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Effect of Biochar Properties on Biochar Co-compost

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ABSTRACT

Rice straw biochar (RSBC), maize stover biochar (MSBC), gram residue biochar (GRBC), and eighteen biochar co-composts at different combinations of rice straw (RS) and maize stover (MS) infused with RSBC, MSBC, and GRBC at the ratio of 7:1, 9:1, and 11:1 (wt/wt) were prepared and characterized for various chemical, physical, physico−chemical and spectral properties. All the biochar co-compost was having high alkalinity in terms of pH, EC, CCE (Calcium Carbonate Equivalent). The pH of biochar co-composts varied between 7.78 and 8.86, which was recorded higher for rice straw co-composts (varied in between 7.78 and 8.42) than maize stover co-compost (ranged from 7.78 to 8.42), and the pH decreased with the increment of the respective ratio of residue to biochar. The EC and CCE of biochar co-compost varied from 2.18 to 4.73 dS m^{-1} and 25.5% to 30.5% and a decrement was observed in the case of EC of biochar co-composts when GRBC (high ash content) was replaced by MSBC and RSBC having low ash content. Total Carbon (TC) content in biochar co-composts varied between 12.5 [RS + RSBC (11:1)] and 20.2% [MS + GRBC (9:1)]. The C:N ratio of composts varied between 14.4 and 21.1. The average T_{Na}, T_K, T_{P2O5}, T_S%, T_{Ca} and T_{Mg}, was found to be 0.25%, 0.33%, 0.09%, 0.39%, 0.81% and 0.20%, respectively. T_{Fe}, T_{Mn}, T_{Zn}, T_{Cu}, 0.15%, 370.60 mg g^{-1},182.30 mg g^{-1}, 31.15 mg g^{-1} , respectively. The biochar co-composts derived from different residues and biochar combination had clearly shown the effect of input material on final product.

Keywords: Biochar, Alkaline-Biochar co-compost

INTRODUCTION

India generates about 500-550 million tonnes (Mt) of crop residues (GOI, 2016). The major problem in rice-wheat cropping system is how to manage the large quantities of crop residues with special reference to the rice straws left over in the field due to the use of mechanized combined harvester (Purakayastha *et al.*, 2015). As the window between harvest of rice and sowing of wheat is hardly less than a month, the only and the easiest option left to the farmers is to burn the residues in the field causing huge losses of essential plant nutrients and environmental pollution by liberating suspended particulate matter, smoke and greenhouse gases (Liu *et al.*, 2018). It is a matter of worry that in Indian state of Punjab alone, nearly 70 to 80 million tons of rice and wheat straw are burned annually releasing approximately 140 million tons of CO_2 (carbon dioxide) to the atmosphere, in addition to methane, nitrous oxide and air pollutants (Punia *et al.*, 2008). In this scenario, conversion of rice residues to bioenergy and biochar thus produced as a by-product could be one of the green technologies for residue management. Soil acidification is a major problem in agricultural production, affecting 30%–40% of the world's arable land (Foy, 1988; Kochian, 1995). According to FAO estimates, only 11% of the Earth's surface area is currently cultivated (1406 Mha) and about 24% (3.90 Mha) is potentially arable, most of which, 2500 Mha, is composed of acid soils with 1700 Mha located in the humid tropics. According to a rough estimate about 48-49 million hectares (Mha) in India is under acidic soil out which nearly 25 Mha of land are having pH below 5.5 and 23 Mha fall under the pH range of 5.6-6.5 (Mandal, 1997). Soil acidity influence numerous chemical and biological reactions that govern plant nutrient availability and element toxicity (Lavelle *et al.*, 1995). Crop productivity on such soils is mostly constrained by aluminium (Al) and iron (Fe) toxicity, phosphorus (P) deficiency, low base saturation, impaired biological activity and other acidity-induced soil fertility and plant nutritional problems (Kumar *et al.*, 2012). These acidic soils thus require reclamation to tackle the above problems and make these soils suitable for optimum crop production.

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The major limitation using lime as an amendment to reclaim acid soils is difficulty in getting pure/agricultural grade lime in right quantity and right time and higher cost involved with its purchase. Alternative to lime is the farmyard manure (FYM) or compost, the long-term applications of which were also reported to buffer the soil acidity to neutral pH range (Singh *et al.*, 2009); can act as an organic fertilizer and an amendment to reclaim acid soil (Maeda *et al.*, 2010; Jurado *et al.*, 2015). Preparation of compost takes longer time and availability of dung is a problem due to faster mechanization of agriculture under severe labor shortage in rural areas. The major drawback of composts as liming material is that it is very slow acting and less efficient in ameliorating acidic soils. Therefore, the application of farmyard manure (FYM) or compost on long-term basis may not be a viable option to reclaim acidic soils. If some material having ameliorating properties is infused into composts, its value as amendment and fertilizer could be increased. Nevertheless, during the composting process, loss of nutrients especially nitrogen is one of the most important factors that influence the quality of final product. During the thermophilic (45-65^{o}C) stage of composting due to ammonifying activities of microorganisms, organic nitrogen is converted into ammonia and is lost as ammonia gas into atmosphere (Sánchez-Mondereo *et al.*, 2001; Villasenor *et al.*, 2011) which created a problem during compost making process (Chen *et al.*, 2010). Alternatively, biochar, a co-product of thermo-chemical conversion of lingo-cellulosic materials into advanced bio-fuels; often contains a major ash component, which is alkaline in nature. Being a pyrolyzed product with aromatic in nature is inherently protected from rapid microbial degradation, and therefore it has huge potential for long-term carbon sequestration in soil (Mao *et al.*, 2012; Purakayastha *et al.*, 2015). Besides the environmental benefits, biochar has been reported to improve quality and fertility of soil (Martinsen *et al.*, 2015) and plant productivity (Chan *et al.* 2008 a & b), and nitrogen use efficiency (NUE) (Laird *et al.*, 2010). The major limitations of using biochar alone are its poor nutrient contents and high C:N ratio.

Biochar being having high cation exchange capacity and alkaline in nature can be used as amendments during compost making. Biochar being highly porous (Hina *et al.*, 2010) has high surface area (Van-Zwieten *et al.*, 2009) and cation and anion exchange property. Thus, it can hold more cationic and anionic forms of nutrients (Mukherjee *et al.*, 2011). Therefore, co-composting with biochar is a novel idea which not only makes biochar nutrient rich but also providing a mechanism for releasing nitrogen fertilizers in a slow-release process (Clough *et al.*, 2013) to synchronize the crop demand, reclamation of acid soils, C sequestration and enhancing nutrient availability and biological properties of soil. The blending of biochar with compost can enhance the composting performance as increase the organic matter (OM) content of the composting feedstock, better and/or faster decomposition, decrease in element losses and odours (Zhang and Sun, 2014) and offset potential negative effects of the composting system such as emissions of CH_4 (methane) (Vandecasteele *et al.*, 2016), Nitrous oxide (N_2O) (Clough *et al.*, 2013; Felber *et al.*, 2014)) and ammonia (NH_3) (Clough *et al.*, 2013). Positive impact of biochar on the degree of organic matter humification during composting (Zhang and Sun, 2014) is also a benefit of co-composting. This co-composting with alkaline biochar enhances the temperature, aeration and oxygen uptake of composting process and help to reduce the bulk density, total nitrogen losses, increase pH, CEC, OM, TC, nutrients, and germination index of compost. It also services to enhance the total microorganism population of the bacteria and total aerobic heterotrophs, lactic acid bacteria, actinomycetes, activity of polyphenol oxidase dehydrogenase beta-glucosidase and phosphatase (Wu *et al.*, 2017).

The variation in the quality of the starting materials, the specified experimental conditions and interactions among inputs etc. results chemical and biochemical changes in resultant product; are the area in dark, demanding more research to be solved and henceforth, a justification for a wide range of organic wastes and composting operations may be valuable. There is a paucity of information available on the effect of biochar on reducing nutrient losses during biochar manure co-compost preparation. This study will help to understand the liming efficacy of biochar prepared from rice straw, maize stover, gram residues and biochar manure co-compost with optimal ratio of biochar and feedstock of compost making. In this study, we investigated the following research questions; 1. What is the effect of feedstock on properties of biochar? 2. Does the ratio of different combinations of residue to biochar influence the properties biochar co-composts.

To address these questions, we prepared biochar from rice straw, maize stover and gram residues and biochar co-composts from the above biochar in combination with rice residue, maize stover at 7:1, 9:1, and 11:1 ratio. The biochar and biochar co-composts were characterized for various physical, chemical, physico-chemical and spectral properties.

MATERIALS AND METHODS

Characterization of residue and dung samples

Rice (*Oryza sativa* L.) straw, maize (*Zea mays* L.) stover residue and cow dung samples were air-dried and then oven-dried in hot air oven at 60 ± 5 °C until the attainment of a constant weight. The dried plant and dung samples were ground, sieved (0.2 mm), and analyzed for total C and N of residue and dung sample were determined in a CHNS analyzer (Euro Vector, Euro EA3000) by following the dry combustion method (Nelson and Sommers, 1982). The TC, TN and C: N ratio of rice straw (45.1% N, 0.46% P, 98:1 C: N), maize stover (44.8% N, 0.81% P, 56:1 C: N), and dung samples (45.1% N, 0.46% P, 98:1 C:N) estimated.

Preparation and Characterisation of Biochar

Three biochar as Rice straw biochar, maize stover biochar and gram residue biochar of alkaline nature was prepared by Nain *et al.*, (2022), which were characterized with respect to physical, chemical and spectral characters. In continuation with aforementioned study these biochars were selected for compost formation (Table 1).

Table 1: Physical and chemical properties of biochar

Parameter	Rice straw biochar	Maize stover biochar	Gram residue biochar
pH	8.20b[§]±1.34	7.86c±1.28	9.51a±1.55
EC (dS m^{-1})	6.19b±1.01	4.16c±0.68	6.56a±1.07
CEC [cmol (p^{+}) kg^{-1}]	56.5a±9.23	54.2b±8.85	57.8a±9.44
CCE (%)	36.6b±5.98	29.7c±4.85	42.1a±6.88
BD (Mg m^{-3})	0.21b±0.03	0.23b±0.04	0.27a±0.04
PD (Mg m^{-3})	0.40b±0.07	0.43b±0.07	0.57a±0.09
Porosity (%)	48b±7.84	47b±7.68	53a±8.66
Moisture (%)	5.86b0.96	6.80a±1.11	3.20c±0.52
MWHC (%)	593b±96.84	586b±95.69	660c±107.78
VM (%)	27.0a±4.41	23.0b±3.76	21.0c±3.43
Ash (%)	37.1b±6.06	31.1c±5.08	39.1a±6.39
C (%)	57.6c±9.41	62.6a±10.22	58.4b±9.54
N (%)	0.68b±0.11	0.67b±0.11	1.69a±0.28
C:N	85:1b±0.41	94:1a±0.49	35:1c±0.05

[§] *Data followed by different lower-case letters in a row representing specific property is significant according to Duncan's Multiple Range Test at p = 0.05. Data followed by ± representing Standard Deviation, EC: Electrical conductivity; CEC: Cation exchange capacity; CCE: Calcium carbonate equivalent; BD: Bulk density; PD: Particle density; MWHC: Maximum water holding capacity, VM: Volatile matter*

Preparation of biochar co-compost

For preparation of biochar co-compost, rice straw (RS), maize stover (MS), and gram residues (GR) were cut in to small pieces (30 − 50 mm) and mixed with RSBC, MSBC, and GRBC in the ratio of 7:1, 9:1 and 11:1. Composting was done in plastic container with a dimension of 2 ft× 1.5 ft × 1ft with addition of N form of urea to bring down the C:N ratio of composting mixture to (50-60:1) (Sharma *et al.*, 2014). Required amount of urea, 10% dung slurry and PUSA decomposer, a microbial consortium of cellulolytic fungi, Aspergillus awamori, Trichoderma viridae, Phanerochaete chryosporium and Aspergillus nidulans) at the rate of 5 mL kg^{-1} were evenly mixed with biochar and residues. The compost mixture was sprinkled with water on a regular interval to maintain the moisture level to 60 % throughout the composting process. The composting piles were turned on weekly basis. The maturity of compost was decided based on the C: N of biochar co-compost reached at 20:1. Subsequently prepared biochar co-composts were sieved through 4-mm sieve and stored in closed plastic container.

Characterization of biochar co-compost

The pH and electrical conductivity (EC) of biochar co-composts were measured at 1:5 (w/v) ratio after shaking for an hour (Biofertilizers and Organic Fertilizers - Fertilizer (Control) Order, 1985). Calcium carbonate equivalent was determined according to the procedure given by Rayment and Higginson, (1992). Total C and N contents in biochar co-compost in a CHNS analyser (Euro Vector, Euro EA3000) (Tabatabai and Bremner,1991). The biochar co-compost samples were analyzed in three replicated samples. Total elemental analysis was done using ICPMS (Agilent ICP-MS 7900 with UHMI). The mean data was separated by Duncan's Multiple Range Test at 5% level of significance.

Results and discussion

Physical properties of Biochar co-compost

The results indicate that the bulk density and moisture content biochar co-compost ranged between 0.9 to 1.3 Mg m^{-3}and 22.0 to 26.4% for different compost types and the moisture content. The moisture content values ranged respectively, for different compost types. Compost containing the MSBC had shown higher moisture content. The physical properties (bulk density, moisture content) of the composts (Table 2). The results indicate that the bulk density biochar co-compost ranged between 0.9 to 1.3 Mg m^{-3} for different compost types. In most cases the BD showed the effect of the biochar as with the replacement of RSBC and MSBC with GRBC, BD got increased. BD also gets increased with widening of the ratio of residue to biochar pile. Findings by Steiner *et al.* (2010) shows that bulk density of compost can be changed by applying biochar to a compost pile along with the improved moisture content, and microbial proliferation.

Table 2: Physical and Physico-chemical properties of Biochar co-compost

Biochar co-compost	pH	EC (dS m^{-1})	CCE	C (%)	N (%)	C:N	Moisture (%)	BD (Mgm^{-3})
RS+RSBC (7:1)	8.50a[§]±1.39	3.97c±0.65	27.1de±4.43	16.7abc±2.73	0.93bcd±0.16	17.9de±2.92	24.4a±1.4	0.9b±0.052
RS+RSBC (9:1)	8.42c±1.37	3.57f±0.58	26.5efg±4.33	15.3bc±2.5	0.91def±0.15	16.9ef±2.76	23.0a±1.32	1b±0.057
RS+RSBC (11:1)	8.35cd±1.36	3.24g±0.53	27.1de±4.43	12.5d±2.04	0.81h±0.13	15.5fg±2.53	22.9a±1.32	1.1b±0.063
RS+MSBC (7:1)	8.24ef±1.35	3.22g±0.52	25.9ghi±4.23	18.1a±2.96	0.91cde±0.15	19.9abc±3.25	26.0a±1.49	1±b0.057
RS+MSBC (9:1)	8.16gh±1.33	3.91cd±0.64	25.5hi±4.16	15.6bc±2.55	0.88defg±0.15	17.6e±2.87	22.9a±1.32	1±b0.057
RS+MSBC (11:1)	7.94i±1.3	3.53f±0.58	25.3i±4.13	15.5bc±2.53	0.86fgh±0.14	18.0cde±2.94	23.9a±1.37	1.1b±0.063
RS+GRBC (7:1)	8.86a±1.45	4.20b±0.69	29.3b±4.79	16.7abc±2.73	0.96bc±0.16	17.4e±2.84	23.0a±1.32	1b±0.057
RS+GRBC (9:1)	8.50b±1.39	3.90cd±0.64	28.2c±4.61	17.4ab±2.84	0.98b±0.16	17.9de±2.92	22.9a±1.32	1.1b±0.063
RS+GRBC (11:1)	8.30de±1.36	3.71e±0.6	28.2c±4.61	17.4ab±2.84	0.96bc±0.16	18.1cde±2.96	22.9a±1.32	1.3a±0.075
MS+RSBC (7:1)	7.88ij±1.29	2.95h±0.48	27.1de±4.43	17.4ab±2.84	0.86efg±0.14	20.2ab±3.3	23.9a±1.37	0.9b±0.052
MS+RSBC (9:1)	7.83j±1.28	2.91h±0.47	28.2c±4.61	17.4ab±2.84	0.83gh±0.14	20.9a±3.41	22.9a±1.32	0.9b±0.052
MS+RSBC (11:1)	7.67k±1.25	2.25i±0.37	27.6de±4.51	16.2abc±2.65	0.81h±0.13	20.1ab±3.28	26.0a±1.49	1.1b±0.063
MS+MSBC (7:1)	8.22efg±1.34	2.25ij±0.37	26.5efg±4.33	16.2abc±2.65	0.86fg±h0.14	18.8bcde±3.07	26.4a±1.52	1.1b±0.063
MS+MSBC (9:1)	8.18fgh±1.34	2.21j±0.36	26.1fgh±4.26	16.0abc±2.61	0.83gh±0.14	18.0cde±2.94	23.9a±1.37	0.9b±0.052
MS+MSBC (11:1)	8.12h±1.32	2.10k±0.34	26.8ef±4.38	15.9abc±2.6	0.81gh±0.13	19.7abcd±3.22	22.4a±1.29	1.1b±0.063
MS+GRBC (7:1)	8.42c±1.37	4.70a±0.77	30.5a±4.98	16.9abc±2.76	0.93bcd±0.16	18.2cde±2.97	22.9a±1.32	1.1b±0.063
MS+GRBC (9:1)	8.20fgh±1.34	3.84d±0.63	29.1b±4.75	16.0abc±2.61	0.92cd±0.15	17.5e±2.86	23.4a±1.34	1.1b±0.063
MS+GRBC (11:1)	8.17fgh±1.33	4.23b±0.69	29.3b±4.79	15.1c±2.47	1.05a±0.17	14.4g±2.35	22.0a±1.26	0.9b±0.052

[§] *Data followed by different lower-case letters in a row representing specific property is significant according to Duncan's Multiple Range Test at p = 0.05. Data followed by ± representing Standard Error*

Physico-chemical properties of biochar co-compost

The pH of biochar co-composts showed a decreasing trend when the ratio of residue to biochar increased from 7:1 to 11:1 (Table 2). The EC, also showed a decreasing trend except few occasions. The pH and EC were recorded highest in RS+GRBC (7:1) followed by RS+GRBC (9:1) and RS+RSBC (7:1). The calcium carbonate equivalent (CCE) was recorded highest in MS+GRBC (7:1) followed by

RS+GRBC (7:1), RS+GRBC (9:1/11:1), MS+GRBC (9:11/11:1). The pH increase took place during the bio−oxidative phase (Dias *et al.*, 2010) as a consequence of the degradation and mineralisation of organic compounds (Benito *et al.*, 2003). Specifically, the processes such as ammonification and the dissolution of alkaline minerals are mainly responsible (Dias *et al.*, 2010; Lehmann *et al.*, 2011). The pH of biochar co-composts was influenced by the residue itself, interaction between the components of compost, the characteristics of biochar viz., alkalinity, ash content, CCE and quantity of biochar added. The pH of biochar co-composts in our study varied between7.78 to 8.6. The pH showed a declining trend when the biochar of high alkalinity *i.e.*, GRBC (pH: 9.51) was replaced by RSBC having low alkalinity (pH: 8.2) followed by MSBC (pH: 7.86). The effect biochar on pH increase in compost was confirmed by Czekała *et al.* (2016) also observed pH increase in compost while co-composting a mixture of poultry manure, wheat straw and biochar (5 and 10% wet weight), derived from wood chips over the material composted without biochar addition. The increase in pH after the addition of biochar is related to its high pH value (Cui *et al.*, 2016). The electrical conductivity (EC) of biochar co-composts varied in between 2.18 dS m^{-1} to 4.73 dS m^{-1}. The EC increased significantly when the rice residue was replaced by maize stover. The EC depends upon many factors e.g., the characteristics of feedstock as most of the compost containing rice straw as feedstock had shown high EC than the compost derived from maize stover. Secondly, EC of final compost was affected by the type of biochar added *i.e.,* the EC showed the decreasing trend with the replacement of high salt containing biochars *i.e.,* GRBC (EC 6.56 dS m^{-1}) to the biochar comprised of low salt content as RSBC (EC:6.19 dSm^{-1}) followed by MSBC (EC 4.16 dSm^{-1}). Thirdly, it gets affected by the amount of the salt added through the application of biochar *i.e.* the compost prepared from rice straw and RSBC showed a diminishing trend in EC from 3.96 to 3.24 dS m^{-1} with decreasing the amount of biochar added or increasing the ratio of residue to biochar from 7:1 to 11:1.

The CCE was highest in MS+GRBC (7:1) followed by RS+GRBC (7:1). Overall, the C and N contents in biochar co-composts showed a decreasing trend due to increase in residue to biochar ratio. The maize stover derived co-composts showed higher CCE than rice straw starw derived composts. Calcium Carbonate Equivalent (CCE) varied from 25.5% to 30.5% among all composts) which is directly related to the amount of carbonate salt present in the compost. The CCE showed the decreasing trend when biochar of high CCE was replaced with low CCE biochar. This clearly demonstrates that biochar had significant role in enhancing the liming potential of biochar co-compost. The presence of carbonates in biochar and high alkalinity in biochar significantly contributed to CCE of biochar co-compost. The XRD analysis of biochar clearly demonstrates the presence calcite, dolomite and other alkaline minerals which might have contributed to alkalinity in biochar co-compost. The C contents in RS+RSBC and RS+MSBC decreased significantly when the rice residue to biochar increased from 7:1 to 9:1 (Table 2). In the case of other biochar co-composts the C contents did not vary significantly. The C content was highest in RS+MSBC (7:1) (18.1%) which was statistically at par with most of the co-composts except RS+RSBC (9:1/11:1), RS+MSBC (9:1/11:1). The N content decreased significantly in all the biochar co-composts except RS+GRBC and MS+MSBC when the residue to biochar ratio decreased from 7:1 to 11:1. The N content was recorded highest in MS+GRBC followed by RS+GRBC (7:1/9:1/11:1), and RS+GRBC (7:1). In the course of the composting process, the C:N ratio decreased in the treatments with and without the addition of biochar, due to the mineralisation of the substrates or increase of total N taking place after C degradation (Jindo *et al.*, 2016; Zhang *et al.*, 2016). It was also suggested that such an effect can be produced by the presence of C resistant to degradation (originating from biochar) and reduced mineralisation of substances in composts with biochar addition (Zhang *et al.*, 2016; Steiner *et al.*, 2010). In our study, in majority of the cases, the TC and TN contents in biochar co-composts decreased as the ratio of residue to biochar increased. However, the addition of more biochar resulted in a notably lower decrease of C:N ratio compared to the material composted with less biochar addition.

Table 3: Metal contents in biochar co-composts

Compost	T_{Na}		T_{K2O}		T_{P2O5}		T_{S}		T_{Ca}		T_{Mg}	
	(%)		(%)		(%)		(%)		(%)		(%)	
RS+RSBC (7:1)	0.26[§]abc	±0.005	0.3fg	±0.034	0.063d	±0.035	0.21e	±0.030	0.21a	±0.090	0.34ab	±0.042
RS+RSBC (9:1)	0.23cd	±0.005	0.23h	±0.031	0.053d	±0.031	0.21e	±0.028	0.19abc	±0.082	0.34ab	±0.038
RS+RSBC (11:1)	0.22d	±0.004	0.26gh	±0.028	0.063d	±0.028	0.253de	±0.025	0.23bcd	±0.074	0.23cd	±0.034
RS+MSBC (7:1)	0.27ab	±0.005	0.36cde	±0.027	0.07d	±0.026	0.13cde	±0.033	0.253cd	±0.201	0.2cd	±0.098
RS+MSBC (9:1)	0.22d	±0.005	0.3fg	±0.024	0.07d	±0.023	0.21cde	±0.030	0.13ef	±0.182	0.2cd	±0.089
RS+MSBC (11:1)	0.22d	±0.004	0.3fg	±0.022	0.053d	±0.021	0.253cde	±0.027	0.18ab	±0.164	0.09ef	±0.080
RS+GRBC (7:1)	0.25abc	±0.005	0.38bc	±0.015	0.053d	±0.030	0.23cde	±0.018	0.39abc	±0.039	0.2cd	±0.060
RS+GRBC (9:1)	0.24abc	±0.005	0.33cdef	±0.014	0.063d	±0.027	0.32cde	±0.017	0.21abc	±0.036	0.37a	±0.054
RS+GRBC (11:1)	0.24abc	±0.004	0.31efg	±0.012	0.063d	±0.024	0.18cde	±0.015	0.33abc	±0.032	0.23cd	±0.049
MS+RSBC (7:1)	0.23cd	±0.012	0.44a	±0.032	0.07d	±0.021	0.23cde	±0.057	2.74abc	±0.041	0.33ab	±0.070
MS+RSBC (9:1)	0.24abc	±0.011	0.37cd	±0.029	0.063d	±0.019	2.74cde	±0.052	0.253ef	±0.037	0.28bc	±0.064
MS+RSBC (11:1)	0.24abc	±0.010	0.43ab	±0.026	0.08d	±0.017	0.39cde	±0.047	0.21fg	±0.034	0.03f	±0.057
MS+MSBC (7:1)	0.27ab	±0.010	0.43ab	±0.021	0.17d	±0.026	0.33bcde	±0.741	0.21de	±0.034	0.2cd	±0.058
MS+MSBC (9:1)	0.25abc	±0.009	0.26gh	±0.019	0.14c	±0.023	0.19bcde	±0.674	0.21g	±0.031	0.03f	±0.052
MS+MSBC (11:1)	0.23cd	±0.008	0.26gh	±0.017	0.163bc	±0.021	0.21bcd	±0.607	0.18abcd	±0.028	0.03f	±0.047
MS+GRBC (7:1)	0.27ab	±0.008	0.32defg	±0.050	0.14bc	±0.021	0.18bc	±0.032	0.23abcd	±0.150	0.063f	±0.145
MS+GRBC (9:1)	0.28a	±0.007	0.32defg	±0.046	0.13ab	±0.019	0.3b	±0.029	0.32bcd	±0.136	0.167de	±0.131
MS+GRBC (11:1)	0.25abc	±0.006	0.27fgh	±0.041	0.06a	±0.017	0.21a	±0.026	0.3a	±0.123	0.34ab	±0.118

[§]Data followed by different lower-case letters in a row representing specific property is significant according to Duncan's Multiple Range Test at $p = 0.05$. Data followed by ± representing Standard Error

Metal, heavy metal and metalloid contents

Total elemental composition of the biochar co-composts prepared from different residues at three ratios with biochars, is presented in Table 3 & 4. On an average, the maize stover (with three different biochar) derived composts showed marginally higher contents of T_{Na}, .3$T_K$and T_{P2O5} (0.24% in vs. 0.23%;0.33 % in vs. 0.30 % and 0.12% in vs. 0.05%) than rice straw (with three different biochar) derived composts. Generally, the T_{Na} contents in biochar co-compost increased when we substituted RSBC (T_{Na}: 0.23%, for rice straw derived compost; T_{Na}: 0.24% for maize stover derived compost) to MSBC (T_{Na}: 0.23% for rice straw derived compost; T_{Na}: 0.25% for maize stover derived compost). The T_{K2O} contents in biochar co-compost increased when we substituted RSBC (T_{K2O}: 0.26%, for rice straw derived compost; T_{K2O}: 0.41% for maize stover derived compost) to GRBC (T_{K2O}:0.34% for rice straw derived compost). The T_{P2O5} contents in biochar co-compost increased when we substituted RSBC (T_{P2O5}: 0.05%), for rice straw derived compost; T_{P2O5}: 0.0.07 % for maize stover derived compost) to MSBC (T_{P2O5}: 0.06 % for rice straw derived compost and T_{P2O5}:0.07 % for maize stover derived compost) and to GRBC (T_{P2O5}: 0.05 % for rice straw derived compost and T_{P2O5}: 0.13 % for maize stover derived compost). Variation of T_S% among all composts varied between 0.18 (MS+GRBC (7:1), RS+GRBC (11:1)) and 2.74% (MS+RSBC (9:1)). Compost made with maize straw with different biochars displayed the average 0.54% T_S than the compost made from rice straw with three different biochar. Biochar co-compost is of alkaline nature and having a good amount of T_{Ca} and T_{Mg}, oscillates in between 0.44% (MS+RSBC (11:1)) and 1.03% (RS+RSBC (7:1)) for T_{Ca} and 0.03% (MS+RSBC (11:1), MS+MSBC (11:1)) and 0.54% (MS+GRBC (11:1)) for T_{Mg}. Compost made with rice straw with different biochars displayed the average 0.90 % T_{Ca} and 0.24 % T_{Mg} than the compost made from maize stover with three different biochar with the value of 0.73% and 0.17%.

Table 4: Heavy metal, contents in biochar co-composts

Compost	Fe (%)		Mn (mg kg^{-1})		Zn (mg kg^{-1})		Cu (mg kg^{-1})	
RS+RSBC (7:1)	0.14cde[§]	±0.008	448b	±98	252a	±31.9	26de	±0.60
RS+RSBC (9:1)	0.153cd	±0.007	480b	±89	160efgh	±29.0	50b	±0.54
RS+RSBC (11:1)	0.08g	±0.006	516b	±80	248a	±26.2	24def	±0.49
RS+MSBC (7:1)	0.09g	±0.003	480b	±105	184cdef	±7.3	96a	±8.23
RS+MSBC (9:1)	0.08g	±0.003	516b	±95	128gh	±6.6	44bcde	±7.48
RS+MSBC (11:1)	0.1fg	±0.002	748a	±86	252a	±6.0	44bcde	±6.74
RS+GRBC (7:1)	0.163c	±0.045	492b	±110	132fgh	±32.2	26de	±1.04
RS+GRBC (9:1)	0.14cde	±0.041	460b	±100	144efgh	±29.3	26de	±0.94
RS+GRBC (11:1)	0.253a	±0.037	472b	±90	192bcde	±26.4	22fg	±0.85
MS+RSBC (7:1)	0.2b	±0.029	280c	±88	176cdefgh	±15.7	22fg	±23.43
MS+RSBC (9:1)	0.163c	±0.026	244cd	±80	240ab	±14.3	26de	±21.31
MS+RSBC (11:1)	0.253a	±0.024	288c	±72	224abc	±12.9	24def	±19.19
MS+MSBC (7:1)	0.2c	±0.022	144de	±104	168defgh	±34.1	24def	±8.32
MS+MSBC (9:1)	0.153cd	±0.020	120e	±95	132fgh	±31.0	20fg	±7.56
MS+MSBC (11:1)	0.063b	±0.018	128e	±85	124h	±28.0	20fg	±6.81
MS+GRBC (7:1)	0.13de	±0.041	144de	±164	128gh	±13.5	14g	±5.71
MS+GRBC (9:1)	0.12ef	±0.037	251cd	±149	179cdefg	±12.3	18fg	±5.19
MS+GRBC (11:1)	0.147cde	±0.034	460b	±135	218abcd	±11.1	35cd	±4.68

[§] Data followed by different lower-case letters in a row representing specific property is significant according to Duncan's Multiple Range Test at $p = 0.05$. Data followed by ± representing Standard Error

The T_{Ca} and T_{Mg} contents in biochar co-compost decreased as the ratio of residue to biochar increased. Composts were found as a good source of heavy metals as Fe, Mn, Zn and Cu. On an average, the maize stover (with three different biochar) derived composts showed marginally higher T_{Fe} contents (0.17% in vs. 0.13 %) than rice straw (with three different biochar) derived composts. The T_{Fe} contents in most of the biochar co-compost decreased as the ratio of residue to biochar increased. Normally, the T_{Fe} contents in biochar co-compost derived from rice straw increased when we substituted MSBC (T_{Fe}: 0.09 %) to RSBC (T_{Fe}: 0.20%) and to GRBC (T_{Fe}: 0.18%). But for compost derived from maize stover T_{Fe} get increased with the replacement of GRBC (0.13%) to MSBC (0.17%) and RSBC (0.20%).T_{Mn} content of composts varied in between 120 (MS+MSBC (9:1)) and 748 ppm (RS+MSBC (11:1)); T_{Zn} varied in between 124 (MS+GRBC (9:1)) and 252 ppm (RS+RSBC (7:1)), T_{Cu} content varied in between 12 (MS+GRBC (9:1)) and 96 ppm (RS+MSBC (7:1)). On an average, the rice straw (with three different biochar) derived composts showed marginally higher T_{Mn}, T_{Zn} and T_{Cu} contents (512 ppm in vs. 179 ppm, 188 ppm in vs. 168 ppm and 40 ppm in vs. 21 ppm respectively) than maize stover (with three different biochar) derived composts. Normally, the T_{Cu} contents in biochar co-compost derived from rice straw increased when we substituted GRBC (T_{Cu}: 24 ppm) to RSBC (T_{Cu}: 33 ppm) and to MSBC (T_{Cu}: 61 ppm). But for compost derived from maize stover, this pattern was reversed as T_{Cu} get increased with the replacement of MSBC (21 ppm) to RSBC (21 ppm) and GRBC (26 ppm). Apart from nitrogen, compost contains also other important nutrients, such as P, K, Ca, Mg, Na and S. Their levels depend on the kind of composted material i.e., Biochar and crop residue, but P and K occur at significantly larger amounts than the other macro-elements. This is usually independent of the materials from which the compost is produced. Loss of those elements in the course of biochar addition to composted organic matter has a positive effect on the fertiliser properties of compost resulting from the presence of the above-mentioned macro elements. Zhang *et al.* (2016) observed that an addition of biochar derived from wheat straw (at temperature of 500-600°C), at a rate of 10 or 15% wet weight, to pig manure with wheat straw (wheat straw constituted 30% of pig manure), caused an increase in the amount of P, K, Ca and Mg ions in the compost. Biochar may sorb a broad range of organic and inorganic compounds from compost (Hale *et al.*, 2015). Prost *et al.* (2013) observed a considerable increase in the CEC of co-composted biochar due to sorption of organic leachates during the composting process, which shows the high cation retaining capacity of the compost containing biochar. In majority of the cases, the $T_{Na,}$ T_{K2O} T_{Ca} and T_{Mg} contents in biochar co-compost decreased as the ratio of residue to biochar increased which relates the amount of biochar added and nutrient present in the feedstock. The nutrient content of co-compost simultaneously increased when biochar having less amount of particular nutrient substituted with biochar containing high amount of that nutrient.

Based on result it may be concluded that the physical, chemical, physico−chemical properties of biochar co-compost was significantly affected by feedstock type. Alkaline nature of gram residue biochar (GRBC), maize stover biochar (MSBC), and rice straw biochar (RSBC) results co-compost of alkaline nature. The alkalinity and CCE and other nutrients of biochar co-composts were dictated by residue to biochar ratio during co-composting and the 7:1 performed well with respect to nutritional content and alkalinity, which could be further explored by more experimentation using these as an amendment in acidic soil.

REFERENCES

Benito, D., M., Masaguer, A., Moliner, A., Arrigo, N. and Palma, R.M., (2003) Chemical and microbiological parameters for the characterization of the stability and maturity of pruning waste compost. *Biology and Fertility of Soils* **37** (3): 184−189.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2008a) Agronomic values of green-waste biochar as a soil amendment. *Soil Research* **45** (8): 629−634.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2008b) Using poultry litter biochars as soil amendments. *Soil Research* **46** (5): 437−444.

Chen, Y.X., Huang, X.D., Han, Z.Y., Huang, X., Hu, B., Shi, D.Z. and Wu, W.X. (2010) Effects of bamboo charcoal and bamboo vinegar on nitrogen conservation and heavy metals immobility during pig manure composting. *Chemosphere* **78** (9): 1177−1181.

Clough, T.J., Condron, L.M., Kammann, C. and Müller, C. (2013) A review of biochar and soil nitrogen dynamics. *Agronomy*, **3**(2), 275−293.

Cui, E., Wu, Y., Zuo, Y. and Chen, H., (2016) Effect of different biochars on antibiotic resistance genes and bacterial community during chicken manure composting. *Bioresource Technology,* **203**, 11−17.

Czekała, W., Malińska, K., Cáceres, R., Janczak, D., Dach, J. and Lewicki, A. (2016) Co-composting of poultry manure mixtures amended with biochar–The effect of biochar on temperature and C−CO_2 emission. *Bioresource Technology*, **200**, 921−927.

Dias, B.O., Silva, C.A., Higashikawa, F.S., Roig, A. and Sánchez−Monedero, M.A. (2010) Use of biochar as bulking agent for the composting of poultry manure: effect on organic matter degradation and humification. *Bioresource Technology*, **101**(4), pp.1239−1246.

Felber R., Leifeld, J., Horák, J. and Neftel, A. (2014) Nitrous oxide emission reduction with green-waste biochar: comparison of laboratory and field experiments. *European Journal of Soil Science*, **65**(1), 128−138.

Biofertilizers and Organic Fertilizers - Fertilizer (Control) Order, 1985, Schedule –IV, Part D, “Methods of analysis of organic fertilisers”. National Centre of Organic Farming.

Foy, C.D., (1988) Plant adaptation to acid, aluminum-toxic soils. *Communications in Soil Science and Plant Analysis*, **19**(7-12), 959-987.

GOI, (2016) Annual Report Govt of India, Ministry of New and Renewable Energy, New Delhi.

Hale, L., Luth, M. and Crowley, D. (2015) Biochar characteristics relate to its utility as an alternative soil inoculum carrier to peat and vermiculite. *Soil Biology and Biochemistry*, ***81***, pp.228−235.

Hina, K., Bishop, P., Arbestain, M.C., Calvelo−Pereira, R., Maciá−Agulló, J.A., Hindmarsh, J., Hanly, J.A., Macìas, F. and Hedley, M.J. (2010) Producing biochars with enhanced surface activity through alkaline pre-treatment of feedstocks. *Soil Research,* **48**(7), 606−617.

Jindo, K., Sonoki, T., Matsumoto, K., Canellas, L., Roig, A. and Sanchez−Monedero, M.A. (2016) Influence of biochar addition on the humic substances of composting manures. *Waste Management,* **49**, 545−552.

Jurado, M.M., Suárez−Estrella, F., López, M.J., Vargas−García, M.C., López−González, J.A. and Moreno, J. (2015) Enhanced turnover of organic matter fractions by microbial stimulation during lignocellulosic waste composting. *Bioresource Technology,* **186**, 15−24.

Kochian, L.V. (1995) Cellular mechanisms of aluminum toxicity and resistance in plants. *Annual review of plant biology,* **46**(1), 237-260.

Kumar, M., Khan, M.H., Singh, P., Ngachan, S.V., Rajkhowa, D.J., Kumar, A. and Devi, M.H. (2012) Variable lime requirement based on differences in organic matter content of iso−acidic soils. *Indian Journal of Hill Farming*, **25**(1), 26−30.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B. and Karlen, D.L. (2010) Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma,* **158** (3−4), 443−449.

Lavelle, P., Chauvel, A. and Fragoso, C. (1995) Faunal activity in acid soils. In Plant−Soil Interactions at Low pH: Principles and Management, 201−211. *Springer*, Dordrecht.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C. and Crowley, D. (2011) Biochar effects on soil biota–a review. *Soil Biology and Biochemistry*, **43**(9), 1812−1836.

Liu, T., Marlier, M.E., DeFries, R.S., Westervelt, D.M., Xia, K.R., Fiore, A.M., Mickley, L.J., Cusworth, D.H. and Milly, G. (2018) Seasonal impact of regional outdoor biomass burning on air pollution in three Indian cities: Delhi, Bengaluru, and Pune. *Atmospheric Environment,* **172**, 83−92.

Maeda, K., Hanajima, D., Morioka, R. and Osada, T. (2010) Characterization and spatial distribution of bacterial communities within passively aerated cattle manure composting piles. *Bioresource Technology*, **101**(24), 9631−9637.

Mandal, S.C. (1997) Introduction and historical overview. In: “"Mandal, S.C., Mahapatra, I.C., Misra, C., Mitra, G., Panda, N. (eds) Acidic soil of India” (Eds.) ICAR, New Delhi, 3−24.

Mao, J.D., Johnson, R.L., Lehmann, J., Olk, D.C., Neves, E.G., Thompson, M.L. and Schmidt−Rohr, K. (2012) Abundant and stable char residues in soils: implications for soil fertility and carbon sequestration. *Environmental Science and Technology*, **46**(17), 9571−957

Martinsen, V., Alling, V., Nurida, N.L., Mulder, J., Hale, S.E., Ritz, C., Rutherford, D.W., Heikens, A., Breedveld, G.D. and Cornelissen, G. (2015) pH effects of the addition of three biochars to acidic Indonesian mineral soils. *Soil Science and Plant Nutrition*, **61**(5), 821−834.

Mukherjee, A., Zimmerman, A.R. and Harris, W. (2011) Surface chemistry variations among a series of laboratory−produced biochars. *Geoderma,* **163**(3−4), 247−255.

Nain, P, Purakayastha, T. J., Sarkar, B. Bhowmik, A., Biswas, D.R., Kumar, S., Shukla, L. and Das, N. (2022). "Nitrogen-enriched biochar co-compost for the amelioration of degraded tropical soil." *Environmental Technology* pp: 1-16.

Nelson, D.W. and Sommers, L. (1982) Total carbon, organic carbon, and organic matter. Methods of soil analysis: *Part 2 chemical and microbiological properties*, 9, 539−579.

Prost, K., Borchard, N., Siemens, J., Kautz, T., Séquaris, J.M., Möller, A. and Amelung, W. (2013) Biochar affected by composting with farmyard manure. *Journal of Environmental Quality*, ***42***(1), pp.164−172.

Punia, M., Nautiyal, V.P. and Kant, Y. (2008) Identifying biomass burned patches of agriculture residue using satellite remote sensing data. *Current Science*, 1185−1190.

Purakayastha, T.J., Kumari, S. and Pathak, H., (2015) Characterisation, stability, and microbial effects of four biochars produced from crop residues. *Geoderma,* 239, 293−303.

Rayment, G.E. and Higginson, F.R., 1992. Australian laboratory handbook of soil and water chemical methods. Inkata Press Pty Ltd.

Sánchez−Monedero, M.A., Roig, A., Paredes, C. and Bernal, M.P. (2001) Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. *Bioresource Technology,* **78**(3), 301−308.

Sharma, A., Sharma, R., Arora, A., Shah, R., Singh, A., Pranaw, K. and Nain, L. (2014) Insights into rapid composting of paddy straw augmented with efficient microorganism consortium. *International Journal of Recycling of Organic Waste in Agriculture*, **3**(2), p.54.

Singh, A.K., Sarkar, A.K., Kumar, A. and Singh, B.P. (2009) Effect of long−term use of mineral fertilizers, lime and farmyard manure on the crop yield, available plant nutrient and heavy metal status in an acidic loam soil. *Journal of the Indian Society of Soil Science,* **57**(3), 362−365.

Steiner, C., Das, K.C., Melear, N. and Lakly, D. (2010) Reducing nitrogen loss during poultry litter composting using biochar. *Journal of Environmental Quality*, **39**(4), 1236−1242.

Tabatabai, M.A. and Bremner, J.M. (1991) Automated instruments for determination of total carbon, nitrogen, and sulphur in soils by combustion techniques. *Soil Analysis*, 261−286.

Van Zwieten, L., Singh, B.P., Joseph, S., Kimber, S., Cowie, A. and Chan, Y. (2009) Biochar reduces emissions of non-CO_2 GHG from soil. *Biochar for Environmental Management*.pp. 227-249.

Vandecasteele, B., Sinicco, T., D'Hose, T., Nest, T.V. and Mondini, C. (2016) Biochar amendment before or after composting affects compost quality and N losses, but not P plant uptake. *Journal of Environmental Management,* **168**, 200−209.

Villasenor, J., Rodriguez, L. and Fernandez, F.J. (2011) Composting domestic sewage sludge with natural zeolites in a rotary drum reactor. *Bioresource Technology,* **102**(2), 1447−1454.

Wu, H., Lai, C., Zeng, G., Liang, J., Chen, J., Xu, J., Dai, J., Li, X., Liu, J., Chen, M. and Lu, L. (2017) The interactions of composting and biochar and their implications for soil amendment and pollution remediation: a review. *Critical Reviews in Biotechnology,* **37**(6), pp.754-764.

Zhang, J., Chen, G., Sun, H., Zhou, S. and Zou, G. (2016) Straw biochar hastens organic matter degradation and produces nutrient−rich compost. *Bioresource Technology*, **200**, 876−883.

Zhang, L. and Sun, X. (2014) Changes in physical, chemical, and microbiological properties during the two−stage co-composting of green waste with spent mushroom compost and biochar. *Bioresource Technology*, **171**, 274−284.