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ORIGINAL RESEARCH

Humification of poultry waste and rice husk using additives and its application

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Abstract

Purpose The purpose of this study was to assess the efficacy of inorganic additives during the humification of poultry waste and rice husk.

Methods Poultry waste mixture was treated with aluminum sulfate 3% and rock phosphate 2% during co-composting of mixture in mechanical composter and evaluated the potential of humification and compost nitrogen mineralization in incubation and pot study.

Results The mesophilic to thermophilic phase of composting mixture is prolonged due to the rise in temperature, pH and ammonia that steadily decrease near the maturation phase. The humification rate (HR), humification index (HI), degree of polymerization (DP) and cation exchange capacity (CEC) increased in enriched compost as compared to unenriched with the composting process. The germination index (GI) of enriched compost (C/N:10.8) was significantly greater than unenriched compost (C/N:23.43). These all maturity indices, i.e., C/N, CE, HI, DP, HR revealed the significant correlation with each other. In the incubation study, nitrogen mineralization was also evaluated and nitrogen was applied at the rate of 50 kg-N/ha using the enriched and unenriched compost and found high mineralization in enriched compost due to low C/N. A laboratory-scale pot experiment was also conducted, applied the compost at a rate of 100 kg-N/ha and recorded the encouraging results in growth and nutrition value of *Abelmoschus esculentus* plant.

Conclusion It was concluded that use of additives have a significant impact on humification of poultry waste.

Keywords Compost · Enrichment · Experiment · Mixing · Humification

Introduction

In Pakistan, there are several poultry farms that produce a large amount of poultry waste daily and all poultry farms' owners are facing problems due to lack of storage, disposal and handling facilities. Problems related to regulatory pressure, urban invasion, fly control, and proximate land base for waste disposal compel the search for an alternative waste management system (Yadav et al. 2017). The commonly used livestock solid waste disposal techniques include on-site burial, landfill, incineration and composting. However, its direct use for plantations, pastures and open field's area reduced the variety, quality and can disrupt the biological structure of the soil. Poultry waste is a mixture of poultry feces, bedding material, waste feed and feathers that have an important financial and viable potential for composting. The selection of the composting process depends upon the climate condition, nature of waste, type of animal waste, economic conditions and its application. The aerobic and anaerobic composting process are commonly used for poultry waste decomposition and are better compared to burning and other different drying techniques (Chen and Jiang 2014). The microbiological, chemical processed and recycled chicken feces waste are significantly used as organic fertilizer and widely spread on productive land. Poultry waste contains different concentrations of water and nutrients for plants' growth like calcium, boron, phosphorus, potassium, magnesium, manganese, copper, nitrogen, sulfur, zinc, iron, molybdenum and organic matter. It is easily available at low cost from vicinity farms to restore and improve the chemical,

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physical and biological fertility of the degraded soil (Liang et al. 2017; Yee 2017).

However, the fresh poultry waste may contain an inappropriate C/N ratio, pathogens, an improper amount of plant nutrients, annoying odors and its application may slow down the germination of seed, lessen the growth of plant and harm the crops by rivaling for oxygen or may cause phytotoxicity to plants due to scarcity in organic matter (Chaudhry et al. 2013). Due to these concerns, the demand for humification and high cost of synthetic fertilizer, farmers prefer to adopt the organic farming techniques. Composting is a low investment technology that can transform organic waste into valuable organic matter through bio-oxidation which enhances the quality of soil for plant growth by augmenting aeration, water status, micro- and macronutrients. The compost production in Pakistan is of low quality for plants and its efficiency is also extremely poor. Therefore, it is the need of the hour to enrich the poultry waste materials for maximum nutrient availability to plants and reduce the time of humification through microbial activity. An extensive literature survey was conducted and it was found that many scientists have studied the impact of enrichment on a variety of wastes and found encouraging results during humification, nutrients' dynamic, plant toxicity and humification/decomposition time. They used ash, lime, rock phosphate, ferrous sulfate, calcium hydroxide and peroxide (Nishanth and Biswas 2008; Himanen and Hannieen 2009; Iqbal et al. 2010, 2015, 2016; Yadav et al. 2017). Moreover, composting of poultry waste in Pakistan is currently not conducted scientifically by private contractors, where it takes 4 months to produce compost for use and their humification quality is still ambiguous. Therefore, the present study was conducted to examine the influence of aluminum sulfate and rock phosphate on poultry waste humification and uptake of compost nutrients by *Abelmoschus esculentus* (ladyfinger) plants in pot and incubation study.

Materials and methods

Poultry waste was collected from Raiwind poultry farm, Lahore and taken to the composting plant at PCSIR laboratories complex in Lahore. Rice husk was purchased from the local market and was used to reduce the moisture of poultry waste. Rice husk was added in poultry waste at the rate of 30% to adjust the moisture content of mixture for composting. Poultry waste and rice husk was blended in mechanical composter of 10 L capacity. The drum of composter is the main unit which is of 300 mm length and 250 mm diameter and is made up of a 3 mm thick sheet of stainless steel. The drum was griped on an iron metal stand and the inner side of the composter is made of stainless steel (SS) and the steel angles were welded horizontally for complete mixing of waste. Simultaneously, two holes, one which was 200 mm in size and the other 100 mm, were made on drum both at the upper and the lower portion, respectively. The poultry waste and rice husk mixture was loaded into the composter manually and filled up to fifty percent of the entire volume. The composter runs frequently 5 h daily at 500 RPM which was adjusted by the electrical gearbox and the temperature of mixture was monitored during this period. Aluminum sulfate (3%) and rock phosphate (2%) were used as inorganic additives, that were spread on the mixture [poultry waste (70%) and rice husk (30%)] and mixed in a mechanical composter in an experimental batch (enriched). In a similar manner but without additives, the unenriched compost was run and analyzed with the same parameters. Each batch was done in triplicates and their results were reported as an average. The 300 gm samples were collected from each run after every five days regularly up to 60 days. Samples were dried at 75 °C and passed through a sieve of 2 mm to examine the pattern of HI, DP, ash, C/N ratio and HR.

Nitrogen mineralization

The sandy clay loam soil (BD: 50.43 kgm^3) 300 g was kept in a plastic container (diameter: 5 cm) to study the N-mineralization of both types of compost under the incubation process. The air-dried soil (size: 2 mm) was kept at 50% moisture by the addition of demineralized water and was incubated for 7 days to optimize the condition of soil at a constant temperature of 20 °C. On area basis, the unenriched and enriched composts were applied at the rate of 50 kg-N/ha to each pot and then deionized water was added and the mixture was mixed regularly after a 5-day interval to minimize denitrification. Pots were incubated in a growth chamber at 25 °C and nitrogen mineralization rate (NMR) was calculated in a similar manner to our previous study (Iqbal et al. 2010).

Pot experiment

The ladyfinger seeds were planted in pots (diameter 20.0 cm and height 20.0 cm) under controlled laboratory conditions and the pots were filled at the rate of 5 kg soil/pot with air-dried sandy clay loam soil (2 mm) and two seeds were permitted to grow in each pot. The pots were arranged as a randomized absolute block design with three treatments, C_1 (enriched compost), C_2 (unenriched compost) and C_3 (control soil) and three replicates were practically performed at the rate of 100 kg-N/ha. P and K were applied at a rate of 50 kg/ha using single super phosphate and potassium according to the need of crop. Canal water was used to irrigate the soil and the quality of water [electrical conductivity (EC) 0.0.05 µs/cm, sodium absorption ratio (SAR), 0.3 m mole/l] was in accordance with the requirement of crop.

Analytical methods

The moisture content of poultry waste and both composts was analyzed gravimetrically at 105 °C by heating up to a constant weight. pH of all samples was determined by extracting the samples with double distilled water (DD) in a ratio of 1:10 using the pH meter (HANA-1121). The humification of compost was determined by stirring 1.0 g of the compost mixtures with 30 ml of 0.1 M NaOH for 20 h to determine humic acid (HA). To obtain a clear supernatant, the suspension for about 10 min was centrifuged at 10,000 rpm which was stated as NaOH soluble fraction (HA ± FA). Sodium hydroxide soluble fraction about 15 ml was acidified with conc. H_2SO_4 to pH 1.0. The supernatant was assigned as FA and HA as precipitation after 12 h of centrifugation and standing, 4 ml of the FA and 2 ml of the NaOH were isolated, dichromate oxidation method used to determine the carbon content (Aparna et al. 2008). Carbon content of the humic acid was calculated as the difference in carbon content between the fulvic acid (FA) and NaOH soluble fraction. Moreover, the HR, DP, HI, ash and CEC of compost were calculated as per our previous study (Iqbal et al. 2014):

$$\mathrm{HI} = \mathrm{HA}/\mathrm{TOC} \times 100$$

$$\mathrm{DP} = \mathrm{HA}/\mathrm{FA}$$

$$\mathrm{HR}\,(\%) = \mathrm{HA} \pm \mathrm{FA}/\mathrm{TOC} \times 100$$

The chemical properties of compost, poultry waste, rice husk and soil micronutrients like EC, N, P,K, Ash, OM, Zn, Mn, Pb, Cu were evaluated using the ASTM method. The total amount of N and total C in compost/soil was carried out by catalytic tube combustion using the Vario Macro elementar CHNS analyzer (S.N:11046079). The C/N ratio was calculated as the quotient of total carbon over total nitrogen. Phytotoxicity and particle size procedure was adopted similar to our last study (Iqbal et al. 2014).

Statistical analysis

The compost and poultry waste were analyzed three times and the results were reported as an average with standard deviation using Microsoft 2010. The Pearson correlation was also determined between compost parameters FA, HA, DP, HI, C/N and HR with SPSS.19.

Results and discussion

pH of compost

A variation was exhibited in the composting process as a consequence of the chemical changes in the composting mixture. Initially, pH showed a decline due to the formation of organic acids and later on increased to neutral due to acid consumption and formation of ammonia (Lopez-Cano et al. 2016). The present study's results defined that pH value was significantly affected by addition of inorganic salts and rock phosphate (Fig. 1a). The addition of rock phosphate enhanced the pH of poultry mixture due to metabolic activities of organic compounds and protein degradation which liberates the ammonia in the environment. The maximum pH (9.42) was raised on 35th day in enriched and pH (8.25) on 55th day in unenriched compost, which later on at the end of the composting, there was no remarkable difference in their values. The decrease in pH was comparatively less in enriched compost than unenriched because of the release of ammonia. The present study's findings are also in accordance with Iqbal et al. (2015).

Temperature of the compost

Temperature is the live indication of microbial activity occurring during the composting process. It helps to monitor the performance and rate of humification in the composting matrix. It has a dynamic part in succession and evaluation of microbiological communities in the entire biological process. It promotes the degradation of complex substrate into simpler compounds (Waqas et al. 2017). The temperature of the decaying waste increased quickly as composting preceded; however, temperature decreased slowly after the thermophilic stage and became stable (Iqbal et al. 2014). In this current study, the temperature was recorded daily over the entire composting process but was reported at 5-day intervals. In the enriched compost, the temperature was raised rapidly in first 20 days which subsequently exhibited the decline in their temperature. It means the humification of composting matrix was higher than the unenriched compost. Temperature peak for unenriched compost revealed that the humification rate is much slow than the enriched compost due to the addition of inorganic additive which promoted the decomposition or humification of enriched compost (Fig. 1b). Moreover, the temperature of enriched compost and ambient was not significantly different at the end of composting process. Composting phenomena is primarily based on moisture and aeration, which regulate the

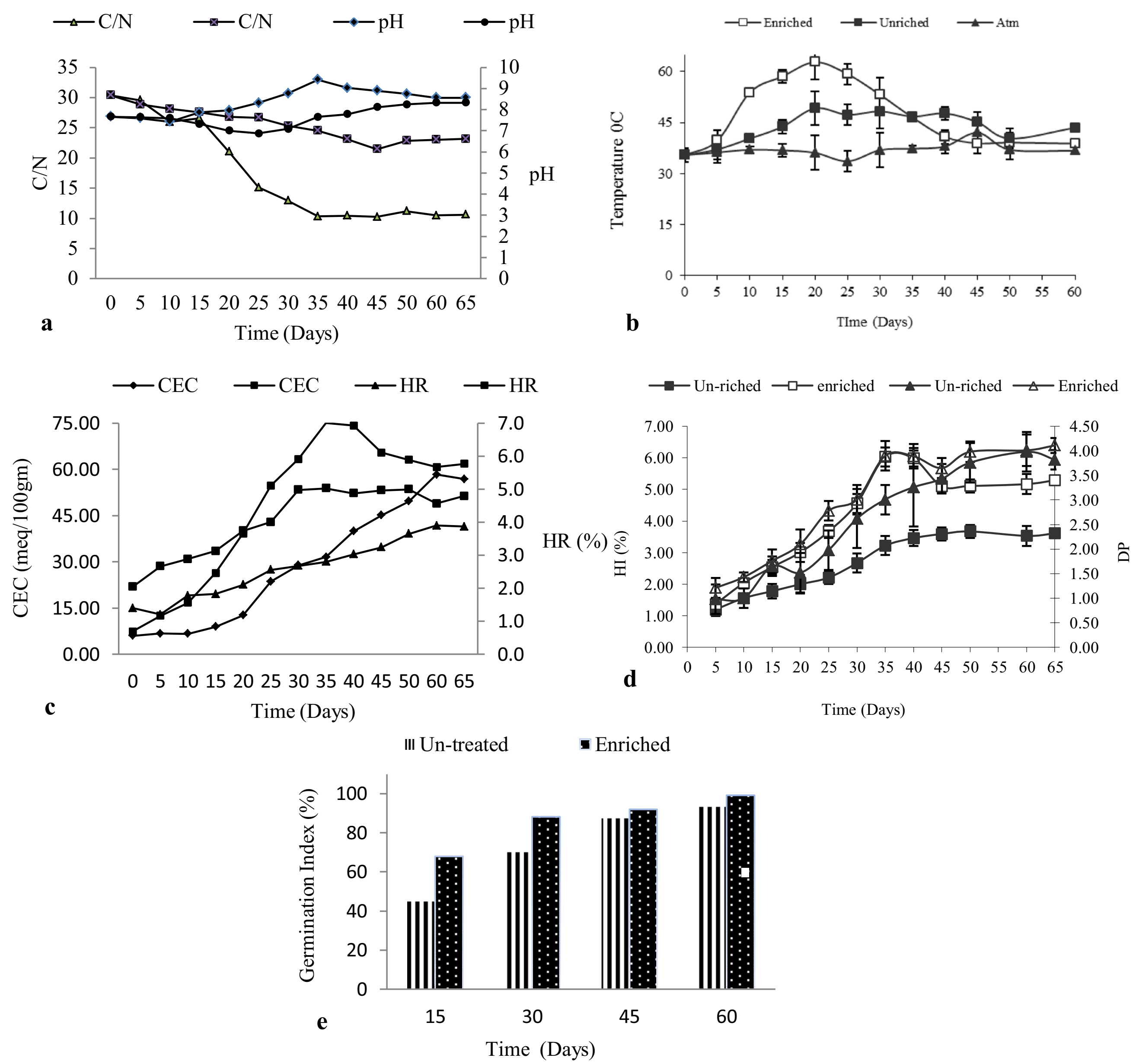

Fig. 1 Effect of enrichment on humification parameters. **a** pH and C/N, **b** temperature, **c** CEC and HR, **d** HI and HR, **e** GI. Enrichment of aluminum sulfate 3%, and rock phosphate 2% on co-composting of poultry waste and rice husk. All results are based on three observations and their S.D (±3) is also reported

mineralization of organic materials. When mineralization of composting matrix attained a peak, then the temperature of decomposed material shifted to ambient temperature, the material became soft, finer, and dark brown in color, no malodors were detected and C/N became stable. It means the composting matrix revealed the completion of humification process and compost maturity (Chaudhry et al. 2013).

C/N ratio of compost

It is the reflection of organic matter (OM) decomposition and its increase is a positive sign of humification. Present study results depicted that with the rise of composting time there is a fall in carbon and nitrogen ratio in enriched and unenriched composts. The bio-oxidation of carbon into carbon dioxide is due to the impact of rock phosphate and other inorganic additives in early stage of composting. C/N data elucidated that it did not show variation in first 15 days in both composts, later on it decreased rapidly and became stable on 35th day of composting process in enriched compost and was 57.9% less C/N than unenriched compost (Fig. 1a). There was a great significant difference was found in C/N at the end of the experiment between enriched (C/N:10.61) and unenriched compost (C/N:23.13). According to Golueke (1981) below 20 the carbon nitrogen ratio showed the adequate maturity and C/N of 15 or minimum of this is preferable. The present findings were also coherent with many scientists' results (Saidi et al. 2008; Iqbal et al. 2010). The nitrate and ammonia reduction data were also collected but presently not reported here.

Organic matter and ash of compost

The composting process is the decomposition of organic carbon or degradation of organic matter (OM) and increase of ash contents with the passage of time is a significant angle for humification of composting matrix. Organic matter and ash are inversely proportional to each other. When OM is high then it leads to a low content of ash which means that it is a slow humification process and vice versa. In the study, the OM with passage of time gradually reduced due to various biochemical reactions which transformed complex substrates into simpler components (Zhang et al. 2016). Higher humification rates depicted the higher microbial activities in enriched compost than unenriched compost (Sun et al. 2016). The incorporation of additives enhances the microbial activities which provide favorable conditions for the microbes for degradation of poultry substances. Moreover, the rice husk has a high percentage of ash contents which enhances the micronutrients in the composting process. It builds up the mechanism of compost to raise the humification process more efficiently. The ash content in this study was observed as in the initial stage of composting, the OM was high and ash was low but with progression of time, the total amount of OM reduced, and as a result, the ash was linearly increased. This linear increase in ash content was more observed in enriched compost than unenriched (Waquas et al. 2017; Kalaivanan and Hattab 2016). Ash is the inorganic portion of substrate predominantly comprised of a variety of inorganic minerals like manganese, magnesium, calcium, iron, and sodium along with other trace metals. Usually, these cations are associated with phosphate, carbonate, sulfate, and nitrate. These compounds are either produced as a result of OM degradation or present in the substrate and mostly remained unaffected by biological actions hence pass through composting without any modification. (Venglovsky et al. 2005). The higher ash content results in a greater humification process and there was a remarkable difference between these two composts' results (Table 1).

Table 1 Chemical characteristics of poultry waste, enriched, unenriched compost and rice husk

Parameters	Poultry waste	Enriched compost	Unenriched compost	Rice husk
Moisture (%)	60.8	26.43	34.98	9.43
pH	8.39	8.65	8.21	5.12
Ash (%)	47.67	59.20	52.08	65.97
Organic matter (%)	52.33	40.8	47.92	34.03
Total nitrogen (%)	4.02	6.21	4.19	0.69
Total carbon (%)	122.9	67.56	98.21	20.43
C/N ratio	30.4	10.8	23.43	29.61
Total P (%)	1.5	2.09	1.43	0.11
Total K (%)	1.97	2.05	2.02	0.03
Total sulfur (%)	0.32	0.13	0.25	0.41
Total hydrogen (%)	6.71	2.93	3.88	1.04
Zn (mg/kg)	32.13	19.82	22.30	0.01
Pb (mg/kg)	0.90	0.56	0.1	0.00
Mn (mg/kg)	1.39	1.11	1.24	0.01
Cu (mg/kg)	0.51	0.45	0.43	0.02

Table 2 Pearson's correlation between chemical characteristics of enriched compost

	DP	HR	CEC	C/N	HI
DP	1	0.99**	0.99**	− 0.96**	0.97**
HR		1	0.99**	− 0.95**	0.98*
CEC			1	− 0.96**	0.98*
C/N				1	− 0.96**
HI					1

*Correlation is significant at the 0.05 level (two-tailed). n.s: non-significant

**Correlation is significant at the 0.01 level (two-tailed)

Humification of compost

In humification, carbon reduction is an important indicator of the composting process. The maturity and stability indicators FA, HA, HI, DP, HR and CEC are a result of carbon degradation during composting of waste. These are all directly correlated with each other and it was also ascertained statistically (Table 2). In the current scenario, the carbon content showed a linear decline with the composting time due to blending of the additives. It was observed much more in the enriched compost than the unenriched compost, because microorganisms utilize these organic compounds as a source of nutrition (Sun et al. 2016). Satisha and Devarajan (2007) used zinc sulfate, rock phosphate and iron sulfate for composting of sugar industry press mud and they found encouraging results.

Minerals in soil that are negatively charged attract and retained cations like calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na). The CEC is a reversible process that holds these nutrients from leaching and then releases them for crop at a mature humified phase. CEC during composting increased gradually and after 65 days both unenriched and enriched compost exhibited no significant difference in their values, whereas the enriched compost's results revealed the maximum values at 35th day of composting and it was 58% more than the unenriched compost (Fig. 1c). These results depicted the impact of enrichment on humification of poultry waste. Conversion of lingo-cellulose into humus by microbes may cause the enhancement in CEC. When the temperature of compost became equal to the ambient temperature, humification lead to the formation of humic compounds during polymerization reaction. These results are also in line with Iqbal et al. (2010) that used ferrous sulfate and rock phosphate for the decay of the MSW. Formation of humic substances depends on the OM in which humification and polymerization have taken place.

The humic acid concentration increased during the process, whereas fulvic acid (FA) increased initially and later on decreased throughout the process.

The variation of humification index (HI) and degree of polymerization (DP) with time during the humification of poultry waste is shown in Fig. 1d. Both the humification parameters HI and DP increased in the composting process. HI improved its concentration to 66% and 73.5% in unenriched and enriched compost at the end of the composting in comparison to the fifth day. The same observations were recorded in the case of DP and there was no particular disparity in their net results. The increasing pattern in both parameters specify an increase in the structural complexity of the humic substances, similarly due to a lower proportion of more easily degradable substances, which would be incorporated in the FA fraction. As regards to humification rate, it increased steadily during the composting like CEC and HI and DP.

Stability and maturity of the compost

It can be gauged by phytotoxicity. It was caused by an increase in the concentration of toxic substances like ammonia, phenolic compounds and heavy metals. Germination Index (GI) is the test used to confirm the maturity of compost that has no phytotoxic compounds or heavy metals that hamper the growth of the plants. The immature compost's phytotoxicity depends upon the composting methodology, maturation time, phenolic compounds and the nature of the stock material. The enriched and unenriched samples of the compost were collected at different days of composting such as on 15th, 30th, 45th and 65th day and their germination test results were reported in Fig. 1e. The germination index percentage depicted a low range of 45% and 68% on the 15th day of composting in enriched and unenriched composts, respectively, whereas 34% GI was seen in enriched compost than the unenriched one. It depicted that the decomposition or humification process was in initial stage and all organic acids and ammonia production was slow. Both composts behaved in a positive trend up to 93 and 99%, respectively, at the end of composting. According to Zucconi et al. (1981), when GI of any compost is 80%, then there is no sign of phytotoxicity. Moreover, both composts had obtained more than 80% germination index on the 45th day of humification. The results of present study were also in line with many other researchers (Aboukila et al. 2016; Himanen and Hanninen 2009; Iqbal et al. 2014).

N-mineralization of compost

It is a biological process and nitrogen concentration released into the soil depends upon lignin, cellulose, hemicellulose, phenolic compounds and the carbon–nitrogen ratio of compost material. The compost having a high nitrogen content and low C/N ratio exhibited maximum mineralization of nitrogen than having low nitrogen content and a high carbon/nitrogen ratio (Mohanty et al. 2011). The present study results are also coherent to these results, because the enriched compost has a low C/N ratio than the unenriched compost. The enriched compost showed 64.7% more nitrogen mineralization at 60th day of incubation than soil (control) (Fig. 2). Moreover, enriched compost results showed significantly increased with incubation time than control and unenriched compost. Masunga et al. (2016) used four organic adjustments, i.e., vegetable, fresh dairy cattle manure, fruit and yard waste compost, and fresh white clover poplar tree compost; it was found that the mineralization was faster in clover-amended soil due to low C/N ratio and microbial activity. Do et al. (2013) conducted the study with the main objective to investigate the influence of sludge pretreatment on the nitrification rate and found that the nitrogen

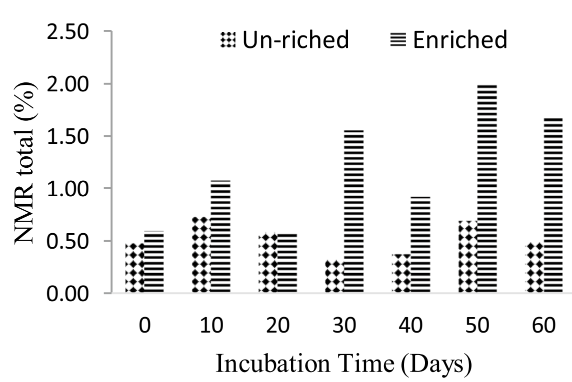

Fig. 2 Effect of enrichment on mineralization of nitrogen

removal efficiency reduced from 85 to 74%. Moreover, similar results are also coherent with other authors (Banu et al. 2008, 2009).

Pot study

The compost was applied for the growth of plants and the physical characteristics of the plants was observed. The root length of ladyfinger was the highest in enriched compost (C_1) than control soil (C_3). It was 15.84% and 38.8% more than C_2 (unenriched) and C_3, respectively. The enriched compost contains a high nutrient concentration which binds with soil for plant growth, whereas in unenriched compost nutrients' binding capacity was less than enriched compost but greater than control soil due to humus concentration. Comparison of C_1 with C_2 and C_3 may result in specifically greater root dry weight (24.18 and 44.65%). The greatest root dry weight was observed in C_1 and it was significant different in their weights in respect of unenriched compost and control soil (Joardar and Rahman 2018). The plants treated with C_1 enhanced the number of fruits as compared to C_2 and C_3, but there was no remarkable variation between C_1 and C_3. Moreover, the fruit production percentage was greater in C_1 than C_3. It was due to less nutrient concentration in C_3. In the same way, there was no incredible difference in weight of fruit between C_1 and C_3, but was 24.4% more in C_1 than C_3. The results of enriched compost application on the physical characteristics of plant revealed that the application of C_1 compost augmented the percentage of stem height about 11% and 29% more than C_2 and C_3, respectively. Oliva et al. (2017) used two types of sewage sludge compost in different proportions in soil incubation and the pot experiment found that the addition of compost enhanced the soil's organic carbon content, maximizied the pH, electrical conductivity, improved enzyme activities, soil respiration and plant growth. Furthermore, the addition of biochar compost imparts a positive impact on root length and growth biomass of plant as described by Cárdenas et al. (2017). With respect to the growth of stem, there was no major difference between C_1, C_2 and C_3. It was also proved by statistical software DMR. The nutrients' concentration and health of plant depends upon the nature of soil, water and humus quality. The enriched compost has a high concentration of nutrients and humus raised the dry matter (DM) of plants. It was 20.2% more than unenriched compost, while it was 40% more than C_3 (Table 3). The enriched compost (C_1) application has a positive and significant impact on the availability of N, P and K nutrients in plants and soil. The concentration of these nutrients was high in enriched compost-treated plants and soil than unenriched compost. The unenriched compost did not show a complete maturity and stability, due this reason the nutrients were released into the soil and utilized for the plants easily (Table 4).

Table 3 Effect of enriched, unenriched compost and control on characteristics of plants

Parameters	C_1	C_2	C_3
Root length (cm)	54.9a	46.2b	33.6c
Root dry weight (gm/Pot)	21.5a	16.3b,c	11.9c
No of fruits/pot	33b	27b	9c
Fresh fruit weight/pot (g/pot)	86b	83b	65c
Stem height (cm)	138b	123a	98c
Stem girth (cm)	29b	27b,c	24c
DM/plant (gm)	13.8b	11.01b,c	8.3c

*Values having same letters in the column do not differ significantly at $P < 0.05$, according to Duncan's multiple range test (DMR)

Conclusion

The application of inorganic additives in the mechanical co-composting of poultry waste and rice husk lessens the humification period and C/N ratio, which enhanced the nitrogen mineralization. Pearson correlation validates the humification process parameters. The application of enriched compost in pot study of ladyfinger plant perks up the phytochemical properties than unenriched compost due to the humification angle. The present study's formulation can be applied on various wastes to enhance the humification process to ultimately reduce the decomposition time.

Table 4 Effect of treatments on nutrient uptake by plant and soil

Treatments	Plant			Soil		
	Nitrogen (g/plant)	Potassium (g/plant)	Phosphate (g/plant)	Nitrogen (g/kg)	Potassium (g/kg)	Phosphate (g/kg)
C_1	2.15	1.01	0.76	2.32	1.15	1.09
C_2	1.21	0.81	0.14	1.63	0.95	0.43
C_3	0.13	0.01	0.001	0.17	0.02	0.01

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