson RA, Rhoades HF (1964) Evaluating the sulfur status of soils by plants and soil tests. Soil Sci Soc Amer Proc 28: 243-246. https://doi.org/10.2136/sssaj1964.03615995002800020034x

Hati KM, Swarup A, Dwivedi A, Misra A, Bandyopadhyay K (2007) Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. Agric Ecosyst Environ 119(1):127-134. https://doi.org/10.1016/j.agee.2006.06.017

Hossain MB, Rahman MM, Biswas JC, Miah MMU, Akhter S, Maniruzzaman M, Choudhury AK, Ahmed F, Shiragi MHK, Kalra N (2017) Carbon mineralization and carbon dioxide emission from organic matter added soil under different temperature regimes. Int J Recycl Org Waste Agricult 6: 311–319. https://doi.org/10.1007/s40093-017-0179-1

Houot S, Verge-Leviel C, Poitrenaud M (2012) Potential mineralization of various organic pollutants during composting. Pedosphere 22(4): 536–543. https://doi.org/10.1016/S1002-0160(12)60038-1

Jahiruddin M, Rahman MA, Haque MA, Rahman MM, Islam MR (2012) Integrated nutrient management for sustainable crop production in Bangladesh. Acta Hort 958: 85-90. https://doi.org/10.17660/ActaHortic.2012.958.8

Johnson N (2012) Fertilizer for the future. A phosphorus perspective. Nuffield Arden Scholarship, UK

Kavitha R, Subramanian P (2007) Effect of enriched soil waste compost application on growth, plant nutrient uptake and yield of rice. J Agron 6(4): 586-592. https://doi.org/10.3923/ja.2007.586.592

Keeney DR, Nelson DW (1982) Nitrogen – Inorganic forms. In: Methods of soil analysis, Part 2, Page et al. (eds.) American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp. 643-698

Khan MU, Qasim M, Khan IU (2007) Effect of integrated nutrient management on crop yields in rice-wheat cropping system. Sarhad J Agric 23(4): 1019-1025

Kirkby CA, Richardson AE, Wade LJ, Passioura JB, Batten GD, Blanchard C, Kirkegaard JA (2014) Nutrient availability limits carbon sequestration in arable soils. Soil Biol Biochem 68: 402–9. https://doi.org/10.1016/j.soilbio.2013.09.032

Klimek B, Chodak M, Jazwa M, Azarbad H, Niklinska M (2020) Soil physicochemical and microbial drivers of temperature sensitivity of soil organic matter decomposition under boreal forests. Pedosphere 30(4): 528-534. https://doi.org/10.1016/S1002-0160(17)60400-4

Knudsen D, Peterson GA, Pratt PF (1982) Lithium, sodium and potassium. In: Methods of soil analysis, Part 2: Chemical and microbiological properties, Page et al. (eds.) American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp. 225-245. https://doi.org/10.2134/agronmonogr9.2.2ed.c13

Li ZP, Han CW, Han FX (2010) Organic C and N mineralization as affected by dissolved organic matter in paddy soils of subtropical China. Geoderma 157: 206–213.

https://doi.org/10.1016/j.geoderma.2010.04.015

Ling-ling LI, Shu-tian LI (2014) Nitrogen mineralization from animal manures and its relation to organic N fractions. J Integr Agric 13: 2040–2048. https://doi.org/10.1016/S2095-3119(14)60769-3

Liu M, Hu F, Chen X, Huang Q, Jiao J, Zhang B, Li H (2009) Organic amendments with reduced chemical fertilizer promote soil microbial development and nutrient availability in a subtropical paddy field: The influence of quantity, type and application time of organic amendments. Appl Soil Ecol 42: 166–175. https://doi.org/10.1016/j.apsoil.2009.03.006

Naher UA, Hashem MA, Mitra BK, Uddin MK, Saleque MA (2004) Effect of rice straw and lime on phosphorus and potassium mineralization from cowdung and poultry manure under covered and uncovered conditions in the tropical environment. Pak J Biol Sci 7(1): 45-48. https://doi.org/10.3923/pjbs.2004.45.48

Nelson DW, Sommer LE (1982) Total carbon, organic carbon and organic matter. In: Methods of soil analysis, Part 2: Chemical and microbiological properties, Page et al. (eds.) American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp. 539-579

Olsen SR, Sommer LE (1982) Phosphorus. In: Methods of soil analysis, Part 2: Chemical and microbiological properties, Page et al. (eds.) American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp. 403-430. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis: Part 2: Chemical and microbiological properties. American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA

Pinto R, Brito LM, Coutinho J (2020) Nitrogen mineralization from organic amendments predicted by laboratory and field incubations. Commun Soil Sci Plant Anal 51(4): 515-526. https://doi.org/10.1080/00103624.2020.1717510

Rahn CR, Bending GD, Turner MK, Lillywhite RD (2003) Management of N mineralization from crop residues of high N content using amendment materials of varying quality. Soil Use Manage 19: 193–200. https://doi.org/10.1111/j.1475-2743.2003.tb00304.x

Ros GH (2012) Predicting soil N mineralization using organic matter fractions and soil properties: A re-analysis of literature data. Soil Biol Biochem 45: 132–135. https://doi.org/10.1016/j.soilbio.2011.10.015

Ros GH, Hanegraaf MC, Hoffland E, Riemsdijk W (2011) Predicting soil N mineralization: Relevance of organic matter fractions and soil properties. Soil Biol Biochem 43: 1714–1722. https://doi.org/10.1016/j.soilbio.2011.04.017

Roth PJ, Lehndorff E, Zhuang SY, Bannert A, Wissing L, Schlter M, Knabner IK, Amelung W (2011) Accumulation of nitrogen and microbial residues during 2000 years of rice paddy and non-paddy soil development in the Yangtze River Delta, China. Global Change Biol 17: 3405–3417. https://doi.org/10.1111/j.1365-2486.2011.02500.x

Rui YC, Wang SP, Xu ZH, Wang YF, Chen CR, Zhou XQ, Kang XW, Lu SB, Hu YG, Lin QY, Luo CY (2011) Warming and grazing affect soil labile carbon and nitrogen pools differently in an alpine meadow of the Qinghai-Tibet Plateau in China. J Soil Sediment 11: 903–914. https://doi.org/10.1007/s11368-011-0388-6

Sano S, Yanai J, Kosaki T (2006) Relationships between labile organic matter and nitrogen mineralization in Japanese agricultural soils with reference to land use and soil type. Soil Sci Plant Nutr 52: 49–60. https://doi.org/10.1111/j.1747-0765.2006.00003.x

Stanford G, Smith SJ (1972) Nitrogen mineralization potentials of soils. Soil Sci Soc Amer Proc 36: 465-72. https://doi.org/10.2136/sssaj1972.03615995003600030029x

Torkashvand AM (2010) Improvement of compost quality by addition of some amendments. Austr J Crop Sci 4(4): 252-257

Walpola BC, Arunakumara KKIU (2010) Effect of salt stress on decomposition of organic matter and nitrogen mineralization in animal manure amended soils. J Agric Sci 5: 9-18. https://doi.org/10.4038/jas.v5i1.2319

Wang L, Sun X, Li S, Zhang T, Zhang W, Zhai P (2014) Application of organic amendments to a coastal saline soil in north China: Effects on soil physical and chemical properties and tree growth. Plos One 9(2): e89185. https://doi.org/10.1371/journal.pone.0089185

Whalen JK, Bottomley PJ, Myrold DD (2000) Carbon and nitrogen mineralization from light-and heavy-fraction additions to soil. Soil Biol Biochem 32: 1345–1352. https://doi.org/10.1016/S0038-0717(00)00040-7

Wu YP, Shaaban M, Deng CJ, Peng QA, Hu RG (2017) Changes in the soil N potential mineralization and nitrification in a rice paddy after 20 yr application of chemical fertilizers and organic matter. Canad J Soil Sci 97(2): 290-299. https://doi.org/10.1139/cjss-2016-0065

Xiao KC, Xu JM, Tang CX, Zhang JB, Brookes PC (2013) Differences in carbon and nitrogen mineralization in soils of differing initial pH induced by electrokinesis and receiving crop residue amendments. Soil Biol Biochem 67: 70–84. https://doi.org/10.1016/j.soilbio.2013.08.012

Yin F, Fu BJ, Mao RZ (2007) Effects of nitrogen fertilizer application rates on nitrate nitrogen distribution in saline soil in the Hai River Basin, China. J Soil Sediment 136-142. https://doi.org/10.1065/jss2007.04.218

Zhang JB, Zhu TB, Cai ZC, Qin SW, Muller C (2012) Effects of long-term repeated mineral and organic fertilizer applications on soil nitrogen transformations. Eurasian J Soil Sci 63: 75-85. https://doi.org/10.1111/j.1365-2389.2011.01410.x

Zhang X, Wang Q, Xu J, Gilliam FS, Tremblay N, Li C (2015) In situ nitrogen mineralization, nitrification, and ammonia volatilization in maize field fertilized with urea in Huanghuaihai region of Northern China. Plos One 10: e0115649. https://doi.org/10.1371/journal.pone.0115649

Zhang ZJ, Wang XZ, Liang LY, Huang E, Tao XH (2020) Phosphorus fertilization alters complexity of paddy soil dissolved organic matter. J Integr Agric 19(9): 2301–2312. https://doi.org/10.1016/S2095-3119(20)63215-4