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Effect of biochar on soil quality index in red sandy loam soils under rabi groundnut crop of North coastal Andhra Pradesh

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Abstract
A field experiment was conducted to study the soil quality impacted by addition of various rates of biochar in combination of recommended dose (100% RDF or 75% RDF) of chemical fertilizers to groundnut crop in red sandy loam soils of North Coastal Andhra Pradesh during *rabi*, 2018-19. The quality of initial soil before imposing various treatments *viz.*, control (T_1), 100% RDF only (T_2), 100% RDF + biochar @ 2 t ha^{-1} (T_3), 100% RDF + biochar @ 4 t ha^{-1} (T_4), 100% RDF + biochar @ 6 t ha^{-1} (T_5), 75% RDF + biochar @ 2 t ha^{-1} (T_6), 75% RDF + biochar @ 4 t ha^{-1} (T_7) and 75% RDF + biochar @ 6 t ha^{-1} (T_8) was belong to class III with soil quality index of 290 and relative soil quality index of 72.5%. After completion of the experiment with groundnut crop, the SQI and RSQI values for T_1 (control) treatment @ 284 and 71% respectively. The highest SQI and RSQI values @ 352 and 88.0% were recorded in the treatment received biochar @ 6 t ha^{-1} + 100% RDF (T_5) which was followed by T_4, T_8, T_3, T_7, T_6, T_2 and T_1. The soil under control (T_1) and 100% RDF alone (T_2) treatments was remain in same soil quality class III after completion of the experiment. Substantial improvement in some of the soil quality indicators like cation exchange capacity (CEC), organic carbon content, available N, P_2O_5 and K_2O, microbial biomass, soil respiration, activity of urease and phosphatase enzymes, which in turn shifted the soil quality category of T_3, T_4, T_5, T_6, T_7 and T_8 treatments from Class III to Class II at the end of experiment.

Keywords: Soil quality index, groundnut, biochar, red sandy loam soils

Introduction
Soil quality is generally used to refer to a soil’s capacity to perform its production and environment related functions, to produce healthy and nutritious crops, resist erosion and reduce the impact of environmental stresses on plants, soil biota, human beings and animals. Several soil physical, chemical and biological properties are used as indicators of soil quality. Soil quality assessment is important for formulating effective soil management strategies. Groundnut crop is predominantly grown in sandy loams of North Coastal Andhra Pradesh. The major problem is the deterioration of soil physical properties due to monocropping and impaired soil fertility due to indiscriminate application of nutrients through the chemical fertilizers alone with the threat of the declining productivity. Sojka *et al*. (2003) [12] suggested that various soil indicators can be used to develop agricultural management practices that maintain or enhance crop productivity and soil quality through proper soil management. Limited information is available on the effect of biochar on soil quality. Hence the present investigation was carried out to assess the soil quality index using various soil indicators of sandy loam soils put to groundnut crop impacted by addition of biochar in combination of chemical fertilizer for sustainable crop production.

Material and Methods
The present study was carried out during *rabi*, 2018-19. The experimental plot was geographically situated at an altitude of 12 m above mean sea level, 83^0 56.602^l E longitude and 18^o 22.752^l N latitude in the Agricultural College Farm, North Coastal Andhra Pradesh. The experimental soil was sandy loam in texture, neutral in reaction, low in organic carbon. Biochar was prepared under the low oxygen conditions by pyrolysis process at low temperatures of 300- 350 ^0C using 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 N, P_2O_5 and K_2O respectively)
T_3 - 100% RDF + biochar @ 2 t ha^{-1}
T_4 - 100% RDF + biochar @ 4 t ha^{-1}
T_5 - 100% RDF + biochar @ 6 t ha^{-1}
T_6 - 75% RDF + biochar @ 2 t ha^{-1}
T_7 - 75% RDF + biochar @ 4 t ha^{-1}
T_8 - 75% RDF + biochar @ 6 t ha^{-1}

Analysis of soil quality indicators

Soil bulk density was determined by adopting core sampler method suggested by Black (1965) [2]. Porosity was calculated by using the formula: Porosity = [1- BD/PD] x 100; Where, BD = Bulk density of soil (Mg m^{-3}) and PD = Particle density (Mg m^{-3}) of soil. Hydraulic conductivity was determined by adopting constant head method as per the procedure outlined by Jalota *et al*. (1998) [7]. Infiltration rate (cm hr^{-1}) was determined *in situ*, by using double ring infiltro-meter as suggested by Bertrand (1965) [1]. The water holding capacity of soils was estimated by Keens Cup method (Black, 1965) [2]. The soil reaction (pH) and EC were determined in 1: 2.5 soil water suspension using pH meter and EC bridge (Jackson, 1973) [5]. Cation exchange capacity (CEC) of soil was determined by using neutral normal ammonium acetate method as given by Bower *et al*. (1952) [3]. Organic carbon (%) content of soil was determined by Walkley and Black (1934) [19] method. Available Nitrogen (kg ha^{-1}) was estimated by alkaline permanganate method (Subbiah and Asija, 1956) [14]. Available phosphorus (kg ha^{-1}) was extracted from soil by using Olsen's extractant (0.5 M $NaHCO_3$ of pH 8.5) and estimated by using spectrophotometer (Tandon, 1989) [17]. Available potassium (kg ha^{-1}) was extracted from the soil using neutral normal ammonium acetate (Tandon, 1989) [17] in 1:5 ratio and the readings were recorded on Flame photo meter. $CaCO_3$ of soil was determined by acid neutralization method (Richards *et al*. 1954) [10]. Available micronutrient metal cations in soil (Zn, Cu, Fe and Mn) were determined as per the procedure outlined by Lindsay and Norvell (1978) [8]. Soil respiration (CO_2 evolution) was determined by titration method (Jaggi, 1976) [6]; while, microbial biomass was estimated by fumigation extraction technique (Sparling and West, 1988) [13]. Soil urease enzyme (μ g NH + released g $^{-1}$ soil hr $^{-1}$) was estimated by the procedure as described by Tabatabai and Bremner (1972) [16]. Acid phosphatase and Alkaline phosphatase (μg of p- nitrophenol released g^{-1} soil h^{-1}) were assessed by adopting procedure as described by Tabatabai and Bremner (1969) [15] and soil dehydrogenase enzyme (mg of TPF produced g^{-1} soil d^{-1}) was estimated by adopting procedure of Casida *et al*. (1964) [4].

Assessment of soil quality index

The following steps were adopting to calculate soil quality index suggested by Singh, (2007) [11] using the data set of 22 indicators (Table 1). Each indicator was assigned weightage on the basis of existing soil and agro-climatic conditions. The sum of all the weightage was on the basis of existing soil and agro-climatic conditions. The sum of all the weights was normalized to 100%. Each indicator was divided into four (4) classes; *viz*, I, II, III and IV. Marks of 4, 3, 2, 1 were allotted to class I, II, III and IV, respectively. Quantitative evaluation of changes in soil quality by introducing the concept of relative soil quality index (RSQI) was adopted. The relative soil quality index (RSQI) was worked out by combining 22 indicators selected for the study. The equation was RSQI = (SQI / SQI_M) x 100: where SQI = Soil Quality Index and SQI_M = Maximum value of SQI. Wang and Fang (1978) [18] reported that the maximum value of SQI for a soil is 400 and minimum value is 100. SQI was calculated as SQI = W_i I_i: where W_i = Weight of the indicators and I_i = marks of the indicator classes. SQI of every indicator was calculated separately by multiplying the weight of indicators with marks allotted to each class. The summation of all indicators was considered as SQI. The normalized RSQI is 100, but the real soil will have lower values which directly indicate their deviation from the optimal soil. The soils were further classified into five soil quality categories from best to worst based on the RSQI values *i.e.,* I (90 – 100), II (80-90), III (70-80), IV (60-70) and V (< 60). The change in RSQI in the soil quality was determined by deducting the RSQI values of initial soil sample (before start of the experiment) from the RSQI values of various treatments at the end of the crop stage during which period only test treatments imposed were grouped into six classes: great increase (> 15), moderate increase (15 to 5), slight increase (5 to 0), slight decrease (0 to –5), moderate decrease (-5 to –15) and great decrease (< -15). The data obtained on various parameters were subjected to the analysis of variance.

Results and discussion

The soil quality index improved progressively with increased levels of biochar and fertilizer application (Table 3). The initial soil sample had a SQI and RSQI of 290 and 72.5% before start of the experiment and after application of 100% RDF + biochar @ 6 t ha^{-1} (T_5), the corresponding SQI and RSQI values increased to 352 and 88.0% respectively This was followed by T_4 (100% RDF + biochar @ 4 t ha^{-1}) and T_8 treatments (75% RDF + biochar @ 6 t ha^{-1}) where SQI values of 347, 346 and RSQI of 86.75% and 86.5% was noticed. In T_3 (100% RDF + biochar @ 2 t ha^{-1}) and T_7 treatments (75% RDF + biochar @ 4 t ha^{-1}), similar SQI and RSQI values revealed that 25% reduction in RDF can be compensated by application of additional biochar of 2 t ha^{-1} to maintain soil quality. Among the biochar applied treatments the lowest SQI and RSQI values (326, 81.5%) were noticed in T_6 treatment where in 75% RDF + biochar @ 2 t ha^{-1} was added.

The soil quality index value which is the sum total of 22 quality indicators was recorded low (284) in the T_1 (control) treatment compared to the expected maximum value of 400 for high quality soil (Wang and Fang, 1978) [18]. Application of recommended dose of 30:40: 50 kg ha^{-1} N, P_2O_5 and K_2O, respectively through the chemical fertilizers *i.e.,* (100% RDF alone) in T_2 treatment slightly improved the soil quality index value from 284 (in control) to 304. The category of the initial soil before imposition of treatments was qualified to class III which was attributed to non application of fertilizers and biochar but shifted to class II category in T_3, T_4, T_5, T_6, T_7 and T_8 treatments at completion of the crop could be due to application of biochar at various rates (2 t ha^{-1}, 4 t ha^{-1} and 6 t ha^{-1}) in combination with different levels of fertilizer addition (100% RDF or 75% RDF). In control treatment (T_1) the soil quality index was slightly lower (284) than initial soil quality index (290) could be attributed to crop removal of available nutrients from soil. Both T_1 (control) and T_2 (100% RDF alone), were remain in same soil quality class III after completion of the experiment.

The improvement in soil quality due to the application of biochar in combination with fertilizers in groundnut crop could be due to the substantial improvement in some of the soil quality indicators like cation exchange capacity (ECE), organic carbon content, available N, P_2O_5 and K_2O, microbial biomass, soil respiration, activity of urease and phosphatase enzymes. This in turn shifted the category of the soil from Class III to Class II at the end of experiment. The change in relative soil quality index (ΔRSQI) indicated that there was a slight decrease in T_1 treatment(control) and slight increase in T_2 (100% RDF) and moderate increase in T_4 (100% RDF + biochar @ 4 t ha^{-1}), T_8 (75% RDF + biochar @ 6 t ha^{-1}), T_7 (75% RDF + biochar @ 4 t ha^{-1}), T_3 (100% RDF + biochar @ 2 t ha^{-1}), T_6 (75% RDF + biochar @ 2 t ha^{-1}) treatments and great increase in T_5 (100% RDF + biochar @ 6 t ha^{-1}) at the end of experiment.

The shift in soil quality category from III to II with in a crop season was due to the effect of biochar in combination of RDF which in turn improved the soil physical properties viz., bulk density, porosity and water holding capacity of the soil in addition to the improvement in biological properties and nutrient availability.

Conclusion

The present investigation thus indicated that the scope to improve over all soil quality is quite prospectus by application of biochar in combination with fertilizers. Shift in soil quality class III to II in biochar application @ 4 t ha^{-1} to 6 t ha^{-1} in combination of 75% RDF or 100% RDF was a notable observation. If this practice is continued over a long term, the soil physical, physico-chemical and chemical properties are likely to improve and maintain sustainable soil health for efficient crop production on one hand and minimize the rate of fertilizer application on the other to minimize the risk of pollution to nearby water bodies as well as the environment.

Table 1: Soil quality indicators, their weights and classes for the evaluation of soil quality.

Appendix		4	3	2	1
Indicators	**Weights**	**Class I**	**Class II**	**Class III**	**Class IV**
1. Bulk density (g cm $^{-3}$)	8	< 1.4	1.5	1.6	> 1.6
2. WHC (%)	8	> 40	35-40	30-35	< 30
3. Hydraulic conductivity (cm h^{-1})	3	> 0.30	0.25-0.3	0.2-0.25	< 0.2
4. Porosity (%)	5	> 40	35-40	30-35	< 30
5. Infiltration (mm h^{-1})	4	> 7	6.5-7	6.0-6.5	< 6.0
6. pH	2	5.5-7.0	7.1-8.0	8.0-8.5	8.5-9.0
7. EC (dS m^{-1})	4	< 0.4	0.4-0.5	0.5-0.6	> 0.6
8. CEC (c mol (p+) kg^{-1})	5	> 15	10-15	5-10	< 5
9. OC (%)	8	> 0.3	0.2-0.3	0.1-0.2	< 0.1
10. N (kg ha^{-1})	8	> 400	300-400	200-300	< 200
11. P_2O_5 (kg ha^{-1})	8	> 15	10-15	5-10	< 5
12. K_2O (kg ha^{-1})	6	> 250	200-250	100-200	< 100
13. CaCO3 (%)	3	< 0.5	0.5-1.0	1.0-1.5	> 1.5
14. Zn (mg kg^{-1} soil)	5	> 0.6	0.5-0.6	0.45-0.5	< 0.45
15. Cu (mg kg^{-1}soil)	2	> 0.2	0.10-0.2	0.05-0.10	< 0.05
16. Fe (mg kg^{-1} soil)	4	< 4	3-4	2-3	1-2
17. Mn (mg kg^{-1} soil)	1	< 3	2-3	1-2	< 1
18. CO (µ g CO, g^{-1} soil 24 hours)	5	> 0.04	0.03-0.02	0.01-0.02	< 0.01
19. Micro biomass (µg g^{-1} soil)	5	> 150	100-150	75-100	< 75
20. Urease (µg g^{-1} soil)	2	> 2	1.5-2	1-1.5	<1
21. Phosphatase (P-nitro phenol g^{-1}soil h^{-1})	2	> 150	100-150	75-100	< 75
22. Dehydrogenase (µg g^{-1} soil 24 h^{-1})	2	> 15	12-15	10-12	< 10

Class I: Most suitable plant growth, Class II: Suitable for Plant growth with less limitation, Class III: Suitable for plant growth with serious limitation, Class IV: Suitable for plant growth with more severe limitation.

Table 2: Soil quality indicators, impacted by imposing treatments (Figures in parenthesis are SQI values of each parameter).

S. No	Soil quality parameter	Initial	Change of soil quality due to imposing treatments							
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
1	Bulk density (g cm $^{-3}$)	1.61 (8)	1.62 (8)	1.60 (8)	1.52 (16)	1.45 (24)	1.43 (24)	1.53 (16)	1.44 (24)	1.43 (24)
2	WHC (%)	38.53 (24)	38.17 (24)	39.17 (24)	41.95 (32)	43.28 (32)	44.73 (32)	41.37 (32)	43.08 (32)	46.25 (32)
3	Hydraulic onductivity (cm h^{-1})	2.40 (12)	2.25 (12)	2.21 (12)	2.17 (12)	2.10 (12)	1.91 (12)	2.13 (12)	1.92 (12)	1.96 (12)
4	Porosity (%)	39.25 (15)	38.87 (15)	39.62 (15)	42.64 (20)	45.28 (20)	46.04 (20)	42.26 (20)	45.66 (20)	46.05 (20)
5	Infiltration (mm h^{-1})	18.67 (16)	15.20 (16)	15.57 (16)	15.20 (16)	14.37 (16)	14.57 (16)	14.21 (16)	14.57 (16)	13.86 (16)
6	pH	6.70 (8)	6.77 (8)	6.87 (8)	6.99 (8)	7.17 (8)	7.33 (8)	6.98 (8)	7.11 (8)	7.28 (8)
7	EC (dS m^{-1})	0.38 (16)	0.31 (16)	0.32 (16)	0.32 (16)	0.34 (16)	0.36 (16)	0.31 (16)	0.33 (16)	0.34 (16)
8	CEC (c mol (p+) kg^{-1})	14.02 (15)	14.39 (15)	14.52 (15)	16.09 (20)	17.21 (20)	18.19 (20)	15.84 (20)	16.37 (20)	17.78 (20)
9	OC (%)	0.32 (32)	0.34 (32)	0.34 (32)	0.43 (32)	0.48 (32)	0.53 (32)	0.44 (32)	0.48 (32)	0.54 (32)

10	N (kg ha^{-1})	130.5 (8)	102.4 (8)	145.8 (8)	150.4 (8)	154.6 (8)	159.9 (8)	130.3 (8)	141.6 (8)	152.7 (8)
11	P_2O_5(kg ha^{-1})	15.67 (32)	12.8 (24)	18.60 (32)	21.42 (32)	23.99 (32)	25.38 (32)	15.10 (32)	19.42 (32)	20.30 (32)
12	K_2O (kg ha^{-1})	195.4 (12)	184.0 (12)	265.7 (24)	288.8 (24)	296.7 (24)	308.1 (24)	223.1 (18)	231.9 (18)	238.6 (18)
13	CaCO3 (%)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)	0.0 (12)
14	Zn (mg kg^{-1})	0.62 (20)	0.58 (15)	0.60 (15)	0.57 (15)	0.58 (15)	0.55 (15)	0.57 (15)	0.56 (15)	0.56 (15)
15	Cu (mg kg^{-1})	1.74 (8)	1.11 (8)	1.19 (8)	1.15 (8)	1.12 (8)	1.10 (8)	1.14 (8)	1.10 (8)	1.09 (8)
16	Fe (mg kg^{-1})	17.28 (16)	14.70 (16)	15.52 (16)	14.38 (16)	13.03 (16)	12.95 (16)	14.28 (16)	13.53 (16)	13.16 (16)
17	Mn (mg kg^{-1})	13.68 (4)	13.28 (4)	13.77 (4)	13.07 (4)	12.44 (4)	12.07 (4)	12.96 (4)	12.89 (4)	12.45 (4)
18	CO_2 (µ g CO, g^{-1} soil 24 hours)	0.008 (5)	0.009 (5)	0.01 (5)	0.014 (10)	0.018 (10)	0.022 (15)	0.015 (10)	0.017 (10)	0.021 (15)
19	Micro biomass (ìg^{-1}g^{-1} soil)	117 (15)	182.6 (20)	178.9 (20)	277.3 (20)	291.8 (20)	335.7 (20)	271.5 (20)	290.2 (20)	349.4 (20)
20	Urease (ìg^{-1}g^{-1} soil)	83.27 (8)	91 (8)	106.3 (8)	125.6 (8)	135 (8)	140.6 (8)	117.6 (8)	122.3 (8)	138.6 (8)
21	Phosphatase (P-nitro phenol g^{-1}soil h^{-1})	15.35 (2)	17.76 (2)	20.37 (2)	26.40 (2)	35.22 (2)	38.23 (2)	27.61 (2)	33.56 (2)	33.66 (2)
22	Dehydrogenaseìg^{-1}g^{-1} soil 24 h^{-1})	8.25 (2)	10.55 (4)	10.63 (4)	16.51 (8)	17.02 (8)	19.82 (8)	13.06 (6)	15.60 (8)	19.39 (8)

Table 3: Soil quality changes from initial to completion of the experiment in various treatments under biochar and fertilizer application

Treatments	SQI	RSQI	ΔRSQI	Soil quality class	Changed class
Initial Soil Sample	290	72.50	-	III	-
T_1	284	71.00	-1.50	III	No Notable Difference
T_2	304	76.00	3.50	III	Slight Increase
T_3	339	84.75	12.25	II	Moderate Increase
T_4	347	86.75	13.75	II	Moderate Increase
T_5	352	88.00	15.50	II	Great Increase
T_6	331	82.75	10.25	II	Moderate Increase
T_7	341	85.25	12.75	II	Moderate Increase
T_8	346	86.50	14.00	II	Moderate Increase

(**Note:** Before Imposition of treatments the initial experimental soil was qualified for class III with SQI and RSQI values of 290 and 72.5, respectively).

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