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Impact of coconut husk biochar on soil physical and biological properties, growth characters and yield of banana

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Abstract
A field experiment was conducted at College of Agriculture, Vellayani, Kerala Agricultural University during, 2016-17 to study the impact of biochar derived from tender coconut husk on soil physical and biological properties, growth characters, total dry matter production, yield and fruit quality of banana. The 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 the application of biochar @ 10 kg plant^{-1} coupled with 75% STBR (Soil Test Based fertilizer Recommendation) enhanced the physical properties of the soil by imparting 57.11% increase in the water holding capacity (WHC), 35.32% increase in porosity, 7.31% decrease in the bulk density (BD) and 55.9% enhancement in soil dehydrogenase activity. Plant biometric characters like plant height at 2, 4, 6 and 8 months after planting (MAP), number of leaves per plant at 2 and 6 MAP, pseudo stem girth at 4 and 8 MAP, 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 were highest recorded with same treatment. Simultaneously, fruit quality parameters like TSS (34 ^{0} B), ascorbic acid content (2.18 mg 100 g^{-1}) and shelf life (9.66 days) of fruits were found to be superior with application of biochar @ 10 kg plant^{-1} coupled with 75% (NPK + secondary & micronutrients as per STBR) treatment.

Keywords: Biochar, banana, WHC, porosity, bulk density, dehydrogenase activity, growth characters and bunch weight

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]. About 2.25 billion coconuts are consumed as tender coconuts in India. Of late it has been reported that there has been a 130% increase in the sale of tender coconuts in Kerala. 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 thermo chemical 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 physical 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 properties like total porosity, pore size distribution, soil density, soil moisture content, water holding capacity/plant available water content and infiltration/hydraulic conductivity (Atkinson *et al*., 2010) [2].
The enhancement in particle surface area and storage of water within its porous structure enables biochar to improve the WHC of soil (Lehmann *et al*., 2003) [21]. Application of biochar (5 t ha^{-1}) increases WHC by 2.5% in a sandy loam textured soil at the surface soil layer (Pandian *et al*., 2016) [3]. Asai *et al*. (2009) [4] found an increase in WHC by applying biochar @ 9 t ha^{-1} or 16 t ha^{-1}.

Masulili *et al*. (2010) [5] did a study where WHC was enhanced from 11.3% for untreated control soil to 15.5% for soil treated with rice husk biochar. Southavong *et al*. (2012) [6] in a study on the impact of biochar and biodigester effluent on soil fertility changes and biomass production of water spinach observed that application of biochar @ 40 t ha^{-1} improved WHC of the soil by 40-60%.

Jones *et al*. (2012) [7] concluded that addition of 40 and 80 t ha^{-1} of green waste biochar to bauxite processing residue coarse sand had a marked declining effect on macro porosity (pore diameters >0.29 µm) while significantly improving meso porosity (pore diameters between 0.20 and 0.29 µm). This is due to biochar partially filling the voids existing within the coarse sand particles. Belyaeva and Haynes (2012) [8] also found that application of biochar at enhanced rate (50 or 100 t ha^{-1}) greatly decreased macro porosity and increased meso porosity and in some cases micro porosity. Consequently, there was a considerable enhancement in the water holding capacity. Total porosity and water holding capacity enhanced by 2% and 3%, respectively in medium textured soil by the application of biochar @ 5 t ha^{-1} (Pandian *et al*., 2016) [3].

Zhang *et al*. (2010) [9] observed that the wheat straw biochar addition had a depressing effect in the bulk density of a rice paddy soil at 40 t ha^{-1}. Liu *et al*. (2012) [10] suggested that the addition of 8-16 g kg^{-1} of sawdust biochar significantly enhanced the aggregate stability. Pandian *et al*. (2016) [3] reported that bulk density got reduced from 1.41 to 1.36 g cm^{-3} in medium textured soil by the amelioration with biochar @ 5 t ha^{-1}. Decreased bulk density, enhanced porosity and saturated water content were resulted by the addition of acacia green waste biochar at rate of 47 t ha^{-1} (Hardie *et al*., 2014) [11].

Since pyrolysis ensures complete sterility, any immediate bearing on the biotic microbes is their elimination during pyrolysis (Thies *et al*., 2015) [12]. On the other hand, the high porosity of biochar may have an indirect favourable bearing on microbes which indirectly increase soil microbial biomass and basal activity (Lehmann *et al*., 2015) [13] by ensuring a protected and aerate environment for microbial growth (Schmalenberger and Fox, 2016) [14]. There can be other cases too in which biochar can have a direct bearing in amending soil microbial population fabric by ensuring the needed nutrient supply (Schmalenberger and Fox, 2016) [14]. The enormous internal surface area of biochar expands the organic and inorganic compound adsorption capability of soil, in a way that there is an enhanced supply of mineral nutrients and energy to microbial population facilitating their proliferation (Gul *et al*., 2015) [15]. Biochar has been reported to have both direct and indirect influence on physical and biological properties, which can have impacts on plant growth (Blackwell *et al*., 2009) [16]. The present study was carried out at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala Agricultural University, Kerala, India to study the impact of biochar derived from tender coconut husk on soil physical and biological properties, total dry matter production, growth characters, yield and fruit quality of banana.

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. Characterization and analysis of produced biochar was done by standard procedures and it had an alkaline pH (8.53), C: N (46.11), C:P (175.25), C:S (259.62) and C:N:P:S (350:7.5:2:1) ratios. Electrical Conductivity, total C, N, P, K, Ca, Mg, S, Fe, Mn and B were 1.70 dS m^{-1}, 70.10%, 1.52%, 0.40%, 2.26%, 0.54%, 0.46%, 0.27%, 89.9 mg kg^{-1}, 2.84 mg kg^{-1} and 6.78 mg kg^{-1} respectively. A field experiment was conducted at a site classified as Loamy, kaolinitic, isohyperthermic, Typic Kandiustults, which was acidic in reaction (4.73±0.04), normal in electrical conductivity (0.71 0.09 dS m^{-1}) medium in organic carbon content (1.13±0.08%), available N (225.57±12.42 kg ha^{-1}) and K (130.20±23.99 kg ha^{-1}). The available P (80.40±8.11 kg ha^{-1}) content was very high. Soil physical (Gupta and Dakshinamoorthy, 1980) [17] and biological (Lenhard, 1956) [18] properties were analyzed by standard procedure and it had low bulk density (1.37±0.03 Mg m^{-3}), normal porosity (47.0±1.99%), water holding capacity (28.28±1.02%) and dehydrogenase activity (38.62 (µg TPF g^{-1} soil 24 h^{-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. The experiment was laid out in randomly block design replicated thrice with eleven treatments using Nendran 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 $plant^{-1}$.

Plant biometric characters like plant height, number of leaves and pseudostem girth at 2, 4, 6 and 8 months after planting (MAP), 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) [19]. The data obtained from the field experiment was analysed statistically by applying the techniques of analysis of variance (Gomez and Gomez, 1984) [20]. 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 application on soil physical and biological properties, plant growth characters, yield and fruit quality of banana are detailed below.

Soil physical and biological properties

It is observed from the data that the water holding capacity (WHC) of the soil was significantly influenced by the treatments at the final harvest stage (Table 1). The highest WHC of 38.18% was recorded by BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR (T_{10}). This was on par with BC @ 10 kg $plant^{-1}$ + 75% NPK as per POP (T_5), BC @ 10 kg $plant^{-1}$ + NPK as per POP (T_3), BC @ 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR) (T_8), BC @ 5 kg $plant^{-1}$ + NPK as per POP(T_2) and BC alone 10 kg $plant^{-1}$(T_{11}) recording values of 36.6%, 36.23%, 35.98%, 34.80% and 33.76% respectively. The lowest value of 24.30% was recorded by the package of practices recommendation (T_1) treatment. Biochar is predicted to increase the WHC of soil owing to the enhancement in the extent of surface area by the biochar particle, consequent to which more water molecules can be stored within its porous structure (Lehmann *et al*., 2003) [21]. Masulili *et al*. (2010) [5] conducted an experiment where in the WHC was increased from 11.3 percent for untreated control soil to 15.5% in soils treated with rice husk biochar. An increase in the WHC of the soil has a consequential positive influence on the availability of water and essential nutrients in the soil.

The significantly highest bulk density at final harvest was 1.32 Mg m^{-3} by Package of practices recommendation (T_1) and the lowest (1.23 Mg m^{-3}) for BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) (Table 1). Incorporation of biochar could increase the soil volume, surface area and porosity thereby reducing the bulk density of the soil. Castellini *et al.* (2015) [22] indicated that increasing total organic carbon by the addition of biochar in soils could significantly decrease bulk density by influencing flocculation of soil micro aggregates. Pandian *et al*. (2016) [3] reported that the biochar amendment at the rate of 5 t ha^{-1} reduced the bulk density from 1.41 to 1.36 Mg m^{-3} in medium textured soil.

Table 1: Effect of treatments on soil physical and biological properties

Treatments	Water holding capacity (%)	Bulk density (Mg m^{-3})	Porosity (%)	Dehydrogenase activity (µg TPF g^{-1})
T_1	24.30 ^{e}	1.32 ^{a}	43.12 ^{d}	41.61^{d}
T_2	34.80 ^{abc}	1.27 ^{bcd}	49.56^{bc}	50.49 ^{bcd}
T_3	36.23 ^{ab}	1.24 ^{de}	53.06^{ab}	59.18 ^{ab}
T_4	32.25 ^{bcd}	1.27 ^{bcd}	51.14^{bc}	52.02 ^{bc}
T_5	36.60 ^{ab}	1.24 ^{cde}	55.41^{ab}	58.01 ^{ef}
T_6	26.15 ^{e}	1.25 ^{cde}	53.65 ^{ab}	49.35 ^{cd}
T_7	28.47 ^{de}	1.27^{bc}	49.71^{bc}	53.14 ^{bc}
T_8	35.98 ^{ab}	1.24 ^{cde}	55.15^{ab}	58.19 ^{abc}
T_9	29.58 ^{cde}	1.26^{cde}	51.25 ^{bc}	54.66 ^{bc}
T_{10}	38.18 ^{a}	1.23 ^{e}	58.35 ^{a}	64.87^{a}
T_{11}	33.76 ^{abcd}	1.29 ^{ab}	45.83 ^{cd}	52.37^{bc}
SEm (±)	2.54	0.01	2.94	4.62
CD (0.05)	5.31	0.03	6.14	9.64

* a,b,c,d,e Significant difference between treatments

By the application of treatments at final harvesting stage, porosity was superior for the treatment BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) which recorded a value of 58.35%, which was on par with BC @ 10 kg $plant^{-1}$ + 75% (NPK as per POP) (T_5), BC @ 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR) (T_8), FYM 10 kg $plant^{-1}$ + (NPK + secondary & micronutrients as per STBR) (T_6) and BC @ 10 kg $plant^{-1}$ +75% NPK as per POP (T_3) values of 55.41%, 55.15%, 53.65% and 53.06% respectively (Table 1). The lowest percent of porosity was shown by Package of practices recommendation (T_1) with a value of 43.12%. In medium textured soil, biochar application at the rate of 5 t ha^{-1} increased total soil porosity by 3% (Pandian *et al*., 2016) [3]. Application of biochar to infertile soils decreases soil bulk density and increases total pore volume (Wabel *et al*., 2013) [23].

The significant highest dehydrogenase activity in soil at final harvest stage was obtained in biochar @ 10 kg $plant^{-1}$ + 75% STBR (T_{10}) (64.87 µg TPF g^{-1} 24 h^{-1}) which was on par with BC @ 10 kg $plant^{-1}$ + NPK as per POP (T_3) (59.18 µg TPF g^{-1} 24 h^{-1}) and biochar @ 10 kg $plant^{-1}$ + STBR (T_8) (58.19 µg TPF g^{-1}) (Table 1). Higher application of biochar resulted in higher biological activity in soil. Biochar being highly porous material and the pores with nutrients and water provide the most conducive condition for the proliferation of micro-organism. The large internal surface area of biochar expands the organic and inorganic compound adsorption capability of soil, such that the supply of mineral nutrients and energy to microbes is increased (Gul *et al*., 2015) [15]. Masto *et al*. (2013) [24] reported that the application of biochar @ 2 and 4 t ha^{-1} increased soil enzymes of dehydrogenase activity (60.70 percent) and microbial biomass (25.3 percent).

Growth characters of banana as influenced by biochar based treatments

Plant biometric characters like plant height at 2, 4, 6 and 8 MAP, number of leaves per plant at 2 and 6 MAP and pseudostem girth at 4 and 8 MAP were highest in the biochar @ 10 kg $plant^{-1}$ + 75% (NPK + secondary and micronutrients as per of STBR (T_{10}) treatment followed by 5 kg biochar + 75% of NPK as per POP (Table 2). Biochar applications to soils may increase plant growth and crop yields. Biochar has been reported to have both direct and indirect influence on soil nutrient availability, which can have impacts on plant growth (Blackwell *et al*., 2009) [16].

Effect of treatments on yield, bunch characters and fruit quality 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 3). Addition of nutrients are necessary for good crop growth and yield. Biochar @ 10 kg $plant^{-1}$ 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, followed by biochar (5 kg $plant^{-1}$) with 75% NPK as per POP (Table 3). This implies the improvement of physical and biological properties of soil increased the readily available essential nutrients and in conjunction with biochar was capable of supplying the required nutrients for crop growth and production (Blackwell *et al.*, 2009) [16].

The effect of the biochar based treatments on the fruit quality parameters of banana like total soluble solids, ascorbic acid content and shelf life of the fruits were studied and were found to be statistically significant (Table 3). The highest total soluble solid content of 34% was observed in BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) treatment, followed by BC @ 5 kg $plant^{-1}$ + 75% NPK as per POP (T_4) (33.16%). The highest ascorbic acid content of 2.18 mg 100 g^{-1} was recorded by BC @ 10 kg $plant^{-1}$ + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) treatment. The

BC @ 10 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR) (T_{10}) treatment registered the highest shelf life of 9.66 days and it was on par with the BC @ 5 kg plant^{-1} + 75% NPK as per POP (T_4) and BC @ 5 kg plant^{-1} + 75% (NPK + secondary & micronutrients as per STBR) (T_9) treatment. The lowest soluble solid (31.83%) and ascorbic acid content (0.84 mg 100 g^{-1}) was recorded by the BC alone 10 kg plant^{-1} (T_{11}) treatment.

Table 2: Growth characters of banana as influenced by biochar based treatments

Treatments	Plant height (cm)				Pseudostem girth (cm)				Number of leaves			
	2 MAP	4 MAP	6 MAP	8 MAP	2 MAP	4 MAP	6 MAP	8 MAP	2 MAP	4 MAP	6 MAP	8 MAP
T_1	76.33 ^{j}	156.66 ^{j}	232.66 ^{g}	242.66 ^{ef}	31.83	49.16 ^{d}	50.83 ^{e}	51.50 ^{e}	7.00 ^{c}	11.50 ^{bc}	10.83 ^{ab}	10.83
T_2	82.00 ^{g}	168.00 ^{g}	244.00 ^{e}	257.33 ^{cd}	32.66	52.66 ^{abcd}	51.00 ^{e}	52.33 ^{de}	8.00 ^{bc}	11.50 ^{bc}	9.66 ^{cd}	10.83
T_3	79.00 ^{i}	162.00 ^{i}	238.00 ^{f}	253.66 ^{cd}	30.50	49.83 ^{cd}	51.66 ^{de}	52.16 ^{de}	8.00^{bc}	11.50 ^{bc}	10.16 ^{bcd}	10.83
T_4	85.00 ^{e}	174.00 ^{e}	250.00 ^{d}	290.00 ^{b}	33.33	53.33 ^{abc}	57.33 ^{a}	58.00 ^{a}	9.00 ^{ab}	12.66 ^{a}	10.16 ^{bcd}	11.33
T_5	80.00 ^{h}	164.00 ^{h}	240.00 ^{f}	246.66 ^{de}	32.16	52.16 ^{bcd}	51.16 ^{e}	52.66 ^{d}	8.00 ^{bc}	11.50 ^{bc}	11.00 ^{ab}	10.83
T_6	90.00 ^{c}	184.00 ^{c}	260.00 ^{c}	290.00 ^{b}	32.33	49.00 ^{d}	53.33 ^{cde}	55.00 ^{c}	8.66 ^{ab}	11.66 ^{bc}	10.66 ^{abc}	11.00
T_7	83.00 ^{f}	170.00 ^{f}	246.00 ^{e}	263.33 ^{c}	34.16	54.16 ^{abc}	56.16 ^{abc}	57.50 ^{a}	8.00 ^{bc}	11.33 ^{c}	9.16 ^{d}	10.66
T_8	89.00 ^{d}	182.00 ^{d}	258.00 ^{c}	294.66 ^{b}	34.83	54.83 ^{ab}	55.66 ^{abc}	57.33 ^{ab}	8.00 ^{bc}	12.16 ^{ab}	10.16^{bcd}	10.83
T_9	93.00 ^{b}	190.00 ^{b}	266.00 ^{b}	296.00 ^{b}	33.16	53.16 ^{abc}	54.33 ^{bcd}	56.33 ^{b}	9.00 ^{ab}	11.33 ^{c}	10.83 ^{ab}	10.66
T_{10}	104.33 ^{a}	212.66 ^{a}	288.66 ^{a}	328.66 ^{a}	36.16	56.16 ^{a}	57.00 ^{ab}	58.33 ^{a}	9.33 ^{a}	11.66 ^{bc}	11.33 ^{a}	11.00
T_{11}	75.00 ^{k}	154.00 ^{k}	227.66 ^{h}	234.33 ^{f}	32.83	42.83 ^{e}	46.83 ^{f}	48.16 ^{f}	7.33 ^{c}	9.66 ^{d}	9.33 ^{d}	9.33
SEm (±)	0.30	0.61	1.21	5.15	1.07	1.89	1.39	0.49	0.61	0.38	0.51	0.41
CD (0.05)	0.64	1.29	2.54	10.76	NS	3.96	2.91	1.03	1.29	0.81	1.08	NS

Table 3: Effect of biochar based treatments on total dry matter, bunch yield, bunch characters and fruit quality of banana

Treatments	Total dry matter production (kg)	Weight of bunch (kg)	Number of hands bunch^{-1}	Number of fingers bunch^{-1}	Index Finger		Quality parameters of fruit of banana		
					Length (cm)	Girth (cm)	Total Soluble Solids (^{0} B)	Ascorbic acid (mg 100 g^{-1})	Shelf life (days)
T_1	7773.24 ^{ef}	6.21 ^{fg}	4.25 ^{de}	36.83 ^{de}	19.08 ^{f}	11.76 ^{d}	32.00 ^{d}	0.94 ^{h}	7.66 ^{bc}
T_2	10648.28 ^{bc}	7.02 ^{cde}	5.25 ^{a}	45.33 ^{ab}	19.58 ^{ef}	12.55 ^{abc}	32.50 ^{bcd}	1.36 ^{g}	8.00 ^{bc}
T_3	8197.88 ^{de}	6.90 ^{def}	5.00 ^{abc}	40.00 ^{cd}	20.54 ^{d}	12.22 ^{c}	32.41 ^{bcd}	1.45 ^{ef}	7.00 ^{cd}
T_4	12354.96 ^{a}	8.14 ^{b}	5.25 ^{a}	44.33 ^{abc}	22.04 ^{b}	12.64 ^{ab}	33.16 ^{b}	1.69 ^{c}	9.33 ^{a}
T_5	9979.23 ^{c}	6.83 ^{def}	4.75 ^{bc}	34.50 ^{e}	21.33 ^{bc}	12.24 ^{c}	33.00 ^{bc}	1.56 ^{d}	5.66 ^{e}
T_6	11216.00 ^{b}	7.35 ^{bcd}	5.15 ^{ab}	45.50 ^{a}	20.75 ^{cd}	12.66 a	32.83 ^{bc}	1.51 ^{de}	7.00 ^{cd}
T_7	8910.77 ^{d}	6.36 ^{ef}	4.75 ^{bc}	39.16 ^{d}	20.08 ^{de}	12.24 ^{c}	32.33 ^{cd}	1.42 ^{fg}	6.00 ^{de}
T_8	10015.52 ^{c}	7.02 ^{cde}	4.60 ^{cd}	39.50 ^{d}	20.41 ^{d}	12.30 ^{bc}	32.98 ^{bc}	1.55 ^{d}	7.66 ^{bc}
T_9	11086.92 ^{b}	7.78 ^{bc}	5.00 ^{abc}	41.00 ^{bcd}	21.66 ^{b}	12.54 ^{abc}	32.83 ^{bc}	1.83 ^{b}	8.66 ^{ab}
T_{10}	12742.15 ^{a}	9.34 ^{a}	5.25 ^{a}	46.16 ^{a}	22.83 ^{a}	12.73 ^{a}	34.00 ^{a}	2.18 ^{a}	9.66 ^{a}
T_{11}	6914.02 ^{f}	5.44 ^{g}	4.00 ^{e}	34.33 ^{e}	18.25 ^{g}	10.35 ^{e}	31.83 ^{d}	0.84 ^{i}	7.66 ^{bc}
SEm (±)	467.13	0.37	0.20	2.10	0.36	0.15	0.15	0.03	0.58
CD (0.05)	974.44	0.79	0.42	4.40	0.76	0.33	0.81	0.08	1.21

^{a,b,c,d,e} Significant difference between treatments

Table 4: Correlation of growth characters with yield and yield attributes

	Weight of bunch	Plant height	Pseudostem Girth	Number of leaves	Dry matter production	Number of hands bunch^{-1}	Number of fingers bunch^{-1}	Length of index finger	Girth of index finger
Weight of bunch	1	0.827**	0.570**	0.550**	0.842**	0.492**	0.490**	.842**	0.717**
Plant height		1	0.651**	0.495**	0.797**	0.465**	0.505**	0.797**	0.632**
Pseudostem Girth			1	ns	0.594**	0.600**	0.622**	0.525**	0.655**
Number of leaves				1	0.509**	Ns	Ns	0.448**	0.452**
Dry matter production					1	0.555**	0.521**	0.798**	0.790**
Number of hands bunch^{-1}						1	0.759**	.460**	0.706**
Number of fingers bunch^{-1}							1	ns	0.591**
Length of index finger								1	0.694**
Girth of index finger									1

** and * significant at $p < 0.01$ and 0.05; n.s. not significant

Correlation study of growth characters with yield and yield attributes

Correlation studies revealed that the bunch weight was significantly and positively correlated with plant height, pseudostem girth, number leaves, dry matter production, number of hands bunch^{-1}, number of fingers bunch^{-1} and length and girth of index finger. The girth of pseudostem was positively correlated with dry matter production, number of hands bunch^{-1}, number of fingers bunch^{-1} and length and girth of index finger (Table 3).

Application of biochar @ 10 kg plant^{-1} coupled with 75% (NPK + secondary & micronutrients as per STBR), imparted a 57.11% increase in the water holding capacity (WHC), 35.32% increase in porosity, 7.31% decrease in the bulk density (BD), 55.9% enhancement in soil dehydrogenase activity and 50.40 kg plant^{-1} increase in the yield when compared with package of practices recommendation. (Table 4).

Table 4: Comparison between control and the best treatment

Parameters	Control (T_1- POP)	Best treatment (T_{10}- BC 10 kg plant^{-1} + 75% (NPK as per STBR)	Units increase or decrease	Percentage increase or decrease
WHC (%)	24.30	38.18	13.88	57.11
Bulk density	1.32	1.23	0.09 (decrease)	7.31 (decrease)
Porosity (%)	43.12	58.35	15.23	35.32
Dehydrogenase activity (µg TPF g^{-1})	41.61	64.87	23.26	55.90
Yield (kg plant^{-1})	6.21	9.34	3.13	50.40

Conclusion

It is concluded that application of biochar @ 10 kg plant^{-1} coupled with 75% (NPK + secondary & micronutrients as per STBR) treatments enhanced the soil physical properties, promoted rhizospheric microorganisms and resulted in higher plant biometric characters like plant height at 2, 4, 6 and 8 months after planting, number of leaves per plant at 2 and 6 MAP and pseudostem girth at 4 and 8 MAP, total dry matter production, profitable yield and superior fruit quality of banana. Biochar application imparted favourable physical characteristics to the soil, thus rendering it congenial for the intensified activity of soil microorganisms, ultimately resulting in enhanced bunch yield, superior fruit quality attributes and shelf life in banana.

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