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Deka Kanku
SRF-NICRA, Krishi Vigyan Kendra, Cachar, Assam, India

Medhi BK
Principal Scientist at AICRP on irrigation water management, AAU, Jorhat, Assam, India

Das Janardan
Programme Assistant (Agriculture)-Krishi Vigyan Kendra, Cachar, Assam Agricultural University, Assam, India

Talukdar Bidyasagar
SRF-NICRA, Krishi Vigyan Kendra, Cachar, Assam, India

Nath DC
SMS-Krishi Vigyan Kendra, Cachar, Assam Agricultural University, Assam, India

Chowdhury Pulakabha
Senior Scientist and Head, Krishi Vigyan Kendra, Cachar, Assam Agricultural University, Assam, India

Correspondence
Deka Kanku
SRF-NICRA, Krishi Vigyan Kendra, Cachar, Assam, India

Biochar production, characterization and evaluation for correcting soil acidity and Al Toxicity

Deka Kanku, Medhi BK, Das Janardan, Talukdar Bidyasagar, Nath DC and Chowdhury Pulakabha

Abstract
An experiment was conducted during 2014-16 at Assam Agricultural University, Jorhat to produce biochar from locally available bio-wastes *viz.* rice straw, rice husk, *toria* stover and bamboo leaves and characterization of their physic chemical properties and evaluation for correcting soil acidity and Al toxicity under Assam condition. Two samples of feedstock each from 5 development blocks of Jorhat district were collected, dried and pyrolysed in slow pyrolysis (300 – 400 ^{0}C) process for production of char for their physico-chemical properties. Percent moisture, ash content and specific surface area of biochars ranged from 3.26 to 4.91%, 3.70 to 24.97% and 89.40 to 184.75 m^2/g, whereas pH, EC, CEC, total Carbon varied from 7.74 to 9.46, 0.272 to 1.005 dsm^{-1}, 12.74 to 16.68 c mol (p^+)/kg and 36.63 to 49.424%, respectively. Percent total N, P, and K had their value ranged from 47.27 to 60.07, 0.017 to 0.032, and 0.237 to 0.453; while, Ca and Mg, Fe, Zn, and Cu ranged from 1.11 to 5.23 and 0.148 to 1.326 c mol $(p^{+)}$/kg, 16.65 to 2.91, 30 to 162, and 8.6 to 43 mg/kg of biochar. Rice straw biochar being alkaline was considered for incubation study at 3, 6 and 9 weeks of incubation periods where three doses of biochar (0, 0.5 and 1%) and five levels of liming material was applied. Increase in levels of liming material and biochars doses increased soil pH as well as ECEC significantly irrespective of incubation periods. Percentage of aluminium neutralized to its initial Al content was found increasing due to increase in levels of liming and biochars materials. Such increase was to the tune of 82% due to biochar and 95% because of application liming material.

Keywords: Biochar, pyrolysis, rice straw, pH, soil acidity, aluminium toxicity, EC, CEC, ECEC

1. Introduction
Crop residue burning has emerged a great challenge in recent years and contributed significantly to the pollution level in the country (IIT, Kanpur, 2016). The current availability of biomass in India (2010-2011) is estimated at about 500 million tons/year. Studies sponsored by the Ministry of New and Renewable Energy (MNRE), Govt. of India have estimated surplus biomass availability at about 120–150 million tons/ annum (MNRE, 2009). Of this, about 93 million tons of crop residues are burned in each year (IARI 2012). It has estimated that about 11.43 Mt of crop residues and crop residue surplus 2.34 Mt are generated every year in Assam. Although residue burn is uncommon in North East, Assam burnt on an average about 1.42 Mt (based on IPCC coefficients) crop residues annually (IARI, 2012).
As suggested by various researcher and research group the surplus crop residue could be used for alternative activities including biochar making instead of burning in the field (IARI, 2012; IIT, Kanpur, 2016 and Kannan, 2013) [16]. Biochar is a carbon rich charcoal that is formed by the pyrolysis (thermal decomposition) of organic biomass or agricultural residues which is used as soil amendment (Xiao *et al*. 2014) [26] and has been estimated that through production of biochar almost 12% of the GHG emissions caused by human activities could be reduced (Woolf *et al*. 2010) [25]. Since biochars are produced from a variety of feedstocks under different production process and conditions, they have different physical, chemical and biological properties and therefore have different effects when applied as soil amendment (Antal and Gronli, 2003) [2]. It is expected that addition of biochar can improve soil fertility, with added option to mitigate climate change through carbon sequestration in agricultural soils. Biochars produced from eleven (11) different feedstocks *viz.* wood, manure, leaf, papermill sludge, poultry litter under 400 ^{0}C and 500 ^{0}C pyrolysis temperatures, with and

without steam activation had significant effect in pH, CEC, basicity, acidity, lime equivalent and nutrients content in acid soils (Singh *et al.*, 2010) [19]. The effect of biochar addition on the chemical properties of acidic soil such as soil pH, electrical conductivity (EC), cation exchange capacity (CEC), exchangeable acidity etc. was earlier investigated to determine the liming potential of biochars in Entisols of USA (Chintala *et al.*, 2014) [10].

In Assam, except few exceptions the major soils of Assam are acidic by nature having pH range from 4.2 to 5.8 (Bhattacharyya *et. al.*, 2015) and it is as high as 96% in Upper Brahmaputra Valley Zone (UBVZ) (Talukdar *et al.*, 2004 and Sen *et al.*, 2003) [22, 23]. The soils of valley region suffer from surface acidity which may increase further because of poor management of soil. Moreover, resulting from fast weathering of minerals under humid climate, many of these soils contain large quantities of exchangeable aluminium throughout the control section (sub-soil acidity) limiting the growth of many field crops (Sen *et al.*, 2003) [23]. Although the effort has been to apply lime as the routine practice to correct soil acidity in most of the acid soil but due to high cost of liming our poor and needy farmers could not afford to apply in their own fields. Therefore, producing biochars under slow pyrolysis from locally available leftover plant materials and applying them in acid soils might be an alternate better option in reducing soil acidity.

Currently, the predictive capacity for biochar ‘performance’ does not exist and how to best optimize the multiple useful characteristics as a function of feedstock has not been assessed. Owing to the variability of biochar types and potential applications, limited information is available on how best to apply it (Casselman 2007 and IBI 2011) [7], keeping all the aspects in view, the present study was conducted with the following objectives, to characterize the physico-chemical properties of biochars produced under slow pyrolysis system, to study the potentialities of biochar to correct soil acidity and potential of biochar to ameliorate Al toxicity.

2. Materials and Methods

The present study was conducted at Department of Soil Science, Assam Agriculture University, Jorhat during 2014-16 and locally available bio-wastes *viz.* rice straw, rice husk, *toria* stover and bamboo leaves were used as raw materials to produce chars in slow pyrolysis process.

2.1 Feedstock collection and biochar production

The feedstocks were collected from five development blocks of Jorhat district *viz*., Ujani Majuli Development Block, Majuli Development Block, Central Jorhat Development Block, Eastern Jorhat Development Block and Titabar Development Block. The collected samples were air dried and subsequently oven-dried overnight at 80 ^{0}C. The dry waste was cut into small pieces or ground to less than 3 cm prior to drag the material into the biochar unit. Biochar production from rice husk, rice straw, *toria* stover and bamboo leaf was carried out using pyrolysis chamber fabricated at AICRP on Water Management AAU. Biochars was pyrolysed at 300-350 ºC with residence time of approximately three hours duration.

After pyrolysis, biochar in the unit was allowed to cool overnight to room temperature. The weights of the biochar collected were measured to obtain pyrolysis yields. The yield of each bio-product was defined as the ratio of the weight of the product to that of the original feedstock. After the pyrolysis process, the biochar was grounded to small granules and pass through 2000 μm sieve in order to have the same particle size as that of the soil. All physico-chemical characterization will be done as per the protocol described by IBI.

2.2 Analysis Physical, chemical and potential of biochar for correcting soil acidity

Moisture Content Determination

A 1.0 g of the activated carbon sample was collected and dried in an oven for four hours at 150 ^{0}C, until the weight of the sample became constant. The moisture content was calculated from the relationship.

$$X0 = \frac{W1 - W2}{W1} \times 100$$

Where,

Xo = Moisture content on weight basis
W_1 = Initial weight of sample, (g)
W_2 = Final weight of sample after drying (g)

2.3 Ash Content

Dry (Activated Carbon) sample (1.0g) was placed in to a porcelain crucible and transferred into a preheated muffle furnace set at a temperature of 1000^{0}C. The furnace was left on for one hour after which the crucible and its content was transferred to desiccator and allowed to cool. The crucible and content was reweighed and the weight lost was recorded as the ash content of the sample. The per cent ash content (dry basis) was calculated from the equation

$$\text{Ash}(\%) = \frac{Wash}{W0} \times 100$$

Where,

W_{ash}= Weight of ash (grams).
W_0 = is the dry weight of carbon sample before ashing.

2.4 *Specific surface area (m$^{2/}$gm)*

The specific surface areas of the samples were determined using the European Spot Method as described by Santamarina *et al.* (2002).

2.5 Determination of chemical properties of biochar

The pH was determined using a digital pH meter, so as EC was by digital EC meter. CEC was determined following Black, 1965 method of CEC determination; likewise Total Carbon (%) was determined as described by Jackson 1973. Total N was determined by the Kjeldahl method (Bremner, 1960) [5], Total P was determined by Vanadomolybdate method, heavy matels like Calcium, Magnesium, Zinc, Iron, and Copper was determined by Atomic Absorption Spectophotometer using DTPA (diethylene triamine penta-acetic acid) method (Lindsay and Norvell, 1978) [20] and Total K was determined by flame photometer.

2.6 Evaluation of potential of biochar for correcting soil acidity

Exchangeable Aluminum determined by colorimetrically according to Jackson 1973, Percent neutralized Aluminium was detrmined by Kamprath, 1970 and Effective Cation Exchange Capacity (ECEC) as per the method outlined by Blake, 1965.

2.7 Incubation Study

An incubation study was conducted in acid soil collected from arable layer (0-15 cm) of ICR farm of AAU, Jorhat. Two hundred grams of dried soil, passed through a 0.5 mm sieve, was brought in plastic containers. The soil was then incubated at 24 ± 1^0C and moisture level was maintained at field capacity all throughout the study period. Five doses of $CaCO_3$ based on the amount of exchangeable Al (L_0 = 0, $L_{1/2}$= half dose to neutralize exch. Al, L= normal dose to neutralize exch. Al, $L_{1.5}$ = Dose to neutralize 1.5 times of exch. Al, and L_2 = Dose to neutralize 2 times of exch. Al, in combination with three doses (0, 0.5 and 1% wt. wt^{-1}) of biochar shaving high alkalinity and specific surface area was chosen for the study. The experiment was designed in fac*toria*l CRD (15 treatments) with 3 replicates per treatment. Periodically, soil samples at 2, 4, 6 and 8 weeks were collected, dried, ground and sieved through 0.5 mm sieve and analyzed for pH, exchangeable Al and ECEC. From the neutralized value of exchangeable Al, potentiality of biochar, either in combination or alone, was determined.

3. Results and Discussion
3.1 Properties of initial soils and biochars
The initial physico-chemical properties of soil are presented in Table 1. The soil was sandy loam in texture with BD (g/cc) 1.49, pH 5.09, EC (ds/m), OC (%) 0.49, CEC (c mol p^+/kg) 7.28, ECEC (c mol p^+/kg) 9.08 and Exchangeable Al (c mol p^+/kg) 1.8. The gravimetric moisture content at field capacity was found to be 22.7% while, at permanent wilting point it was 11.3 percent, respectively.

In the study of Biocar, highest mean gravimetric moisture content was found in rice husk biochar (4.91%) followed by biochars derived from *toria* stover (4.88%), rice straw (3.38%) and bamboo leaves (3.26%). Comparatively, higher percentage of ash content was recorded in biochar prepared from rice straw (24.97%) while, it was low in biochar obtained from bamboo leaves (3.70%). Bamboo leaves biochar had the highest specific surface area (184.75 m^2/g), lowest being in rice husk (89.40) biochar. Highest alkalinity (pH 9.46 & EC 1.001 dsm^{-1}) was observed in rice straw biochar while, it was rice husk biochar that had minimum pH of 7.74. Bamboo leaves biochar showed the lowest EC (0.274 dsm^{-1}) value. Mean value of Cation Exchange Capacity, Total Carbon and Total Nitrogen of biochars followed the order as Bamboo leaves > Rice straw > toria stover > Rice husk. Total P and total K content of biochars was in the order of *toria* stover > rice husk > rice straw > bamboo leaves and *toria* stover > rice and straw > bamboo leaves > rice husk, respectively. Both calcium and magnesium content of biochars was found to be highest in rice straw biochar, lowest being observed in bamboo leaves biochar following the sequence of rice straw > *toria* stover > rice husk > bamboo leaves. Highest Cu and Zn content was recorded in rice straw biochar whereas lowest was estimated in toria stover for Cu and bamboo leaves biochar for Zn. Biochar derived from *toria* stover recorded the highest Fe content while the lowest was estimated in rice husk biochar. Above describe detail results are showing in the table 2 and similar results were earlier reported by many scientists Hernandez-Mena *et al* (2014), Brown *et. al*. 2006, Weixiang Wu, 2012 and Lehmann and Joseph, 2009.

Correlation study shows that there was significant positive correlations of pH with EC (0.800**), total K (0.748**), Ca (0.911**), Mg (0.702**), Cu (0.656**) and Zn (0.788**). CEC had significant positive correlations with total C (0.583**), total N (0.587**), total K (0.443**). Significant positive correlation of total C with total N (0.998**) (table 3) were observed.

Table 1: Initial soil properties

Soil Property		Value
Texture	:	Sandy loam (Sand 74%, Silt 11% and Clay 15%)
BD (g/cc)	:	1.49
Ph	:	5.09
EC (ds/m)	:	0.02
O.C. (%)	:	0.49
CEC (c mol p^+/kg)	:	7.28
Exchangeable Al (c mol p^+/kg)	:	0.45
ECEC (c mol p^+/kg)	:	7.73
Moisture content at Field capacity (%)	:	22.7
Moisture content (PWP) (%)	:	11.3

Table 2: Selected attributes of biochars produced from rice husk, rice straw, *toria* stover and bamboo leaves.

Biochar type	Physical parameter		Chemical properties											
	Moisture Content (%)	Ash content (%)	pH	EC	CEC	C (%)	N	P	K	Ca	Mg	Cu	Fe	Zn
Rice husk	4.91± 0.60	13.17± 1.44	7.74 ± 0.188	0.457± 0.041	12.74± 1.30	36.63± 1.88	0.473± 0.017	0.0237 ± 0.0025	0.237 ± 0.014	2.191 ± 0.139	0.822 ± 0.092	17.3 ± 2.91	66 ± 3.50	2.918 ± 0.213
Rice straw	3.38± 0.33	24.97± 3.05	9.46 ± 0.332	1.005 ± 0.070	15.67 ± 0.86	41.16 ± 4.54	0.526 ± 0.046	0.0185 ± 0.0037	0.420 ± 0.028	5.234 ± 0.377	1.326 ± 0.118	43 ± 4.35	162.6 ± 6.80	5.49 ± 0.500
Toria stover	4.88± 0.49	5.63± 0.38	8.68 ± 0.154	1.001 ± 0.098	14.72 ± 0.69	39.26 ± 0.38	0.0499 ±0.005	0.0324± 0.0020	0.453± 0.057	3.767± 0.154	1.062 ± 0.074	8.6 ± 2.01	54.6 ± 4.40	16.655± 0.399
Bamboo leaves	3.26± 0.53	3.70± 0.30	7.96 ± 0.050	0.272 ± 0.093	16.68 ± 1.15	49.424± 0.26	0.601± 0.0039	0.0173 ± 0.0022	0.337 ± 0.041	1.111 ± 0.073	0.148± 0.047	11.6± 2.27	30± 5.73	4.644 ± 0.246

EC, Electrical Conductivity; CEC, Cation exchange capacity; C (%), Total Carbon (C); N, Total Nitrogen, P, Total phosphorus; K, Total Potassium; Ca, Calcium; Mg, Magnesium; Cu, Copper; Fe, Iron; Zn, Zinc

Table 2: Correlations among the chemical properties of biochars

	pH	EC	CEC	Tot C	Tot N	Tot P	Tot K	Ca	Mg	Cu	Zn	Fe
pH	1											
EC	0.800**	1										
CEC	0.29	0.005	1									
Tot C	-0.081	-0.428**	0.583**	1								
Tot N	-0.07	-0.422**	0.587**	0.998**	1							
Tot P	-0.043	0.446**	-0.309	-0.499**	-0.499**	1						
Tot K	0.748**	0.707**	0.443**	0.126	0.133	0.264	1					
Ca	0.911**	0.910**	0.009	-0.414**	-0.403**	0.155	0.628**	1				
Mg	0.702**	0.870**	-0.298	-0.633**	-0.624**	0.340**	0.403**	0.909**	1			
Cu	0.656**	0.443**	0.127	-0.133	-0.118	-0.439**	0.184	0.691**	0.598**	1		
Zn	0.788**	0.624**	0.02	-0.26	-0.246	-0.263	0.304	0.846**	0.768**	0.939**	1	
Fe	0.214	0.613**	0.048	-0.18	-0.179	0.772**	0.690**	0.344**	0.319**	-0.379**	-0.177	1

*, ** significant at 0.05 and 0.01 levels, respectively

Table 3: Effect of levels of biochar and lime on Effective Cation Exchange Capacity (c mole p⁺/kg) at 3, 6 and 9 weeks of incubation

Biochar doses	3 weeks						6 weeks						9 weeks					
	Levels of agricultural lime						Levels of agricultural lime						Levels of agricultural lime					
	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean
B_0	0.450	0.202	0.115	0.068	0.054	0.178	0.448	0.197	0.104	0.047	0.039	0.167	0.448	0.184	0.100	0.044	0.031	0.161
$B_{0.5}$	0.324	0.178	0.107	0.038	0.021	0.134	0.309	0.141	0.098	0.019	0.011	0.116	0.310	0.137	0.089	0.017	0.018	0.114
$B_{1.0}$	0.297	0.147	0.098	0.028	0.011	0.116	0.212	0.112	0.052	0.010	0.007	0.079	0.209	0.109	0.057	0.010	0.010	0.079
Mean	0.357	0.176	0.107	0.045	0.029		0.323	0.150	0.085	0.025	0.019		0.322	0.143	0.082	0.024	0.020	
CD (0.05) 0.035 (B)							CD (0.05) 0.041 (B)						CD 0.05) 0.041 (B)					
CD (0.05) 0.104 (L)							CD (0.05) 0.110 (L)						CD 0.05) 0.159 (L)					
CV (%) 4.98							CV (%) 5.12						CV (%) 4.39					

Incubation Study Result

Considering biochar from rice straw being highest level of alkalinity (pH, Ca and Mg) and specific surface area was used to correct soil acidity along with the liming materials. Biochar with three graded doses (0, 0.5 & 1% wt. wt^{-1}) in combination with five levels of $CaCO_3$ (L_0 = 0, $L_{1/2}$= half dose to neutralize exch. Al, L= normal dose to neutralize exch. Al, $L_{1.5}$ = Dose to neutralize 1.5 times of exch. Al, and L_2 = Dose to neutralize 2 times of exch. Al) corresponding to 0, 0.23, 0.46, 0.69 and 0.92 tons per hectare was used for the incubation study. During the study period pH, exchangeable Al, ECEC and percent neutralized Al at 3, 6 and 9 weeks were determined and the results are depicted in tables 4, 5, 6 respectively and discussed below.

Table 4: Effect of levels of biochar and lime on pH at 3, 6 and 9 weeks of incubation

Biochar doses	3 weeks						6 weeks						9 weeks					
	Levels of agricultural lime						Levels of agricultural lime						Levels of agricultural lime					
	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean
B_0	5.12	5.43	5.46	5.82	5.86	5.54	5.17	5.55	5.76	5.89	6.17	5.708	5.16	5.57	5.75	5.91	6.15	5.70
$B_{0.5}$	6.30	6.50	6.49	6.38	6.43	6.42	6.19	6.38	6.57	6.66	6.97	6.554	6.17	6.42	6.61	6.69	6.98	6.57
$B_{1.0}$	6.52	6.81	6.72	6.67	6.87	6.72	6.22	6.87	6.84	6.87	7.32	6.824	6.25	6.93	6.80	6.85	7.21	6.80
Mean	5.98	6.25	6.22	6.29	6.38		5.86	6.26	6.39	6.47	6.82		6.25	6.93	6.80	6.85	7.21	
CD (0.05) 0.47 (B)							CD (0.05) 0.82 (B)						CD 0.05) 0.80 (B)					
CD (0.05) 0.20 (L)							CD (0.05) 0.29 (L)						CD (0.05) 0.49 (L)					
CV (%) 5.85							CV (%) 4.15						CV (%) 5.13					

Table 5: Effect of levels of biochar and lime on Effective Cation Exchange Capacity (c mole p⁺/kg) at 3, 6 and 9 weeks of incubation

Biochar doses	3 weeks						6 weeks						9 weeks					
	Levels of agricultural lime						Levels of agricultural lime						Levels of agricultural lime					
	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean
B_0	7.73	7.78	7.84	7.90	7.96	7.84	7.71	7.83	7.84	7.97	8.06	7.88	7.76	7.91	8.03	8.13	8.22	8.01
$B_{0.5}$	11.13	11.29	11.35	11.41	11.47	11.33	11.27	11.39	11.35	11.39	11.51	11.38	11.43	11.53	11.55	11.59	11.67	11.55
$B_{1.0}$	16.60	16.89	16.95	17.01	17.07	16.90	16.89	17.09	17.00	17.00	17.13	17.02	16.97	17.18	17.29	17.25	17.37	17.21
Mean	11.82	11.98	12.04	12.10	12.17		11.95	12.10	12.06	12.12	12.23		12.05	12.20	12.29	12.32	12.42	
CD (0.05) 2.10 (B)							CD (0.05) 2.28 (B)						CD 0.05) 2.29 (B)					
CD 0.05) NS (L)							CD 0.05) NS (L)						CD 0.05) NS (L)					
CV (%) 2.27							CV (%) 3.29						CV (%) 3.11					

Table 6: Effect of levels of biochar and lime on percent neutralize Aluminum at 3, 6 and 9 weeks of incubation

Biochar doses	3 weeks						6 weeks						9 weeks					
	Levels of agricultural lime						Levels of agricultural lime						Levels of agricultural lime					
	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean	L_0	$L_{0.5}$	L	$L_{1.5}$	L_2	Mean
B_0	0.0	55.1	74.4	84.9	88.0	60.5	0.44	56.22	76.89	89.56	91.33	62.89	0.44	59.11	77.78	90.22	93.11	64.13
$B_{0.5}$	28.0	60.4	76.2	91.6	95.3	70.3	31.33	68.67	78.22	95.78	97.56	74.31	31.11	69.56	80.22	96.22	96.00	74.62
$B_{1.0}$	34.0	67.3	78.2	93.8	97.6	74.2	52.89	75.11	88.44	97.78	98.44	82.53	53.56	75.78	87.33	97.78	97.78	82.44
Mean	20.7	61.0	76.3	90.1	93.6		28.22	66.67	81.19	94.37	95.78		28.37	68.15	81.78	94.74	95.63	

Effects of biochar on pH and ECEC

Increase in levels of liming materials and biochars doses increased soil pH as well as ECEC significantly irrespective of incubation periods. The overall mean value of both the parameters was found higher with the days of incubation. Increase in pH with increasing doses of biochar might be ascribed due to biochar (rice straw) with high alkalinity (pH 9.46) that contained considerable level of bases especially Ca and Mg. The effect on pH was much conspicuous at biochar dose of 1% which increased the pH to the tune of 6.82 from its initial pH of 5.09. The alkalinity of most biochar can be beneficial to acidic soils, acting as a liming agent to increase pH, and decrease exchangeable Al (Chan *et al*., 2007, 2008; Major *et al*., 2010) [8, 21]. The ECEC also followed the same trend with pH and the increased in their value with increase the doses of biochar and liming might be due to addition of Ca and Mg from liming material as well from the biochar.

Effects of biochar on Exchangeable Al and per cent Al neutralized

Increase in levels of liming materials and biochars doses decreased exchangeable aluminium significantly irrespective of incubation periods. The overall mean value of exchangeable Al was found decreasing gradually with the progress of incubation periods. The exchangeable Al dropped drastically from 0.450 to 0.079 c mole p^+/kg due to addition of biochar (1%) at 9 weeks and to 0.019 c mole p^+/kg on addition of lime to neutralize double the initial content of exchangeable Al of soil. Percentage of aluminium neutralized w.r.t. its initial content was found decreasing due to increase in levels of liming and biochars materials. Such decrease was to the tune of 82% due to biochar and 95% because of liming materials application. These findings were in conformity with the results published by Major *et al.* (2010) [21].

Increase in levels of liming materials and biochars doses increased soil pH as well as ECEC significantly irrespective of incubation periods. The overall mean value of both the parameters was found higher with the days of incubation. Conversely, increase in levels of liming materials and biochars doses decreased exchangeable aluminium significantly irrespective of incubation periods. The overall mean value of exchangeable Al was found decreasing gradually with the progress of incubation periods. Percentage of aluminium neutralized with respect time its initial content was found increasing due to increase in levels of liming and biochars materials.

The study revealed that biochar characterization of physicochemical properties allowed us to choose appropriate biochars for improving soil productivity. Four biochars derived from rice husk, rice straw, *toria* stover and bamboo leaves were quantitatively showed differences in moisture, ash, SSA, pH, EC, CEC, total C, N, P, K, Ca, Mg, Cu, Zn, and Fe. The higher capacity to improve soil productivity of rice husk, rice straw, *toria* stover and bamboo leaves derived biochars could be predicted from their measured properties. More specifically, the additions of rice straw derived biochar had the highest alkalinity to lower the soil exchangeable Al to a non-toxic level. Incubation study demonstrated the effectiveness of biochars in neutralizing exchangeable Al which increased the soil pH, ECEC, and increased percent of Al neutralized due to application of biochars. Practically, liming is a generally adopted method to suppress exchangeable Al. Application of $CaCO_3$ up to 0.92 $tonha^{-1}$ increased the pH, coinciding with a decrease in exchangeable Al due to neutralizing affect of $CaCO_3$. At this lime rate, more than 93% Al could be neutralized over the doses of rice straw biochar application. However, the highest neutralizing efficiency (74 % - 82%) of Al was due to application of rice straw biochar at 0.1 percent dose.

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