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Tender coconut husk derived biochar influence on nutrient use efficiency, yield and economics of banana (*Musa spp.*)

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Abstract
This study evaluated the tender coconut husk derived biochar influence on nutrient use efficiency, yield and economics of banana (*Musa spp.*) at the Kerala Agricultural University, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. We developed a modified design of micro biochar kiln for the pyrolysis of tender coconut husk to biochar. In order to find out influence of biochar on yield an experiment was laid out in randomly block design replicated thrice with eleven treatments using *Nendran* as the test variety of banana. The results revealed that application of 10 kg biochar + 75% STBR (Soil Test Based Fertilizer Recommendation) recorded highest total dry matter production (12742.15 kg ha^{-1}), weight of bunch (9.34 kg), number of hands per bunch (5.25), number of fingers per bunch (46.16), length (22.83 cm) and girth (12.73 cm) of the index finger, nutrient use efficiency (50.4%) and B:C ratio (2.38).

Keywords: Biochar, banana, bunch weight, economics, nutrient use efficiency

Introduction
Tender coconut water is a popular unique natural beverage. It is an ideal rehydrating, refreshing drink useful in preventing and relieving many health problems (Sanganamoni *et al*., 2017) [1]. Sale of tender coconuts along waysides and parlours located by the side of highways and city roads are rampant. However, the spent tender coconut husks which form a biowaste are discarded along waysides. Hence the viable technological option for the safe disposal of this biomass waste is to convert it to biochar and utilizing it for improving soil health and crop production. Biochar can be produced by the thermochemical degradation of biomass in a zero or limited oxygen environment through the process of pyrolysis. It is perhaps the most recalcitrant form of organic matter in soil, whose sustenance extends from a few hundreds to thousands of years, rendering it an excellent means for carbon sequestration. It improves the chemical properties of soil. Owing to the highly porous nature of biochar, soil application of biochar would ultimately lead to an enhancement of a wide range of soil physical, chemical and biological properties (Atkinson *et al*., 2010) [2].

Hamdani *et al*. (2017) [3] concluded that 1.0% biochar along with reduced fertilizer doses, could be effectively used to improve wheat growth, yield, nutrient content and nutrient uptake under field condition. Moreover, 1.0% biochar along with 75% of inorganic fertilizers can be effectively used in place of 100% inorganic fertilizers to get the highest yield. Chan *et al*. (2007) [4] found that additions of biochar plus fertilizer (NH_4^+) increased radish yields more than the addition of fertilizer alone, indicating reduced N leaching and increased N use efficiency. Lehmann (2007) [5] studied that increasing yields with increasing biochar applications of up to 140 t ha^{-1} on highly weathered soils in the humid tropics, for most of their tests. They concluded that crops respond positively to biochar additions up to 50 Mg ha^{-1} and may show growth reductions only at very high applications. It is reported that black carbon can produce significant benefits when applied to agricultural soils in combination with some fertilizers. Increase in crop yield to the tune of 45-250% has been reported by application of biochar along with chemical fertilizers (Jha *et al*., 2010) [6].

Biochar has been reported to have both direct and indirect influence on physical, chemical and biological properties, which can have impacts on plant growth, nutrient use efficiency and yield (Blackwell *et al*., 2009) [7]. Zainudin *et al*. (2020) [8] reported that the influence of biochar addition on bacterial community and physicochemical properties changes, including ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) contents during the composting of poultry manure. Direct effects are largely associated with the retained feedstock nutrients in biochar, and are apparent when soil nutrients, plant production, and foliar nutrient concentrations are enhanced with biochar applications (Gaskin *et al*., 2010) [9]. A prototype of a cost-effective micro biochar kiln was conceptualized, developed, designed and fabricated indigenously for the pyrolytic conversion of dry tender coconut husk to biochar. This study of influence of biochar (pyrolytically synthesized from tender coconut husk) on yield, nutrient use efficiency and economics of banana (*Musa spp*) was done at the Department of Soil Science and Agricultural Chemistry, College of Agriculture (KAU), Vellayani, Kerala, India.

Materials and Methods

Tender coconut husk biowaste was collected from wayside tender coconut parlours and eateries and dried. Biochar was synthesized from this biomass waste in the prototype biochar micro kiln. The synthesized biochar was allowed to cool, crushed with a ceramic pestle, sieved through 2 mm sieve. The collected biochar samples produced from tender coconut husk was then subjected to various chemical analysis as per standard methodologies (Table 1).

The field experiment was carried out at College of Agriculture, Vellayani. The site is situated at 8^0 25'46" N latitude and 76^0 59'24" E longitude and at an altitude of 19 m above MSL. Soil samples were drawn initially and analysed for physical, chemical and biological properties as per standard procedures for various parameters (Table 2). The experiment was laid out in randomly block design replicated thrice with eleven treatments using *Nendra*n as the test variety of banana. Treatment combinations were T_1- Package of Practices (POP) recommendation, T_2-BC @ 5 kg plant^{-1} + NPK as per POP, T_3- BC @ 10 kg plant^{-1} + NPK as per POP, T_4- BC @ 5 kg plant^{-1} +75% NPK as per POP, T_5- BC @ 10 kg plant^{-1} +75% NPK as per POP, T_6-FYM 10 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR (Soil Test Based fertilizer Recommendation)), T_7-BC @ 5 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR), T_8- BC @ 10 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR), T_9- BC @ 5 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR), T_{10}-BC @ 10 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR) and T_{11}-BC alone 10 kg plant^{-1}. Total dry matter production, weight of bunch, number of hands per bunch, number of fingers per bunch, index finger length and girth were recorded. Bunches were harvested at full maturity as indicated by the disappearance of angles from fingers (Stover and Simmonds, 1987) [10].

Nutrient use efficiency (NUE) in terms of yield was calculated by using the formula.

$$\text{NUE (\%)} = \frac{\text{Yield of treatment with biochar} - \text{Yield of treatment without biochar (POP)}}{\text{Yield of treatment without biochar (POP)}} \times 100$$

Benefit Cost Ratio (BCR) was worked out as the ratio of gross income to cost of cultivation.

$$\text{BCR} = \frac{\text{Gross income (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}}$$

The data obtained from the field experiment was analysed statistically by applying the techniques of analysis of variance (Gomez and Gomez, 1984) [11]. The F values for treatments were compared with the table values. If the effects were significant, critical differences at the 5% significance level were calculated for effecting comparison among the means. Data analytical package Web Agri Stat Package (WASP) ver 2.0 was used for data analysis.

Results and Discussion

Results of biochar (pyrolytically synthesized from tender coconut husk) application on nutrient use efficiency, yield and yield characters and economics of banana detailed below.

Biochar characterization from tender coconut husk biochar

As per the modified micro kiln technology biochar was produced from tender coconut husk by pyrolysis. Biochar produced was analysed for electro-chemical and chemical properties (Table 1). Biochar from tender coconut husk had an alkaline pH (8.53), high total organic carbon (70.10%) and CEC (15.26 cmol kg^{-1}). Nutrient composition of the biochar revealed that it had N (1.52%), P (0.40%), K (2.26%), Ca (0.54%), Mg (0.46%), S (0.27%), Fe (89.9 mg kg^{-1}), Mn (2.84 mg kg^{-1}) and B (6.78 mg kg^{-1}). C:N, C:P, C:S and C:N:P:S ratios were 46.11, 175.25, 259.62 and 350:7.5:2:1 respectively (Table 1). The heavy metal contents (Pb, Cd, Ni, Cr, Zn and Cu) were very low when compared to the maximum allowed threshold levels (Table 2). Shenbagavalli and Mahimairaja (2012) [12] reported identical values for coconut shell biochar. Kumari *et al.* (2017) [13] observed similar values for pH and EC which had the potential for biochar induced short term changes on application as soil amendment rather than long term effects. Hence there is a prospect of biochar being considered as a good soil ameliorant (Dainy, 2015) [14] for enhancement of soil pH in the predominantly acidic soils of Kerala.

Table 1: Electro-chemical characteristics of the biochar synthesized from tender coconut husk

Parameter	Content	Method	Reference
pH (1:20)	8.53 ± 0.13	Potentiometry (Biochar : water (1:20) and equilibration for 90 minutes in shaker)	Rajkovich *et al*. (2011) [15]
EC (1:20) (dS m^{-1} at 25ºC)	1.70 ± 0.02		
CEC (cmol kg^{-1})	15.26 ± 0.64	Neutral 1 *N* NH_4OAc extraction and distillation	Jackson (1973) [16]
TOC (%)	70.10 ± 1.82	TOC analyzer	Piper (1966) [17]
N (%)	1.52 ± 0.85	Microkjeldahl distillation after digestion in H_2SO_4	Jackson (1973) [16]
P (%)	0.40 ± 0.10	Nitric-perchloric (9:4) acid digestion and vanado-molybdo yellow color method and measurement using spectrophotometry	Greenberg *et al*. (1992) [18]
K (%)	2.26 ± 0.05	Nitric-perchloric (9:4) acid digestion and flame photometry	Jackson (1973) [16]
Ca (%)	0.54 ± 0.07		
Mg (%)	0.46 ± 0.07		
S (%)	0.27 ± 0.03	Nitric-perchloric (9:4) acid digestion and turbidimetry	Tabatabai (1982) [19]
Fe (mg kg^{-1})	89.90 ± 0.99	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Jackson (1973) [16]
Mn (mg kg^{-1})	2.84 ± 0.66		
B (mg kg^{-1})	67.89 ± 1.83	Dry ashing at 550 ^{0}C in silica crucibles followed by extraction of ash in 10 ml of 0.36 N H_2SO_4 for one hour at room temperature and filtration through Whatman No. 42 filter paper. Spectrophotometry	Roig *et al*. (1988) [20]

Table 2: Heavy metal content in biochar from tender coconut husk

Heavy metal (mg kg^{-1})	Content	Maximum allowed thresholds (IBI, 2015) [21]	Method	Reference
Pb	0.18 ± 0.18	212-300	Nitric-perchloric (9:4) acid digestion and emission spectroscopy (ICP-OES)	Wei and Yang (2010) [22]
Cd	0.03 ± 0.02	1.9-39		
Ni	0.02 ± 0.01	47-420		
Cr	0.06 ± 0.02	93-1200		
Zn	6.18 ± 1.08	416-7400	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Jackson (1973) [16]
Cu	0.51 ± 0.04	143-6000		

Table 3: Soil fertility parameters of experimental site

Fertility parameters	Content	Status	Method	Reference
Physical properties				
Bulk density (Mg m^{-3})	1.37 ± 0.03	-	Core method	Gupta and Dakshinamoorthy (1980) [23]
Porosity (%)	47.05 ± 1.99	-		
WHC (%)	28.28 ± 1.02	-		
Chemical properties				
pH	4.73 ± 0.04	Very strongly acid	Potentiometry	Jackson (1973) [16]
EC (dS m^{-1} at 25°C)	0.71 ± 0.09	-	Conductometry	Jackson (1973) [16]
CEC (cmol kg^{-1})	3.36 ± 0.06	Low	Neutral 1 *N* NH_4OAc extraction and distillation	Jackson (1973) [16]
OC%	1.13 ± 0.08	Medium	Walkey and Black's rapid wet titration method	Walkey and Black (1934) [24]
N (kg ha^{-1})	225.57 ±12.42	Medium	Alkaline potassium permanganate method	Subbiah and Asija (1956) [25]
P (kg ha^{-1})	80.40 ± 8.11	High	Bray No.1 extraction and spectrophotometry	Jackson (1973) [16]
K (kg ha^{-1})	130.20 ± 23.99	Medium	Neutral 1 *N* NH_4OAc extraction and flame photometry	Jackson (1973) [16]
Ca (mg kg^{-1})	374.90 ± 36.22	Sufficient	Neutral 1 *N* NH_4OAc extraction and Atomic Absorption spectrophotometry	Hesse (1971) [26]
Mg (mg kg^{-1})	47.34 ± 5.14	Deficient		
S (mg kg^{-1})	50.68 ± 10.15	Sufficient	0.15% $CaCl_2$ extraction and turbidimetry	Tabatabai,1982 [19]; Massoumi and Cornfield (1963) [27]
Fe (mg kg^{-1})	26.19 ± 7.35	Sufficient	0.1M HCl extraction and Atomic Absorption Spectrophotometry	Sims and Johnson (1991) [28]
Mn (mg kg^{-1})	6.42 ± 3.18	Sufficient		
Zn (mg kg^{-1})	2.99 ± 0.08	Sufficient		
Cu (mg kg^{-1})	4.70 ± 2.83	Sufficient		
B (mg kg^{-1})	1.71 ± 0.07	Sufficient	Hot water extraction and spectrophotometry (Azomethane-H method)	Gupta (1967) [29]
Biological properties				
Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1})	38.62	-	Reduction of 3% TTC to methanol soluble formazon (TPF) and estimation using spectrophotometry	Lenhard (1956) [30]

Assessment of soil fertility status of experimental area

Field experiment soil was classified as Loamy, kaolinitic, isohyperthermic, Typic Kandiustults. The soil test results of the representative sample from the experimental area is furnished in Table 3. The soil was acidic in reaction, medium in organic carbon content (1.13 ± 0.08%), available N and K. The available P content was very high in the experiment site. Among the secondary nutrients, Ca and S were sufficient and Mg alone was deficient (47.34 ± 5.14 mg kg^{-1}). Fe, Mn, Zn, Cu and B were found to be in sufficient range.

Effect of treatments on nutrient use efficiency

The results of nutrient use efficiencyare presented in Table 4. The highest nutrient use efficiency of 50.4% was recorded in the BC @ 10 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}), followed by BC @ 5 kg plant^{-1} +75% NPK as per POP (T_4) with a value of 31.07%. Blackwell *et al.* (2009) [7] reported application of biochar had both direct and indirect influence on physical, chemical and biological properties, which can have impacts on plant growth, nutrient use efficiency and yield.

Table 4: Effect of treatments on nutrient use efficiency (NUE)

Treatments	Nutrient use efficiency (%)
T_1- Package of practices recommendation	0
T_2- BC @ 5 kg plant^{-1} + NPK as per POP	13.04
T_3- BC @ 10 kg plant^{-1} + NPK as per POP	11.11
T_4- BC @ 5 kg plant^{-1} +75% NPK as per POP	31.07
T_5- BC @ 10 kg plant^{-1} + 75% NPK as per POP	9.98
T_6- FYM 10 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR*)	18.35
T_7- BC @ 5 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR*)	2.41
T_8- BC @ 10 kg plant^{-1} + (NPK + secondary & micronutrients as per STBR*)	13.04
T_9- BC @ 5 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR*)	25.28
T_{10}- BC @ 10 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR*)	50.40
T_{11}-BC alone 10 kg plant^{-1}	0

*BC-Biochar, FYM-Farm yard manure, STBR-Soil test based recommendation

Effect of treatments on bunch yield and bunch characters of banana

The total dry matter production (12742.15 kg ha^{-1}) was significantly higher with biochar (10 kg $plant^{-1}$) with 75% of STBR followed by 5 kg biochar+ 75% NPK as per POP (Table 5). Addition of nutrients are necessary for good crop growth and yield (Table 4). Biochar @ 10kg $plant^{-1}$ added with 75% of STBR fertilizer nutrients resulted in the highest bunch weight (9.34 kg $plant^{-1}$), number of hands per bunch (5.25), number of fingers per bunch (46.16) and both length (22.83 cm) and girth (12.73 cm) of the index finger (Table 5), followed by biochar (5kg $plant^{-1}$) with 75% NPK as per POP. This implies that the chemical properties of the soil improves readily as available essential nutrients in conjunction with biochar was capable of supplying the required nutrients for crop growth and production (Gaskin *et al*., 2010 [9] and Karthik *et al*. 2019 [31]).

Table 5: Effect of treatments on bunch yield and bunch characters of banana

Treatments	Total dry matter production (kg)	Weight of bunch (kg)	Number of hands $bunch^{-1}$	Number of fingers $bunch^{-1}$	Index Finger	
					Length (cm)	Girth (cm)
T_1- Package of practices recommendation	7773.24 ^{ef}	6.21 ^{fg}	4.25 ^{de}	36.83 ^{de}	19.08 ^{f}	11.76 ^{d}
T_2- BC @ 5 kg $plant^{-1}$ + NPK as per POP	10648.28 ^{bc}	7.02 ^{cde}	5.25 ^{a}	45.33 ^{ab}	19.58 ^{ef}	12.55 ^{abc}
T_3- BC @ 10 kg $plant^{-1}$ + NPK as per POP	8197.88 ^{de}	6.90 ^{def}	5.00 ^{abc}	40.00 ^{cd}	20.54 ^{d}	12.22 ^{c}
T_4- BC @ 5 kg $plant^{-1}$ +75% NPK as per POP	12354.96 ^{a}	8.14 ^{b}	5.25 ^{a}	44.33 ^{abc}	22.04 ^{b}	12.64 ^{ab}
T_5- BC @ 10 kg $plant^{-1}$ + 75% NPK as per POP	9979.23 ^{c}	6.83 ^{def}	4.75 ^{bc}	34.50 ^{e}	21.33 ^{bc}	12.24 ^{c}
T_6- FYM 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	11216.00 ^{b}	7.35 ^{bcd}	5.15 ^{ab}	45.50 ^{a}	20.75 ^{cd}	12.66 a
T_7- BC @ 5 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	8910.77 ^{d}	6.36 ^{ef}	4.75 ^{bc}	39.16 ^{d}	20.08 ^{de}	12.24 ^{c}
T_8- BC @ 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	10015.52 ^{c}	7.02 ^{cde}	4.60 ^{cd}	39.50 ^{d}	20.41 ^{d}	12.30 ^{bc}
T_9- BC @ 5 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR*)	11086.92 ^{b}	7.78^{bc}	5.00 ^{abc}	41.00 ^{bcd}	21.66 ^{b}	12.54 ^{abc}
T_{10}- BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR*)	12742.15 ^{a}	9.34 ^{a}	5.25 ^{a}	46.16 ^{a}	22.83 ^{a}	12.73 ^{a}
T_{11}- BC alone 10 kg $plant^{-1}$	6914.02 ^{f}	5.44 ^{g}	4.00 ^{e}	34.33 ^{e}	18.25 ^{g}	10.35 ^{e}
SEm (±)	467.13	0.37	0.20	2.10	0.36	0.15
CD (0.05)	974.44	0.79	0.42	4.40	0.76	0.33

*BC-Biochar, FYM-Farm yard manure, STBR-Soil test based recommendation

Economic analysis

Details regarding the economic analysis are presented in Table 6. The BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) treatment registered the highest gross income (1188200 Rs ha^{-1}), net returns (689336.25 Rs ha^{-1}) and B:C ratio (2.38) compared to all other treatments. Galinato *et al*. (2010) [32] reported biochar will be promoted as a technology for carbon sequestration and market price of biochar is low enough so that farmers could earn a profit by resorting to application of biochar to the crop.

Table 6: Effect of treatments on gross income, net returns and B: C ratio of the treatments

Treatments	Gross income (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1- Package of practices recommendation	807300	191235.00	1.31
T_2- BC @ 5 kg $plant^{-1}$ + NPK as per POP	912600	286535.00	1.46
T_3- BC @ 10 kg $plant^{-1}$ + NPK as per POP	897000	405115.45	1.82
T_4- BC @ 5 kg $plant^{-1}$ +75% NPK as per POP	1058200	556684.50	2.11
T_5- BC @ 10 kg $plant^{-1}$ + 75% NPK as per POP	887900	392458.45	1.79
T_6- FYM 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	955500	484140.00	2.03
T_7- BC @ 5 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	826800	402940.00	1.95
T_8- BC @ 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR*)	912600	441240.00	1.94
T_9- BC @ 5 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR*)	1011400	501136.25	1.98
T_{10}- BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR*)	1188200	689336.25	2.38
T_{11}- BC alone 10 kg $plant^{-1}$	707200	153500.00	1.28

*BC-Biochar, FYM-Farm yard manure, STBR-Soil test based recommendation

Conclusion

It is concluded that application of biochar @ 10 kg $plant^{-1}$ coupled with 75% (NPK + secondary & micronutrients as per STBR) treatments enhanced total dry matter production (12742.15 kg ha^{-1}), weight of bunch (9.34 kg), number of hands per bunch (5.25), number of fingers per bunch (46.16), length (22.83 cm) and girth (12.73 cm) of the index finger, nutrient use efficiency (50.4%) and B:C ratio (2.38). Thus biochar facilitates a quarter dose reduction in soil test based fertilizer application, by way of fertilizer input coupled with an enhanced nutrient use efficiency. It has further led to realising a higher economic output in terms of bunch yield with profitable net returns in banana.

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