Characterization of biochars and their application rates on soil moisture retention in light textured soil of Assam

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Abstract:

"Biochar" is a relatively new term, yet it is not a new substance. Biochar, product of thermal decomposition or incomplete combustion of biomass or bio-wastes under limited oxygen supply, are fine-grained highly porous charcoal substances that are distinguished from other charcoals in its intended use as soil amendments. The state of Assam produces surplus quantities of biowastes and leaves behind bulk quantity of wastes soon after harvest of the main crop(s) remain unutilized annually and these farm wastes have the potential of further reutilization through production of biochar, which may effectively be used in sustainable production system. Characterization of biochar with respect to physico-chemical properties determines the suitability of biochar to conserve soil moisture, which is again regulated by kind and source of feed stock materials. Keeping these aspects in view, a study on characterization of biochars prepared from four different feed stocks, namely rice straw, rice husk, toria stover, and bamboo leaves was conducted at Assam Agricultural University during 2014-15 and 2015-16 to validate its efficiency to conserve soil moisture for longer time. After determining the physicochemical properties of the four biochars, a set of pot culture experiment in poly house taking toria as test crop was conducted with four biochars. Four hundred gram of soil (preferably light textured) in 500 g capacity of plastic pot replicated thrice was designed statistically (factorial CRD) with four doses of biochars (0, 0.5, 1.0, and 1.5% wt/wt). Initially, a moisture level at field capacity was maintained and periodical volumetric soil moisture content (upto 70 days) was monitored to evaluate their efficiency. Gravimetric soil moisture content decreased significantly with the progress in days of experimentation irrespective of types of biochar used. However, increase in biochar doses increased the soil moisture content significantly over the one where no biochar was applied. Highest efficiency to conserve soil moisture over the days of study period was due to the application of bamboo leaves biochar.

Keywords: Biochar, Gravimetric water, Pyrolysis

Introduction:

Biochar, a product of thermal decomposition or incomplete combustion of biomass or biowastes under limited oxygen supply, are fine-grained highly porous charcoal substances that can be used as soil amendments Berek and Hue (2009). The state of Assam produces surplus quantities of biowastes and leaves behind bulk quantity of wastes soon after harvest of the main crop(s) and remain unutilized annually. Considering the rich potential source of these bio-resources, there is enough scope for revitalizing technology backstopping for biochar production in increasing the production potential of crop through efficient use of such bio-resources in agriculture. Biochar's physical, chemical and nutritional properties depend on the chemical composition of the feedstock used, pyrolysis system and production conditions Atkinson *et al.* (2010). Time and temperature also influence the properties of the biochar. The rice straw-derived biocharsespecially produced at 400℃ had high alkalinity and cation exchange capacity, and highlevels of available phosphorus and extractable cations. These properties indicate potential application of rice straw-derived biochar as a fertilizer and soil amendment Weixiang W. *et al. (*2012). Jindo. K. *et al.,* (2014) observed that low-temperature pyrolysis produced high straw biochar yields; incontrast, high-temperature pyrolysis led to biochars with ahigh C content, large surface area and high adsorption characteristics. Due to biochar's surface area and porosity, bulk density, nutrient content, cation exchange capacity (CEC), pH value and carbon content it is expected to improve water retention, nutrient retention and plant uptake of nutrients Troeh and Thompson (2005). Producing biochars under slow pyrolysis from local available leftover plant materials and applying them in acid soils might be an alternate better option in reducing soil acidity. The major benefit associated with the use of biochar as a soil amendment is its ability to maintain soil moisture during the crop growth. In a laboratory study by Novak *et al.* (2009), where different biochar types were added to a loamy sand, biochar either had no significant effect or increased the water holding capacity of the soil. Asai *et al.* (2009) applied biochar to field soil in upland rice at several locations in Laos, and found improved surface infiltration of water. Although infiltration is different from moisture holding capacity, if more moisture enters the soil during rain events, more it can then potentially be retained by soil. A study conducted by Gaskin *et al.* (2007) found 18 per cent higher water retention in a loamy sand soil treated with biochars as compared with highly weathered tropical soils. In Assam, low rainfall during winter creates periods of drought showing soil moisture stress. Chronically drought affected area is nearly 1.0 lakh ha (3.8% of Net

Cropped area) and porous structure and high specific surface area of biochar may help reducing soil moisture deficit. The present research was carried out at Assam agricultural University, Jorhat with two main objectives, *viz.* characterization of the physico-chemical properties of biochars produced under slow pyrolysis system and suitability assessment of biochars to conserve soil moisture.

Methods and Materials:

Biochar unit

A biochar production unit, fabricated in AICRP on Irrigation Water Management Laboratory, AAU, Jorhat, for small scale production of biochars from bio-wastes of agricultural field was used in the present study on trial basis. Until recently much progress has been made in designing aspects of biochar production unit but in most of the cases a number of drawbacks ranging from loading rate, maintenance of temperatures, low production rate etc. were observed. The present design of biochar unit has the potential for easy handling with faster production rate. In designing the kiln, a much emphasis was laid on the requirement to control the loading rate of biochar for optimum churning efficacy without compromising the temperature fluctuation during the process of pyrolysis. The biochar kiln functions on top-draft principle with top ignition system. It consists of iron drum modified from oil tank with capacity of 0.08478 m^3.

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. Biochar was pyrolyzed in slow pyrolysis method at 300-350ºC with residence time of approximately three hours duration.

Biochar preparation

The unit was filled with feedstock, covered with a fitting lid, and pyrolyzed under oxygen-limiting conditions. 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.

Test crop: For conducting the study toria (*Brassica campestris*) was taking as a test crop.

As toria is short duration crop and is grown in Assam condition very well.

Laboratory analysis

Physical parameter

Moisture Content Determination

A 1.0 g of the activated carbon sample was collected and dried in an oven for four hours at 150°C, until the weight of the sample became constant. The moisture content was calculated from the relationship. (Madu and Lajde, 2013)

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

where,

Xo = Moisture content on weight basis

W_1 = Initial weight of sample, (g)

W_2 = Final weight of sample after drying (g)

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 1000^0C. 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 (Madu and Lajde, 2013)

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

Where,

W_{ash}= Weight of ash (grams).

W_0 = is the dry weight of carbon sample before ashing.

Particle Size

Particle size of the biochar was determined with the help of microscope ZEISS (Stemi 2000c). For the particle size determination, 2-3 biochar particles in each biochar samples were placed on the slide of the microscope and determined the particle size of biochar in µm. (Madu and Lajde, 2013)

Determination of Porosity and Bulk Density

One gram sample was dispersed in 20 ml water in a graduated cylinder with the aid of a shaker; this was further centrifuged for 10 minutes. The resulting volume of the water was read as VT and recorded. The equation below was used for the calculation of the porosity and bulk density as the case may be. (Madu and Lajde, 2013)

Porosity = Vw/VT,

Density = ρ/(1 – α) while

ρ = Ma/Vw

Pore Volume

The sample (1 g) was collected and transferred completely into a 10 ml measuring cylinder in order to get the total volume of the sample. The sample was then poured into a beaker containing 20 ml of deionized water and boiled for 5 min. The content in the beaker was then filtered, superficially dried, and weighed. The pore volume of the sample was determined by dividing the increase in weight of the sample by the density of water (Aneke and Okafor, 2005).

Table . 1: Physical properties

Moisture (%)	**3.38 ± 0.33**	**4.9 ± 0.60**	**4.88 ± 0.49**	**3.26 ± 0.53**
Ash content (%)	**24.9 ± 3.05**	**13.17±1.44**	**5.63 ± 0.38**	**3.70 ± 0.30**
BD g/cm3	**0.72 ± 0.09**	**0.629 ± 0.06**	**0.370± 0.30**	**0.178 ± 0.04**
PD g/cm3	**1.91 ± 0.11**	**1.92 ± 0.07**	**2.02 ± 0.20**	**0.85 ± 0.04**
Porosity (%)	**61.5 ± 6.15**	**67.25 ± 3.57**	**68.08 ± 3.95**	**78.90 ± 5.30**
Pore Vol.(ml)	**0.83 ± 0.09**	**1.05 ± 0.12**	**0.96 ± 0.17**	**1.15 ± 0.11**

Particle Size (µm)	**L**	**326 ± 26.9**	**153 ± 8.38**	**331 ± 11.62**	**310 ± 8.27**
	B	**350 ± 18.3**	**209 ± 8.38**	**197 ± 12.17**	**147 ± 5.75**

Chemical properties

pH

One gram of the sample was weighed and dissolved in 10 ml of de-ionized water. The mixture was heated and stirred for 3 minutes to ensure proper dilution of the sample. The solution was filtered and pH was determined using a digital pH meter.

EC

One gram of the sample was weighed and dissolved in 10 ml of de-ionized water. The mixture was heated and stirred for 3 minutes to ensure proper dilution of the sample. The solution was filtered and its EC was determined using a digital EC meter

Cation Exchange Capacity

CEC was determined by leaching the biochars with neutral normal ammonium acetate solution followed by distillation method (Blake, 1965).

Total carbon (%)

0.5 g of sample was weight and pre digest with 5 ml Nitric acid (HNO_3) for 24 hour and complete digestion was performed after addition of 10 ml of di-acid mixture in the digest. Taking the total carbon (%) content was estimated by wet digestion method (Walkley and Black, 1934) as described by Jackson (1973).

Total N

Total N was determined by the Kjeldahl method (Bremner, 1960).

Total P

Total P was determined by Vanadomolybdate method.

Total S

Total S was determined by Turbidimetric Method.

Heavy Metals

Calcium, Magnesium, Zinc, Iron, and Copper was determined by Atomic Absorption Spectophotometer using DTPA (diethylene triamine penta-acetic acid) method (Lindsay and Norvell, 1978).

Metals and Metalloids (K)

0.5 g of sample was weighed and pre digested with 5 ml Nitric acid (HNO_3) for 24 hour followed by addition of 10 ml of diacid mixture for complete digestion. Total K was determined by flame photometer.

Where:

N = the normality of thiosulphate solution

V_1 = the volume of the thiosulphate (ml) used for the titration of the sample –treated aliquot.

V_2 = the volume of the thiosulphate (ml) used for the blank titration,

W i= the mass of the sample used (g).

Table 2: CHEMICAL PROPERTIES

	Rice Straw	**Rice Husk**	**Toria Stover**	**Bamboo leaf**
pH	**9.46 ± 0.332**	**7.74 ± 0.188**	**8.68 ± 0.154**	**7.96 ± 0.050**
EC (dS m^{-1})	**1.005 ± 0.07**	**0.457 ± 0.041**	**1.001 ± 0.09**	**0.27 ± 0.093**
CEC [cmol(p^+)kg^{-1}]	**15.67 ± 0.86**	**12.74 ± 1.30**	**14.72 ± 0.69**	**16.68 ± 1.15**
T C (%)	**41.16 ± 4.54**	**36.63 ± 1.88**	**39.26 ± 0.38**	**49.42 ± 0.26**
T N (%)	**0.526 ± 0.04**	**0.473 ± 0.017**	**0.049± 0.005**	**0.60 ± 0.003**
T P (%)	**0.52 ± 0.04**	**0.023 ± 0.002**	**0.032 ± 0.002**	**0.01 ± 0.002**

T K (%)	**0.420± 0.028**	**0.237 ± 0.014**	**0.453 ± 0.057**	**0.33± 0.041**
T S (%)	**0.05 ± 0.013**	**0.099 ± 0.017**	**0.018 ± 0.005**	**0.06± 0.008**
T Ca $[(p+)kg^{-1}]$	**5.234 ± 0.37**	**2.19 ± 0.13**	**3.767± 0.154**	**1.111 ± 0.07**
T Mg$[(p+)kg^{-1}]$	**1.32 ± 0.118**	**0.822 ± 0.092**	**1.062 ± 0.074**	**0.14 ± 0.047**
T Cu $[(p+)kg^{-1}]$	**43 ± 4.35**	**17.3 ± 2.91**	**8.6 ± 2.01**	**11.6 ± 2.27**
T Zn $[(p+)kg^{-1}]$	**162.6 ± 6.80**	**66 ± 3.50**	**54.6 ± 4.40**	**30 ± 5.73**
T Fe $[(p+)kg^{-1}]$	**5.49 ± 0.50**	**2.918 ± 0.213**	**16.655 ± 0.39**	**4.64± 0.246**

Biochar for soil moisture conservation

For conducting this particular experiment Toria was taken as a test crop. The experiment was carried out under the poly house for minimization of the sun light. The main objective for conducting the experiment was to evaluate the efficiency of different types of biochar to conserve soil moisture for long time. The experiment was carried out with four biochars produced from (i) rice straw, (ii) rice husk, (iii) *toria* stover and (iv) bamboo leaves and four doses of biochar *ie.* 0, 0.5, 1.0 and 1.5% $wt.wt^{-1}$. 400 gram of soil (preferably light textured) in 500 gram capacity of plastic pot replicated thrice was designed statistically (fac*toria*l CRD). The treatment of the experiment was types of biochar and the biochar dose. Four doses with four types of biochar and three replications in each treatment have used in this study. Initially, a moisture level at field capacity was maintained in each pot and periodical volumetric soil moisture content (upto 70 days) was monitored at 15,30,45,60 and 75 days to evaluate their efficiency. The periodical moisture content was measured in volumetric method.

The periodical moisture status of the pot is measured to evaluate their efficiency.

Table 3. 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 4: Moisture retention capacity of rice straw biochar

Biochar dose	**Rice straw biochar**					
	Periods (days)					
	15	30	45	60	75	**Mean**
B_0	22.3	18.4	14.2	10.1	8.7	**14.7**
$B_{0.5}$	23.9	21.2	17.4	14.7	12.1	**17.9**
$B_{1.0}$	24.	22.0	18.5	15.2	13.2	**18.7**

B1.5	25.9	22.9	19.3	15.9	13.9	**19.6**
Mean	**24.2**	**21.1**	**17.4**	**14.0**	**11.9**	
CD (0.05) 1.38 (B), CD (0.05) 2.68 (P) **CV (%) 7.15**						

Table 5: Moisture retention capacity of Toria stover biochar

Biochar dose	***Toria* stover biochar**					
	Periods (days)					
	15	30	45	60	75	**Mean**
B_0	21.3	16.8	14.4	11.6	8.9	**14.6**
$B_{0.5}$	23.4	20.3	17.4	14.0	11.8	**17.4**
$B_{1.0}$	24.1	20.9	17.9	14.5	12.3	**17.9**
$B_{1.5}$	24.8	21.5	18.4	14.9	12.9	**18.5**
Mean	**23.4**	**19.9**	**17.0**	**13.8**	**11.4**	
CD (0.05) 1.79 (B), CD (0.05) 3.15 (P) **CV (%) 6.15**						

Table 6: Moisture retention capacity of rice husk biochar

Biochar dose	**Rice husk biochar**					
	Periods (days)					
	15	30	45	60	75	**Mean**

B_0	20.7	15.2	13.0	11.2	8.70	**13.7**
$B_{0.5}$	21.9	17.0	14.8	13.1	11.1	**15.6**
$B_{1.0}$	22.3	17.8	15.1	13.3	11.9	**16.1**
B1.5	23.3	18.6	15.8	13.9	12.4	**16.8**
Mean	**22.0**	**17.2**	**14.7**	**12.9**	**11.0**	
CD (0.05) 1.19 (B), CD(0.05) 2.48(P) **CV (%) 8.97**						

Table 7: Moisture retention capacity of bamboo leaf biochar

Biochar dose	**Bamboo leaves biochar**					
	Periods (days)					
	15	30	45	60	75	**Mean**
B_0	23.4	20.7	17.5	14.2	8.8	**16.9**
$B_{0.5}$	24.3	21.5	18.2	14.8	12.3	**18.2**
$B_{1.0}$	25.7	22.8	19.2	15.6	13.4	**19.3**
B1.5	26.8	23.7	20.1	16.3	13.9	**20.1**
Mean	**25.0**	**22.2**	**18.8**	**15.2**	**12.1**	
CD(0.05) 1.17(B), CD(0.05) 2.63 (P) **CV (%) 6.47**						

Results and Discussion:

The efficiency of four types of biochars *viz*. rice husk, rice straw, *toria* stover and bamboo leaves to retain soil moisture content was evaluated with graded doses of biochars at 15 days interval up to 75 days of experimentation. Gravimetric soil moisture content decreased significantly with the progress in days of experimentation irrespective of types of biochar used. However, increase in biochar doses increased the soil moisture content significantly over the one where no biochar was applied. Biochar applications to soils have been shown to enhance soil and water quality. Because of its high surface area and high surface charge density biochar increases the ability of soils to retain nutrients and plant available water and reduces leaching of nutrients and agricultural chemicals (Laird *et al*., 2010; Lehmann *et al*., 2003; Glaser *et al*., 2002). Soil water retention capacity is dependent on the distribution of soil pores, which are largely regulated by soil particle sizes (texture), structural characteristics (aggregation), and soil organic matter (SOM) content (Verheijen *et al*. 2009). Therefore, with high porosity, large inner surface area, and the potential ability of affecting soil aggregation through interactions with SOM, minerals, and microorganisms, biochar applied to soils also could change soil moisture retention capacity (Asai *et al*. 2009; Brockhoff *et al*. 2010). Highest efficiency to conserve soil moisture over the days of study period was due to application of bamboo leaves biochar. This might be attributed to low BD, less dimension of particle size, high porosity and high pore volume of bamboo leaves derived biochar. Similar results were reported by Novak *et al.* (2009), Chan *et al.* (2007), Asai *et al.* (2009), Major *et al.* (2009) etc. All the biochars, except rice husk, maintained soil moisture content above PWP at 75 days, maximum being recorded at bamboo leaves biochar.

Conclusion:

As expected, the application of biochar had effects on plant available water in soil. Highest efficiency to conserve soil moisture over the days of study period was due to application of bamboo leaves biochar. All the biochars, except rice husk, maintained soil moisture content above PWP at 75 days, maximum being recorded at bamboo leaves biochar. The characteristics and reactivity of biochars with soil are highly heterogeneous with batches of production using similar feedstock and pyrolytic conditions and the findings of a study could not be applied universally to all biochar materials. However, for accurate prediction of the effects of biochar towards soil characteristics, moisture content and nutrient availability, a deeper understanding of interactions between soil type, biochar production method, biochar feedstock, application rate and field crops is essential.

Tables and photographs

Plates:

Pyrolysis chamber, process and sieving

Rice straw biochar

TORIA STOVER BIOCHAR

RICE HUSK BIOCHAR

BAMBOO LEAF BIOCHAR

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Referrences:

Aneke N A and Okafor J O. Proceedings of the Nigerian Society of Chemical Engineers. 35th Annual Conference, Kaduna, Nigeria; 2005.

Asai H, Samson B K, Stephan H M, Songyikhangsuthor K, Homma K, Kiyon Y, Inoue Y, Shiraiwa T and Horie T. Biochar amendment techniques for upland rice production in Northern Laos 1. Soil physical properties, leaf SPAD and grain yield. Field Crops Research. 2009;111: 81-84.

Atkinson C J, Fitzgerald J D and Hipps N A. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant and Soil. 2010; 337: 1 – 18.

Blake G R. Particle Density. In: C.A Black (Ed). Methods of Soil Analysis Part 1. American Society of Agronomy, Inc. Madison, Wisconsin, USA. 1965

Berek, A. K. and Hue, N. V. (2013). Improving soil productivity with biochars. Annual report, ICGAI, Yogyakarta, Indonesia: 1-23.

Bremner J M. Determination of nitrogen in soil by the Kjeldahl method. The Journal of Agricultural Science. 1960; 55:11-33.

Brockhoff S R, Christians N E, Killorn R J, Horton R and Davis D D. Physical and Mineral-Nutrition Properties of Sand-Based Turfgrass Root ZonesAmended with Biochar. Agronomy Journal, 2010;102: 1627.

Chan K Y, Van Zwieten L, Meszaros I, Downie A and Joseph S. Agronomic values of greenwaste biochar as a soil amendment. Australian Journal of Soil Research, 2007;45: 629-634

Gaskin J W, Speir A, Morris L M, Ogden L, Harris K, Lee D and Das K C. Potential for pyrolysis char to affect soil moisture and nutrient status of loamy sand soil. *In*: Georgia Water Resources Conference. University of Georgia. 2007.

Glaser B, Lehmann J and Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal: A review. Biology and Fertility of Soils. 2002; 35: 219–230.

Jindo K, Mizumoto H, Sawada Y, Sanchez-Monedero A M and Sonoki T. Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences. 2014; 11: 6613–6621.

Laird D A, Fleming P D, Davis D D, Horton, R, Wang B and Karlen D L . Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma. 2010; 158: 443-449.

Lehman J, Da Silva Jr, J P, Steiner C, Nehls T, Zech W and Glaser B. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. Plant and Soil. 2003; 249: 343-357.

Lindsay W L and Norvell W A. Development of a DTPA soil test for zinc, iron, manganese, and copper, Soil Science Society American Journal. 1978; 42: 421-428.

Madu P C and Lajde L. Physicochemical characteristics of activated charcoal derived from melon seed husk. Journal of Chemical and Pharmaceutical Research. 2013; 5(5):94-98.

Major J, Steiner C, Downie A, Lehmann J Biochar effects on nutrient leaching. *In*: Lehmann, C.J.; Joseph, S. (Eds.), Biochar for environmental management: science and technology. Earthscan. 2009*;*1-12.

Novak J M, Busscher W J, Laird D L, Ahmedna M, Watts D W and Niandu M A S. Impact of biochar amendment on fertility of a south eastern coastal plain soil. Soil Sci. 2009; 174:105–112

Santamarina J C, Klein K A, Wang Y H and Prencke E. Specific surface: determination and relevance. Canadian Geotechnical Journal. 2002 ;39: 233-241.

Troeh F R and Thompson L M. Soils and soil fertility. 5th edition, Blackwell, Iowa. 2005

Verheijen F G A, Jeffery S, Van Dar Velde M, and Bastos A C. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. Agriculture, Ecosystems & Environment. 2011; 144 (1) : 175–187.

Walkley A and Black I A. An Examination of the Digestrates. Method for Determining Soil Organic Matter and Propose Modification of the Chronic Acid Titration Method. Soil Sci.1934; 37: 29-38.

Weixiang Wu, Yang M, Feng Q, McGrouther K, Wang H and Chen Y. Chemical characterization of rice straw-derived biochar for soil amendment. Biomass and Bio energy. 2012; 47: 268 -276.