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Biochar for Soil Health Enhancement

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Field experiments were conducted to study the effect of biochar with/without FYM and inorganic fertilizers on soil productivity of cotton – maize – cowpea based cropping system and to examine the direct, cumulative and residual effects of biochar on soil properties at field No.36 B, Eastern block, TNAU, Coimbatore, on an Inceptisol belongs to Periyanaickenpalayam series and *Vertic Ustropept* **in USDA classification. The study reveals that application of biochar irrespective of levels, increased the available N, P and K of the post harvest clay loam soil of cotton. The effect was increased with corresponding increase in the rate of application. Significant improvement was found when biochar was applied in conjunction with fertilizers and FYM. Among the treatments, the trend of results were significantly higher in biochar @ 10 t + 100 % NPK + FYM followed by biochar @ 10 t + 75% NPK + FYM treatment which was statistically on par with biochar @ 7.5 t + 100 % NPK + FYM treatment. Similar trend of direct effect was registered in the post harvest soil of maize grown under both cumulative (continuous application) and residual (one time application) studies. However, the effect was higher under cumulative study than the residual study. Similar trend of results were also registered in the post harvest soil of cowpea under both the cumulative residual (residual effect of continuous application) and second residual (second residual effect of one time application) studies. A significant improvement in the soil properties of post harvest soil of cowpea under second residual study was also recorded. Thus, proving the biochar's ability to sustain the soil fertility over long run.**

Key words: Biochar, Soil health, Residual and cumulative effect

Biochar refers to biomass-derived charcoal, obtained when biomass is "baked" under low or no oxygen conditions (pyrolysis). Biochar holds promise as a tool for improving soil fertility and sequestering carbon (C) in soil among other potential benefits. Use of biochar in agriculture is not new; in ancient times farmers used it to enhance the production of agricultural crops. One such example is the slash and burn cultivation, which is still being practiced in some parts of North East India. Research has shown that crop yields can be improved by biochar application but most data available to date is for single crop. Much interest exists for recommendation of biochar for cropping sequence rather than for mono cropping system. A series of laboratory and field experiments were conducted to examine the direct, cumulative and residual effects of biochar on soil properties of cotton – maize – cowpea based cropping system.

Material and Methods

Field experiments were conducted during 2014-15 to study the effect of biochar with/without FYM and inorganic fertilizers on soil productivity of cotton – maize – cowpea based cropping system and to examine the direct, cumulative and residual effects of biochar on soil properties at field No.36 B, Eastern block, TNAU, Coimbatore, on an Inceptisol belongs to Periyanaickenpalayam series and Vertic Ustropept in USDA classification. Totally five field experiments were conducted; of which one was with cotton to study the direct effect of biochar, two in maize to assess the effect of continuous (cumulative) application of biochar and residual effect of biochar and two in cowpea for examining the longtime residual effect and cumulative residual effect of biochar.

The experiment was conducted in split plot design with three replications, there were four levels of fertilizers *viz.,* control (M_1), 100 % NPK (M_2), 100 % NPK + FYM (M_3) and 75 % NPK + FYM (M_4) in main plot treatments and five levels of biochar (0, 2.5, 5.0, 7.5 and 10 t ha^{-1}) in sub – plot treatments . The fertilizer applied to cotton was 120:60:60 kg ha^{-1}; and for maize was 250:75:75 kg ha^{-1} and cowpea was 250:75:75 kg ha^{-1} of N, P_20_5 and K_20 along with / without FYM @ 12.5 t ha^{-1}. The fertilizers were applied in splits as per crop production guide.

To study the cumulative effect (residual + fresh addition effect) of biochar on maize, the biochar was applied consequently two times, one during cotton crop and another during maize crop in the same plot at same rate. To study the residual effect of biochar (biochar applied to the cotton crop) on maize crop, the experiment was carried out without addition of biochar but with addition of fertilizers. After the cotton and maize crops the cowpea crop was raised to study the cumulative residual and second residual effects of biochar in the same experimental field without disturbing treatment plots of the previous crop (maize)

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under the split plot design. The experiment was carried out, without application of biochar treatments (sub- plot treatments) but with addition of fertilizers treatments (main plot treatments).

Results and Discussion

Direct effect of biochar in post harvest soil available nitrogen content after cotton crop

The available nitrogen was conspicuously increased by about nine per cent due to the application of biochar @ 10 t ha^{-1} over the unamended control. Both FYM and fertilizers along with biochar at all the levels enhanced the available nitrogen content in post harvest cotton soil. The higher nutrient availability for plants could be due to the result of both the direct nutrient additions by the biochar and grater nutrient retention. Since, biochar has high surface area, highly porous, variable charge organic material that has the potential to increase soil water-holding capacity, cation exchange capacity, surface sorption capacity and base saturation when added to soil. Also biochar additions to soil have the potential to alter soil microbial populations and shift functional groups in soil organic compounds. Similar findings were reported by Lehmann *et al*. (2003), Keech *et al.* (2005), Liang *et al*. (2006), and Sohi *et al*. (2009). Furthermore, this has been attributed to a high content of easily decomposable cellulose present in the FYM, which forms a readily available energy source for microorganisms to multiply and immobilize nitrogen. Also, the addition of fertilizer nitrogen could have reduced the loss of N, through immobilization of N or formation of ammonia complexes with the inorganic constituents of fertilizer nitrogen (Singh, 1987) which might be the reason for high content of available N in biochar @ 10 t + 100% NPK + FYM treatment.

Table 1. Physical and chemical properties of Prosopis biochar

Characters	Values
Physical properties	
Bulk density (mg m^{-3})	0.41
Particle density (mg m^{-3})	0.98
Percent pore space (%)	58.2
Moisture content (%)	1.46
Water holding capacity (%)	135
Chemical properties	
pH	9.08
EC(d Sm^{-1})	3.20
Cation exchange capacity (c mol (P^+) kg^{-1})	18.20
Total carbon (g kg^{-1})	78.20
Total Nitrogen (g kg^{-1})	1.20
C:N ratio	65.20
Total Phosphorus (g kg^{-1})	1.36
Total potassium (g kg^{-1})	15.70
Total sulphur (g kg^{-1})	3.54
Sodium (g kg^{-1})	36.00
Calcium (g kg^{-1})	10.20
Magnesium (g kg^{-1})	0.31

Table 2. Initial soil sample analysis

EC (d Sm^{-1})	0.34
pH	8.68
CEC (cmol (P^+) kg^{-1})	28.9
Organic carbon (g kg^{-1} of soil)	2.80
Total nitrogen (%)	0.154
Total nhosphorus (%)	0.065
Total notassium (%)	0.400
Available Nutrients	
Nitrogen (kg ha^{-1})	252.0
Phosphorus (kg ha^{-1})	20.0
Potassium (kg ha^{-1})	341.0

Direct effect of biochar in post harvest soil available phosphorus content after cotton crop

A significant improvement in the status of available phosphorus was observed due to the application of biochar alone and biochar along with fertilizers and FYM treatments irrespective of biochar levels. The adsorption of both organic and inorganic compounds by biochar in soil environments alters the surface properties of the biochar (Liang *et al.*, 2006). Complexation of polyvalent metal cations by carboxylate and/or other oxygen-containing surface functional groups of biochar can transform a surface charge site from negative to positive, effectively creating anion exchange sites. Thus, increase the P availability. Steiner *et al*. (2007) also reported beneficial impact of biochar on the plant-available P in soils enriched with biochar, which in contrast to NH4, is not a characteristics generally associated with soil organic matter, in the context of nutrient availability, the impact of biochar addition on pH may be important. The increase in pH and CEC increased the availability of P in the soil. Similar trend of result was also observed by Tryon (1948) and Glaser *et al*. (2002). Further, the addition of manures with

Table 3. Effect of treatment on soil available nitrogen kg ha^{-1} at post harvest of cotton

Rec. Fertilizers (kg ha^{-1})	Biochar levels (t ha^{-1})					Mean
	S_1 Control	S_2 B @ 2.5	S_3 B @ 5.0	S_4 B @ 7.5	S_5 B @ 10.0	
M_1 (Control)	213.3	218.5	222.2	227.4	231.6	222.6
M_2 (100%)	221.2	227.4	231.3	233.6	235.5	229.8
M_3 (100% + FYM)	225.3	231.4	236.5	238.2	243.6	235.0
M_4 (75% + FYM)	223.4	229.5	234.3	236.6	240.2	232.8
Mean	220.8	226.7	231.1	234.0	237.7	
	M	S	M at S	S at M		
SEd	2.56	3.02	5.97	6.03		
CD (0.05)	6.27	6.14	12.61	12.28		

Table 4. Residual and cumulative effect of treatments on available nitrogen (kg ha^{-1}) status in post harvest soil of maize

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											Mean
	S_1	S_2	S_3	S_4	S_5	**Mean**	S_1	S_2	S_3	S_4	S_5	
	Biochar residual						Biochar cumulative					
M_1	199.5	205.5	210.6	215.5	221.4	210.5	199.5	220.6	225.1	231.4	237.3	222.8
M_2	205.2	216.8	221.5	226.7	231.4	220.3	205.2	231.4	236.4	242.1	246.2	232.3
M_3	208.8	219.2	224.6	229.4	234.5	223.3	208.8	234.6	239.4	244.4	249.3	235.3
M_4	206.6	217.3	222.4	227.6	232.7	221.3	206.6	232.8	237.5	242.3	247.4	233.3
Mean	205.0	214.7	219.8	224.8	230.0		205.0	229.9	234.6	240.1	245.1	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	2.46	2.87	5.69	5.73					2.65	3.04	6.04	6.07
CD (0.05%)	6.02	5.84	12.02	11.68					6.48	6.18	12.78	12.37

biochar might have increased the solubilization of phosphate due to decomposition processes of easily degradable portion of FYM might have reduced the binding energy and phosphorus sorption capacity of

Table 5. Second residual and cumulative residual effect of treatments on nitrogen (kg ha^{-1}) in post harvest soil of cowpea

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											Mean
	S_1	S_2	S_3	S_4	S_5	**Mean**	S_1	S_2	S_3	S_4	S_5	
	Biochar residual						Biochar cumulative					
M_1	182.5	184.8	187.1	189.4	192.0	187.2	182.5	203.4	220.4	223.3	232.4	212.4
M_2	191.4	193.8	198.2	200.1	203.1	197.3	191.4	222.3	225.6	233.3	237.2	222.0
M_3	205.6	208.6	213.8	216.2	219.1	212.7	205.6	225.5	228.4	234.4	238.8	226.5
M_4	201.2	203.4	208.7	211.4	214.3	207.8	201.2	223.4	226.7	233.4	236.4	224.2
Mean	195.2	197.7	202.0	204.3	207.1		195.2	218.7	225.3	231.1	236.2	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	2.18	2.65	5.22	5.30					2.54	2.90	5.78	5.80
CD (0.05%)	5.33	5.40	11.00	10.79					6.22	5.91	12.23	11.82

the manure, favouring higher available P content in the soil. It is also evident from the results that the application of biochar along with fertilizers and manures (biochar @ 10 t + 100% NPK + FYM) had

Table 6. Effect of treatment on soil available phosphorus kg ha^{-1} at post harvest of cotton

Rec. Fertilizers (kg ha^{-1})	Biochar levels (t ha^{-1})					Mean
	S_1 Control	S_2 B @ 2.5	S_3 B @ 5.0	S_4 B @ 7.5	S_5 B @ 10.0	
M_1 (Control)	15.21	15.83	16.54	17.02	17.45	16.41
M_2 (100%)	15.92	16.54	17.21	17.73	18.05	17.09
M_3 (100% + FYM)	16.53	16.84	17.91	18.42	18.75	17.69
M_4 (75% + FYM)	16.32	16.73	17.65	18.21	18.44	17.47
Mean	16.00	16.49	17.33	17.85	18.17	
	M	S	M at S	S at M		
SEd	0.19	0.23	0.45	0.45		
CD (0.05)	0.47	0.46	0.94	0.92		

further increased the available phosphorus contents of soil which might be ascribed to the availability of phosphorus from fertilizer source and increased biological activity.

Table 7. Residual and cumulative effect of treatments on available phosphorus (kg ha^{-1}) status in post harvest soil of maize

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											Mean
	S_1	S_2	S_3	S_4	S_5	**Mean**	S_1	S_2	S_3	S_4	S_5	
	Biochar residual						Biochar cumulative					
M_1	14.42	14.75	15.16	15.57	15.96	15.17	14.42	15.65	16.88	18.01	19.22	16.84
M_2	15.13	15.44	15.85	16.26	16.64	15.86	15.13	16.32	17.52	18.74	19.95	17.53
M_3	15.68	16.01	16.46	16.84	17.21	16.44	15.68	16.86	18.02	19.28	20.49	18.07
M_4	15.49	15.77	16.16	16.57	16.96	16.19	15.49	16.72	17.95	19.18	19.36	17.74
Mean	15.18	15.49	15.91	16.31	16.69		15.18	16.39	17.59	18.80	19.76	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	0.178	0.209	0.413	0.417					0.206	0.230	0.460	0.461
CD (0.05%)	0.436	0.425	0.873	0.850					0.503	0.469	0.975	0.938

Table 8. Second residual and cumulative residual effect of treatments on phosphorus (kg ha^{-1}) in post harvest soil of cowpea

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
	Biochar residual						Biochar cumulative					
M_1	13.05	13.32	13.64	13.95	14.22	13.64	12.05	14.55	15.76	16.95	18.15	15.49
M_2	14.05	14.35	14.69	14.94	15.25	14.66	13.05	15.23	16.41	17.63	18.82	16.23
M_3	14.78	15.05	15.40	15.69	16.02	15.39	13.78	15.76	17.00	18.14	19.35	16.81
M_4	14.56	14.85	15.16	15.44	15.78	15.16	13.56	15.68	16.87	18.09	18.24	16.49
Mean	14.11	14.39	14.72	15.01	15.32		13.11	15.31	16.51	17.70	18.64	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	0.162	0.193	0.381	0.386					0.193	0.429	0.436	0.428
CD (0.05%)	0.396	0.393	0.805	0.787					0.214	0.473	0.909	0.871

Direct effect of biochar in post harvest soil available potassium content after cotton crop

The status of available potassium was also found to be favourably influenced by biochar addition. Lehmann and Rondon (2006) also observed that high rates of biochar addition in the tropical environment have been associated with increased plant uptake of P, K, Ca Zn and Cu. This might be due to the biochar

Table 9. Effect of treatment on soil available potassium kg ha^{-1} at post harvest of cotton

Rec. Fertilizers(kg ha^{-1})	Biochar levels (t ha^{-1})					Mean
	S_1 Control	S_2 B @ 2.5	S_3 B @ 5.0	S_4 B @ 7.5	S_5 B @ 10.0	
M_1 (Control)	286.2	290.3	293.4	297.5	300.6	293.6
M_2 (100%)	289.7	292.5	296.6	300.4	302.5	296.3
M_3 (100% + FYM)	295.5	297.6	301.4	304.9	307.2	301.3
M_4 (75% + FYM)	292.5	295.4	299.2	304.1	305.6	299.4
Mean	291.0	294.0	297.7	301.7	304.0	
	M	S	M at S	S at M		
SEd	3.32	3.90	7.72	7.80		
CD (0.05)	NS	7.94	16.32	15.88		

was made by pyrolysis process and contained at least 0.3 per cent of ash and their application to soils registered an increase in availability of K. The effect of biochar with fertilizers and organic manures was highly significant at all levels of biochar wherein the highest available potassium content was recorded by the biochar @ 10 t + 100 % NPK + FYM treatment which was at par with biochar @ 10 t + 75 % NPK

Table 10. Residual and cumulative effect of treatments on available potassium (kg ha^{-1}) status in post harvest soil of maize

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											
	S_1	S_2	S_3	S_4	S_5	**Mean**	S_1	S_2	S_3	S_4	S_5	Mean
	Biochar Residual						Biochar Cumulative					
M_1	264.5	269.2	274.2	279.2	284.2	274.3	264.5	275.6	286.3	297.1	308.2	286.3
M_2	276.5	281.5	286.5	292.1	297.4	286.8	276.5	288.2	299.5	309.4	320.2	298.8
M_3	280.4	285.3	290.4	295.4	300.2	290.3	280.4	302.5	304.5	313.6	324.5	305.1
M_4	278.2	283.3	288.4	293.2	298.4	288.3	278.2	300.3	302.4	311.2	316.3	301.7
Mean	274.9	279.8	284.9	290.0	295.1		274.9	291.7	298.2	307.8	317.3	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	3.18	3.73	7.40	7.46					3.38	7.76	7.95	7.81
CD (0.05%)	7.79	7.60	15.63	15.20					3.90	8.26	16.41	15.91

+ FYM treatment. The present findings corroborated with the findings of Lehmann and Rondon (2006) and Rondon *et al*. (2007). Literature on the effect of biochar addition on nutrient availability is too voluminous; nevertheless, there is close agreement with findings of Chan *et al. (*2008), Silber (2010), Ding *et al*. (2010) and Laird *et al*. (2010)

Cumulative and residual effect of biochar on post harvest soil available nutrients after maize

In tune with direct effect, the available nutrients contents of post harvest soil of maize were also positively influenced by different levels of biochar application under both cumulative and residual studies. Significant improvement in the available N, P and K status at post harvest soil of maize was evidenced with the conjoint application of biochar with fertilizers and FYM (biochar @ 10 t + 100 % NPK + FYM) under both the studies. The treatments received fertilizers which could have resulted in increase in available nutrients status of soil might be due to the residual effect of added fertilizers. The effect was further improved with the application of FYM, which had not only increased the buildup of nutrients of the soil but also the ability of the soil to sustain the fertility status over long run. This result is consistent with the results of Sukartono *et al*. (2011) confirmed that higher nutrient concentrations of biochar and cattle manure treated plots compared to control is suggestive of the positive contribution of organic amendments to improve soil nutrient availability. However, to sustain these positive effects, cattle manure should be applied for every planting season, whereas a direct application of biochar can maintain these positive attributes for a longer period of time revealed by Islami *et al*. (2011). Among the studies cumulative study found to register significantly higher available nutrients than residual study.

Table 11. Second residual and cumulative residual effect of treatments on post harvest soil of cowpea

Rec. Fertilizers (kg ha^{-1})	Biochar Levels (t ha^{-1})											
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
	Biochar Residual						Biochar Cumulative					
M_1	250.5	255.5	260.8	266.2	271.0	260.8	240.5	269.4	280.6	290.5	302.2	276.6
M_2	261.4	266.6	271.6	277.5	282.8	272.0	251.4	282.5	293.3	303.4	315.2	289.2
M_3	264.6	269.6	274.2	280.5	286.6	275.1	254.6	297.1	300.2	308.8	316.6	295.5
M_4	262.7	267.4	272.6	277.4	274.3	270.9	252.7	294.4	297.2	300.3	311.1	291.1
Mean	259.8	264.8	269.8	275.4	278.7		249.8	285.9	292.8	300.8	311.3	
	M	S	M at S	S at M					M	S	M at S	S at M
SEd	3.01	3.52	6.99	7.05					3.33	7.55	7.71	7.57
CD (0.05%)	7.38	7.18	14.77	14.36					3.79	8.14	15.97	15.42

Cumulative and residual effect of biochar on post harvest soil available nutrients after cowpea

The cumulative residual and second residual effects of biochar on soil available nutrients viz., N, P and K was conspicuous in the succeeding post harvest soil of cowpea as well and the trend of results was similar to that of main crop. Comparing the studies, relatively higher available N, P and K was registered under cumulative residual than second residual study. Thus, in a nutshell, the biochar proved to be not only a conditioner but also a fertilizer.

It has become clear that biochar is likely more important as a soil conditioner and a driver of nutrient transformations and less so as a primary source of nutrients. Biochar can act as a soil conditioner enhancing plant growth by supplying and retaining nutrients and by providing other services such as improving soil physical and biological properties.

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