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Effect of Biochar on Soil Biological Properties and Growth of Groundnut in Red Sandy Loams of North Coastal Andhra Pradesh

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ABSTRACT

A field experiment was conducted in red sandy loam soils of North Coastal Andhra Pradesh to study the effect of bio char on soil microbial population, enzymatic activity and growth of groundnut crop (variety K-6) during *rabi*, 2018-19. Biochar application to soil significantly increased soil bacterial, fungal and actinomycetes population. In general the bacterial population increased from peg penetration to pod development. At pod development stage the highest number of bacterial count (39.0 x10^6 CFU g^{-1} soil) was observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with all the biochar applied treatments (T_3, T_4, T_6, T_7, T_8) and biochar applied @ 6 t ha^{-1} (T_5 & T_8) significantly increased the bacterial population as compared non-biochar applied treatments (T_1 & T_2). Fungal and actinomycetes population followed the similar trend of bacterial count. Soil urease activity was significantly superior in biochar applied treatments (T_3, T_4, T_5, T_6, T_7, T_8) as compared to non-biochar applied treatments (T_1 and T_2). With increased rates of biochar application the urease activity markedly increased in soil. Similar trend was noticed with respect to dehydrogenase, acid phosphatase and alkaline phosphatase enzymes in soil in response to addition of biochar. Slight increase in plant height was observed with bio char application but the increase was not significant. At pod development stage the highest leaf area index (3.16) was recorded in T_5 treatment (100% RDF + biochar @ 6 t ha^{-1}) which was significantly higher than T_1 (control), T_2 (100% RDF) and T_6 (75% RDF + biochar @ 2 t ha^{-1}). In general the dry matter accumulation increased from peg penetration to harvest. The highest dry matter accumulation of 2950.90 kg ha^{-1} and 6427.54 kg ha^{-1}, respectively at peg penetration and pod development stage was observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with T_3 (100% RDF + biochar @ 2 t ha^{-1}), T_4 (100% RDF + biochar @ 4 t ha^{-1}), T_8 (75% RDF + biochar @ 6 t ha^{-1}) treatments. Groundnut pod yield was highest (4019.58 kg ha^{-1}) in T_5 treatment receiving 100% RDF + biochar @ 6 t ha^{-1}, which was on par with T_4 (100% RDF + biochar @ 4 t ha^{-1}) and T_8 (75% RDF + biochar @ 6 t ha^{-1}).

Key words: *bio char, sandy loams, soil enzymes, groundnut.*

Biochar is the charcoal obtained by the low temperature pyrolysis of biomass, *i.e.*, by incomplete thermal decomposition of organic material under low oxygen conditions at relatively low temperatures (< 700°C). Unlike charcoal and similar materials, bio char is produced with the aim of being used as a soil amendment (Lehmann and Joseph, 2009). However, biochar is a more stable solid than the common organic conditioners, due to its very low degradation rate which is estimated as several hundred years for total degradation. Thus its potential effects on the chemical, physical and biological properties of the soil may extend over a long period of time (Atkinson *et al*., 2010). Most of the available studies focus on the biochemical effects of biochar on amended soil, including the nutrients that it makes available, as well as on its impact on CEC, pH, vegetative growth, crop yield and its carbon sequestration potential (Atkinson *et al*., 2010; Mukherjee and Lal, 2013). Incorporation of biochar into the soil may modify biological and enzymatic activities of soil and till to date, little attention has been paid to investigate the biochar-induced changes on biological properties of sandy loam soils.

Several studies have been carried out throughout the world to identify the effects of incorporating organic matter into the soil, and the resulting advantages for its biological properties are well known (Castellini *et al*., 2014). In recent years there has been increased use of bio char as an addition to agricultural soils, since it is potentially improving both crop productivity and soil quality (Vaccari *et al*., 2011; Baronti *et al*., 2014). It is an alternative that may be potentially integrated into sustainable agricultural systems. However an accurate evaluation of the biochar effects on the biological properties and enzymatic activities of the soil is highly essential, since the effects of excessively high inputs are difficult to remedy. There is only very limited information available on impact of biochar on biological properties and enzymatic activities in sandy loam soils, hence, present investigation was taken up.

MATERIAL AND METHODS

The present study was carried out during *rabi*, 2018-19. The experimental plot geographically lies in between 83^0 56.602^1 E longitude and 18^o 22.752^1 N latitude and at an altitude of above 12m MSL in the Agricultural College Farm,Naira, North Coastal Andhra Pradesh. The experimental soil was sandy loam in texture, neutral in reaction and low in organic carbon. Biochar was prepared under the low oxygen conditions by pyrolysis process with dried mesta sticks with 29.4 per cent recovery. The field experiment was laid in RBD with eight treatments using groundnut (Variety - Kadiri 6) as a test crop.

T_1 - Control
T_2 - 100% RDF (30-40-50) only
T_3 - 100% RDF + bio char @ 2 t ha^{-1}
T_4 - 100% RDF + bio char @ 4 t ha^{-1}
T_5 - 100% RDF + bio char @ 6 t ha^{-1}
T_6 - 75% RDF + bio char @ 2 t ha^{-1}
T_7 - 75% RDF + bio char @ 4 t ha^{-1}
T_8 - 75% RDF + bio char @ 6 t ha^{-1}

Organic carbon content of the soil samples was estimated by Walkley and Black (1934) wet digestion method. Microbial biomass was estimated by fumigation extraction technique (Sparling and West, 1988). Bacteria, fungi and actinomycetes population in soil was estimated as per the procedures outlined by Kapoor and Paroda (2007). Enzymatic activity was also determined by using the standard procedures *viz*., Urease (µg NH_4+ released g^{-1} soil 2 hrs^{-1}) as described by (Tabatabai and Bremner, 1972); Acid phosphatase and Alkaline phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1}) as described by Tabatabai and Bremner (1969); and Dehydrogenase (µg of TPF produced g^{-1}soil day^{-1}) as described by Casida *et al*. (1964).

Plant height (cm) was measured from the base of the plant to the top of the main shoot of the five labeled plants in each plot. Leaf area was measured by using leaf area meter and was expressed as leaf area index (LAI) using the formula suggested by Watson (1952). Plant samples for dry matter study were collected at peg penetration, pod development and harvest stages. At each sampling, five plants were uprooted at random in each treatment in the sampling row. These samples were shade dried followed by oven dried at 65°C till a constant weight was recorded. The dry weight of these samples was recorded. Later dry matter production was computed on hectare basis and expressed in kg ha^{-1}. Plants from the net plot area after threshing were sun dried till constant weight was obtained and their weight was recorded as per plot basis and later converted as haulm yield (kg ha^{-1}). Pods from the net plot area were cleaned and pod weight was recorded on the basis of dry pod yield kg per plot. Later the pod yield per net plot was computed on hectare basis and expressed in kg ha^{-1}.

RESULTS AND DISCUSSION

Organic carbon and microbial biomass of soil

The effect of biochar on soil organic carbon content (Table 1) indicated significant increase in organic carbon of soil in T_5 (100% RDF + biochar @ 6 t ha^{-1}), T_8 (75% RDF + biochar @ 6 t ha^{-1}), T_4 (100% RDF + biochar @ 4 t ha^{-1}) & T_7 (75% RDF + biochar @ 4 t ha^{-1}) treatments than other treatments (T_1, T_2, T_3, T_6). Increasing trend of organic carbon was noticed from peg penetration to harvest stage. At harvest stage, the highest organic carbon (0.54%) was observed in T_8 (75% RDF + biochar @ 6 t ha^{-1}) treatment which was on par with T_5 (100% RDF + biochar @ 6 t ha^{-1}) treatment (0.53%) and both the treatments were significantly higher to T_1 (control) and T_2 (100% RDF). The increased rates of application of biochar to soil significantly increased soil organic carbon content. Biochar being high organic carbon source, up on its application to the soil releases carbon into the soil system and also due to the mineralization of biochar adsorbed organic matter in soil system resulted in increased organic carbon content in the soil (Abrishemkesh *et al*., 2015). Furthermore biochar itself is a matrix of organic complex and its application to soil system increases soil organic carbon content (Elangovan *et al*., 2014)

Microbial biomass significantly influenced by biochar addition. The highest microbial biomass of 326.5 µg g^{-1} soil was noticed when bio char applied @ 6 t ha^{-1}+ 75% RDF (T_8) which is on par with T_5 (bio char @ 6 t ha^{-1}+ 100% RDF). The lowest microbial biomass observed in control (T_1). Microbial biomass markedly increased with increasing rates of bio char from 2 to 6 t ha^{-1}.

Microbial population in soil

Biochar application to soil significantly increased bacterial, fungal and actinomycetes population (Table 2). In general the bacterial population increased from peg penetration to pod development and then decreased towards harvest. At pod development stage the highest number of bacterial count (39.0 $x10^6$ CFU g^{-1} soil) was observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with all the biochar applied treatments (T_3, T_4, T_6, T_7, T_8) and were significantly superior to T_1 (control) and T_2 (100% RDF alone). The lowest bacterial population of 24.0 $x10^6$ CFU g^{-1} soil was found in T_1 (control) at pod development stage. Biochar application to soil allowed the development of bacteria in biochar treated soil as compared to control (Atkinson *et al*., 2010). Higher bacterial abundance in biochar added soils was due to higher availability of organic carbon for bacterial proliferation (Ming *et al*., 2016).

Table 1. Effect of bio char on oxidisable organic carbon and microbial biomass carbon in soil

Treatments	Soil oxidisable organic carbon (%)			Soil microbial biomass carbon (μg g^{-1})		
	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest
T_1	0.30	0.30	0.32	116.80	156.10	182.60
T_2	0.32	0.34	0.34	112.60	166.80	178.90
T_3	0.39	0.41	0.43	185.20	252.40	277.30
T_4	0.45	0.46	0.48	203.90	280.30	291.80
T_5	0.51	0.52	0.53	231.30	323.90	335.70
T_6	0.40	0.41	0.44	178.50	236.20	271.50
T_7	0.45	0.47	0.48	195.30	269.70	290.20
T_8	0.52	0.51	0.54	239.10	326.50	349.40
SEm±	0.03	0.04	0.04	14.90	17.10	13.90
CD (p=0.05)	0.09	0.12	0.13	45.20	51.50	41.90
CV (%)	10.82	10.22	11.36	9.96	9.92	11.05

Table 2. Effect of bio char on microbial population (CFU g^{-1} soil) in soil

Treatments	Bacteria (×10^6)			Fungi (×10^3)			Actinomycetes (×10^5)		
	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest
T_1	21.33	24.00	21.00	3.00	3.00	2.67	8.33	7.33	6.67
T_2	22.67	25.33	24.00	3.67	4.67	4.00	9.67	10.33	9.67
T_3	32.00	35.67	32.67	4.33	4.67	4.33	14.00	15.67	15.00
T_4	33.67	37.67	35.33	4.67	6.33	5.67	15.33	17.00	15.67
T_5	37.00	39.00	37.33	6.33	8.33	7.00	17.00	19.67	19.33
T_6	30.67	34.33	31.33	4.00	5.33	4.67	12.33	13.67	12.67
T_7	32.33	35.33	34.00	4.67	5.67	5.33	13.33	15.00	14.00
T_8	34.00	38.66	36.33	5.00	7.33	6.00	15.33	17.33	17.00
SEm±	2.17	1.87	1.92	0.37	0.43	0.36	0.75	1.09	0.92
CD (p=0.05)	6.60	5.77	5.83	1.12	1.33	1.11	2.28	3.33	2.79
CV (%)	12.39	10.97	10.57	14.37	13.40	12.93	10.02	13.13	11.70

In general the fungal population increased from peg penetration to pod development and then decreased towards harvest. At pod development stage the highest fungal count (8.33 x10^3 CFU g^{-1} soil) was observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with T_8 (7.33 x10^3 CFU g^{-1} soil) where 75% RDF + biochar @ 6 t ha^{-1} was applied and both T_5 and T_8 were significantly superior to T_1 (control), T_2 (100% RDF alone), T_3 (100% RDF + biochar @ 2 t ha^{-1}), T_4 (100% RDF + biochar @ 4 t ha^{-1}), T_6 (75% RDF + biochar @ 2 t ha^{-1}) and T_7 (75% RDF + biochar @ 4 t ha^{-1}). Biochar application to soil lead to increased soil organic carbon which may serve as an energy source to fungi and secretion of flavanoids, sesquiterpenes and strigolactones by plant roots might resulted in increased colonization of plant roots by AM fungi and increased spore germination and hyphal branching of AM fungi (Xie *et al*. 1995)

At pod development the highest number of actinomycetes population (19.67 x10^5 CFU g^{-1} soil) was observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with T_8 (75% RDF + biochar @ 6 t ha^{-1}) and both T_5 and T_8 were significantly superior to T_1 (control), T_2 (100% RDF), T_3 (100% RDF + biochar @ 2 t ha^{-1}), T_6 (75% RDF + biochar @ 2 t ha^{-1}) and T_7 (75% RDF + biochar @ 4 t ha^{-1}). The lowest

Table 3. Effect of bio char on enzyme activity in soil

Treatments	Urease ($\mu g\ NH_4^+\ g^{-1} h^{-1}$)			Dehydrogenase (μg TPF $g^{-1} day^{-1}$)			Acid phosphatase (μg PNP $g^{-1} hr^{-1}$)			Alkaline phosphatase (μg PNP $g^{-1}\ hr^{-1}$)		
	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest
T_1	84.00	88.33	91.00	8.02	8.78	10.55	15.09	14.76	17.76	16.21	17.80	19.13
T_2	88.33	94.33	106.33	8.96	9.29	10.63	16.57	17.70	20.37	17.70	18.43	21.43
T_3	108.67	115.00	125.67	11.18	13.56	16.51	20.37	21.90	26.40	24.43	27.77	30.43
T_4	118.67	125.00	135.00	13.00	14.72	17.02	26.33	31.89	35.22	26.50	29.47	32.47
T_5	126.33	134.33	140.67	14.48	16.15	19.82	28.60	34.89	38.23	29.77	31.43	35.43
T_6	102.33	110.67	117.67	10.73	12.40	13.06	25.40	24.61	27.61	22.63	24.30	28.30
T_7	112.67	116.00	122.33	12.37	13.57	15.60	26.67	28.86	33.56	25.40	28.40	30.40
T_8	123.33	129.77	138.67	14.29	16.02	19.39	27.60	31.56	33.66	27.30	29.30	31.63
SEm±	7.08	7.05	7.68	0.67	0.94	0.83	1.79	1.57	1.73	1.67	1.98	1.92
CD (p=0.05)	21.49	21.52	23.30	2.03	2.88	2.53	5.44	4.78	5.25	5.08	6.03	5.83
CV (%)	11.35	10.76	10.89	10.01	12.59	9.46	13.32	10.60	10.30	12.23	13.31	11.62

actinomycetes population (7.33×10^5 CFU g^{-1} soil) was found in T_1 (control) at pod development stage. Increased soil pH due to biochar application, caused increased actinomycetes population in soil (Watzinger *et al*., 2014). Ability of actinomycetes to degrade persistant and complex substrates like biochar could be a reason for increased actinomycetes population (Johnsen *et al*., 2002 and Yun *et al*. (2017).

Soil enzymes activity

The impact of biochar addition on soil enzyme activity (table 3) indicated significant influence from peg penetration to harvest. The highest urease activity of 126.33 $\mu g\ NH_4^+\ g^{-1}\ 2hrs^{-1}$, 134.33 $\mu g\ NH_4^+\ g^{-1}\ 2hrs^{-1}$ and 140.67 $\mu g\ NH_4^+\ g^{-1}\ 2hrs^{-1}$, at peg penetration, pod development and harvest stages of groundnut respectively was found in T_5 (100% RDF + biochar addition @ 6 t ha^{-1}) which was significantly higher than control (T_1) and 100% RDF treatment (T_2). Urease activity increases with increased rates of biochar application from 2 t ha^{-1} to 6 t ha^{-1}. Increase in urease activity with the addition of biochar was earlier reported by Du *et al*. (2014). Highest dehydrogenase enzyme activity of 14.48 μg TPF g^{-1} day^{-1} was recorded in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with T_8 and T_4 and significantly higher to T_1 (control), T_2 (100% RDF only) and T_3 (100% RDF + biochar @ 2 t ha^{-1}) and T_6 (75% RDF + biochar @ 2 t ha^{-1}) and T_7 (75% RDF + biochar @ 4 t ha^{-1}) at peg penetration stage. Volatile matter content in biochar led to higher dehydrogenase activity with higher rates of its addition (Ouyang *et al*., 2014).

Biochar application significantly influenced the acid and alkaline phosphatase activities in soil. The highest acid and alkaline phosphatase activities of 38.23 μg PNP $g^{-1}\ hr^{-1}$ and 29.77 μg PNP $g^{-1}\ hr^{-1}$ were observed in T_5 (100% RDF + biochar @ 6 t ha^{-1}). The increase in acid and alkaline phosphatase activity by biochar addition could be due to enhancement of enzyme function caused by interaction with biochar (Jindo *et al*., 2012, Chen *et al*., 2013).

Table 4. Effect of bio char on growth parameters, dry matter accumulation and yield parameters of groundnut

Treatments	Plant height (cm)			Leaf area index			Dry matter accumulation ($kg\ ha^{-1}$)		Pod yield at harvest ($kg\ ha^{-1}$)
	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	Harvest	Peg penetration	Pod development	
T_1	31.57	43.17	44.00	1.62	2.40	2.33	2134.70	4972.70	2876.70
T_2	34.17	44.00	47.17	1.85	2.68	2.45	2544.60	5643.30	3436.80
T_3	34.17	45.17	48.00	2.01	2.85	2.61	2669.10	5857.90	3538.60
T_4	35.00	46.33	49.18	2.05	2.93	2.69	2834.90	6213.70	3886.80
T_5	35.67	47.17	50.13	2.19	3.16	2.73	2950.90	6427.50	4019.60
T_6	31.00	44.00	45.00	1.83	2.61	2.40	2507.40	5473.00	3392.90
T_7	32.00	44.33	45.67	1.96	2.75	2.42	2732.10	5610.60	3613.00
T_8	33.33	45.00	45.83	1.98	2.83	2.58	2784.30	5705.80	3782.50
SEm±	2.12	2.59	2.66	0.07	0.09	0.07	117.20	244.10	157.00
CD (p=0.05)	NS	NS	NS	0.21	0.26	0.23	355.50	640.50	476.30
CV (%)	11.10	9.89	9.20	6.51	6.63	5.32	7.67	7.36	7.60

Plant growth and yield parameters

Biochar application to soil caused slight increase in plant height but was not significant (Table 4). At harvest stage T_5 treatment (100% RDF + bio char @ 6 t ha^{-1}) recorded higher plant height @ 50.13 cm than other treatments and lower plant height of 44 cm was recorded in T_1 (control). The leaf area index increased from peg penetration to pod development. At pod development stage the highest LAI (3.16) was recorded in T_5 treatment (100% RDF + biochar @ 6 t ha^{-1}) which was significantly higher than T_1 (control), T_2 (100% RDF) and T_6 (75% RDF + biochar @ 2 t ha^{-1}). In general the dry matter accumulation increased from peg penetration to harvest (Table 4). Highest dry matter accumulation of 2950.90 kg ha^{-1} and 6427.54 kg ha^{-1}, respectively at peg penetration and pod development stage was observed in T_5 (100% RDF + biochar @6 t ha^{-1}) which was on par with T_3 (100% RDF + biochar @ 2 t ha^{-1}), T_4 (100% RDF + biochar @ 4 t ha^{-1}), T_8 (75% RDF + biochar @ 6 t ha^{-1}) treatments. However, T_5 was significantly superior to treatments T_6 (75% RDF + biochar @ 2 t ha^{-1}), T_7 (75% RDF + biochar @ 4 t ha^{-1}), T_2 (100% RDF) and T_1 (control). Application of biochar resulted in better soil physical environment and also increased availability of nutrients by improving biological activity which resulted in higher plant growth and biomass production. (Rao *et al*., 2017). Lehmann *et al*. (2003) suggested that biochar not only improve the availability of nutrients but also promote vegetative growth by improving the photosynthetic pigment production and hence increases dry matter production.

Effect of biochar on groundnut pod yield (Table 4) revealed that highest pod yield (4019.58 kg ha^{-1}) in T_5 (100% RDF + biochar @ 6 t ha^{-1}) which was on par with T_4 (3886.77 kg ha^{-1}), T_8 (3782.48 kg ha^{-1}), T_7 (3613.02 kg ha^{-1}). However, the pod yield of groundnut in T_5 was significantly higher than that of T_1 (control), T_2 (100% RDF), T_3 (100% RDF + biochar @ 2 t ha^{-1}) and T_6 (75% RDF + biochar @ 2 t ha^{-1}). The increase in pod yield with the biochar addition was due to increased retention of water and nutrients in soil, availability of soil bound nutrients through chelation with concomitant absorption by the plants (Agegnehu *et al*., 2015).

CONCLUSION

Biochar application @ 2 to 6 t ha^{-1} significantly improved the microbial population and soil enzyme activities (urease, phosphomonoesterases and dehydrogenase) in sandy loam soils. Further, application of bio char @ 6 t ha^{-1} + 100% RDF significantly increased the growth, biomass production and groundnut pod yield which was found to be on par with the treatments 4 t ha^{-1} + 100% RDF and 6 t ha^{-1} + 75% RDF.

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LITERATURE CITED

Abrishamkesh S, Gorji M, Marandi G H and Pourbabaee 2015 Effects of rice husk bio char application on the properties of alkaline soil and lentil growth. *Plant Soil and Environment.* 61(11): 475-482.

Agegnehu G, Bass A M, Nelson P N, Muirhead B, Wright G and Bird M I 2015 Bio char and bio char-compost as soil amendments: Effects on peanut yield, soil properties and greenhouse gas emissions in tropical north Queensland, Australia. *Agriculture, Ecosystems and Environment.* 213: 72-85.

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

Baronti S, Vaccari F P, Miglietta F, Calzolari C, Lugato E, Orlandini S, Pini R, Zulian C, Genesio L 2014 Impact of bio char application on plant water relations in *Vitis vinifera* (L.). *European Journal of Agronomy*. 53:38–44.

Casida L E, Klein D A and Santro J 1964 Soil dehydrogenase activity. *Soil Science*. 98: 371-376.

Castellini M, Pirastru M, Niedda M and Ventrella D 2014 Comparing physical quality of tilled and no- tilled soils in an almond orchard in South Italy. *Italian Journal of Agronomy*. 8: 149–157.

Chen J H, Liu X Y, Zheng J W, Lu H F, Chi Z Z, Pan G X, Li L Q, Zheng J F, Zhang X H, Wang J F and Yu X Y 2013 Bio char soil amendment increased bacterial but decreased fungal gene abundance with shifts in community structure in a slightly acid rice paddy from southwest china. *Applied Soil Ecology*. 71:33-44.

Du Z, Wang Y, Huang J, Lu N, Liu X, Lou Y and Zhang Q 2014 Consecutive bio char application alters soil enzyme activities in the winter wheat-growing season. *Soil Science.* 179(2): 75-83.

Elangovan R and Chandrasekhran N 2014 Effect of bio char application on soil properties and quality parameters in cotton. *An Asian Journal of Soil Science.* 9(1): 1-10.

Jindo K, Suto K, Matsumoto K, Garcia C, Sonoki T and Sanchez-Monedero, M A 2012 Chemical and biochemical characterisation of bio char blended composts prepared from poultry manure. *Bioresource Technology*. 110: 396-404.

Johnsen A R, Winding A, Karlson U and Roslec P 2002 Linking of microorganisms to phenanthrene metabolism in soil by analysis of (13)C- labeled cell lipids. *Applied and Environmental Microbiology*. 68: 6106-6113.

Kapoor K K and Paroda S 2007 Experimental soil micribiology.CBS Publishers and Distributors., New Delhi: 62 -64.

Lehmann J and Joseph S 2009 Bio char for Environmental Management: *Science and Technology*. Earthscan: London, UK.

Lehmann J, Da Silva J P, Nehls T, Zech W, Glaser B 2003 Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central amazon basin: fertilizer, manure and charcoal amendements. *Plant and Soil*. 249: 343-357.

Ming L I, Ming L I U, Zhong-pei L I, Chun-yu J and Meng W U 2016 Soil N transformation and microbial community structure as affected by adding bio char to a paddy soil of subtropical china. *Journal of Integrative Agriculture.* 15(1): 209-219.

Mukherjee A and Lal R 2013 Bio char Impacts on Soil Physical Properties and Greenhouse Gas Emissions. *Agronomy*. 3: 313–339.

Ouyang L, Tang Q, Yu L and Zhang R 2014 Effects of amendment of different bio chars on soil enzyme activities related to carbon mineralization. *Soil Research.* 52: 706-716.

Rao L P, Jayasree G, Prathiba G and Ram Prakash T 2017 Effect of soil amendments on dry matter production, nutrient uptake and yield in maize (*Zea mays*. L). *Environment and Ecology.* 35(3A): 1898-1902.

Sparling G P and West A W 1988 A direct extraction method to estimate soil microbial biomass in soils following recent additions of wheat straw and characterization of the biomass that develops. *Soil Biology and Biochemistry*. 22: 685-694.

Tabatabai M A and Bremner J M 1969 Use of P-nitro phenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*. 1: 301-307.

Tabatabai M A and Bremner J M 1972 Assay of urease activity in soils. *Soil Biology and Biochemistry.* 4: 479-487.

Vaccari F P, Baronti S, Lugato E, Genesio L, Castaldi S, Fornasier F, Miglietta F 2011 Bio char as a strategy to sequester carbon and increase yield in durum wheat. *European Journal of Agronomy*. 34:231–238.

Walkley A J and Black I A 1934 An examination of the wet digestion method for determining soil organic carbon and a proposed modification of the chromic acid titration method. *Soil Science*. 37: 29-33.

Watson D J 1952 The physiological basis for variation in yield. *Advances in Agronomy*. 6 : 103- 109.

Watzinger A, Feichtmair S, Kitzler B, Zehetner F, Kloss S, Wimmer B, Boltenstern S Z and Soja G 2014 Soil microbial communities responded to bio char application in temperate soils and slowly metabolized C^{13} labelled bio char as revealed by C^{13} PLFA analyses: results from a short term incubation and pot experiment. *European Journal of Soil Science*. 65: 40-51.

Xie Z P, Staehelin C, Vierheilig H, Wiemken A, Jabbouri S and Broughton W J 1995 Rhizobial nodulation factors stimulate mycorrhizal colonization of nodulating and nonnodulating soybeans. *Plant Physiology*. 108: 1519-1525.

Yun C, Ma Y, Guo D, Wang Q and Wang G 2017 Chemical properties and microbial responses to bio char and compost amendments in the soil under continuous watermelon cropping. *Plant, Soil and Environment.* 63(1): 1-7.

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