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Direct and residual effect of *Trichoderma* inoculated biocompost with chemical fertilizer on productivity of sugarcane plant-ratoon system

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Abstract
Direct and residual effect of *Trichoderma* inoculated bio compost with chemical fertilizer on productivity of sugarcane plant-ratoon system was conducted from 2012-2016 to in calcareous soil. The dose of K was substituted through bio compost (BC). The application of 100% NPK + BC @ 5 t/ha inoculated with *Trichoderma* was found effective in improving cane and sugar yield, maximum to the tune of 35.0 and 39.6 per cent respectively, in plant crop which was found at par with plots receiving 100% NP +75% K through inorganic fertilizer + 25% K through BC + *Trichoderma.* Number of mill able cane (70-99.1x10^3/ha), cane yield (62.0-83.7 t ha^{-1}) and sugar yield (7.25-10.12 t ha^{-1}) varied significantly due to integrated use of organic and inorganic fertilizer. The residual effect of treatment receiving organic and inorganic fertilizer in combination with *Trichoderma* was also pronounced on number of mill able cane (94.0 x 10^3 ha^{-1}), yield (79.50 t ha^{-1}) and sugar yield (9.32 t ha^{-1}). The uptake of nutrients varied significantly and followed the similar trend as cane yield. *Trichoderma* inoculated bio compost significantly improved the soil properties in terms of organic carbon, available macro and micro nutrients, microbial communities with significant reduction in bulk density of post-harvest soil. The application of *Trichoderma* inoculated bio compost substitute 25% recommended dose of potassium in sugarcane plant-ratoon system. 100% NP +75% K through chemical fertilizer + 25% K through bio compost inoculated with *Trichoderma* improved soil fertility status, nutrient uptake and yield of sugarcane plant-ratoon system in calcareous soil.

Keywords: *Trichoderma*, biocompost, nutrient uptake, soil properties, sugarcane

Introduction
Sugarcane (Saccharum species hybrids) is a very exhaustive crop that can uptake great amount of soil nutrients for its biomass production and as for a cane yield of 100 t ha^{-1} it removes about 205 kg N, 55 kg P_2O_5, 275 kg K_2O and a large amount of micronutrients from the soil (Yaduvanshi and Yadav, 1990) [38]. Deterioration in the physico-chemical and biological properties of the soil is considered to be the prime reason for the declining sugarcane yield and productivity (Speir *et al.*, 2004) [30]. Integrated nutrient management (INM) through balanced use of chemical fertilizers manures and biofertilizers is considered a promising agro-technique to sustain crop yields, increase fertilizer use efficiency and to restore soil fertility (Kennedy *et al.*, 2004) [17]. The application of organic matter from animal manures, crop residues and green manuring has been shown to replenish organic carbon and improve soil structure and fertility. Biocompost is prepared with pressmud and biomethanated distillery effluent in the most of the sugar factory of Bihar and it can be used as a source of organic maunure and nutrients for sugarcane production. The application of biocompost significantly increased yield attributes and crop yield (Davamani *et al.* 2006) [7].

Trichoderma spp. also produce numerous biologically active compounds, like cell wall degrading enzymes, secondary metabolites etc. (Vinale *et al.,* 2008) [35]. Excessive and continuous use of inorganic fertilizers is deteriorating soil quality and crop productivity (Dawe *et al.,* 2003) [8]. Of late, many producers have adopted organic amendments in sugarcane-based production system for sustainable crop growth. Bioagents like *Trichoderma* spp. are now being used to improve the efficacy of organic amendments. Improvements in uptake of nutrients and growth due to application of *Trichoderma* were also noticed (Srivastava *et al*., 2006; Yadav *et al*. 2008) [32, 25]. Uptake of K was found to be higher than N and P in sugarcane as also reported by Shukla *et al*., 2008 [25]. The higher uptake of nutrients might be due to increased biomass in ratoon crop (Muchow *et al.,* 1996; Singh *et al*. 2008b) [21, 26]. Increased nutrition may be directly linked with enhanced yield of ratoon. Efficacy of *Trichoderma* for improving the growth and yield of several short duration crops has been reported by Harman *et al*. (2004) [12] and also established by various workers. Keeping in view the potential of *Trichoderma viride* and available information, the present investigations were conducted to study field performance of *Trichoderma* on soil properties, yield and quality of sugarcane plant-ratoon system in calcareous soil.

Materials and methods

A field experiment was conducted on sandy loam calcareous soils for four years during 2012-13 to 2015-16 i.e., two years in plant crop and two years in ratoon-crop at Crop Research Farm, Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar. The farm is situated at $25^{0}98'$N latitude, $85^{0}67'$E longitude and at an altitude 52.0m above mean sea level and annual rain fall is about 1000 mm. The experimental soil was moderately alkaline (pH 8.25) in nature, rich in free calcium carbonate (31.63%) with low in organic carbon (0.45%) and contains available N (228.0 kgha^{-1}), P_2O_5 (22.2kg ha^{-1}) and K_2O (108.1kg ha^{-1}). The treatment details are T_1: RDF (Control), T_2: 100% NPK + Biocompost @ 5 t/ha + *Trichoderma*, T_3: 100% NP +75% K + 25% through Biocompost + *Trichoderma*, T_4: 100% NP + 50% K + 50% through Biocompost + *Trichoderma* and T_5: 100% NP + 25% K + 75% through Bio-Compost + *Trichoderma*. The BC used in this experiment was characterized and it contains 24.19%, organic carbon 1.53% N, 1.50% P and 3.10% K. The recommended dose of fertilizer (RDF) 150-85-60 kg N-P_2O_5–K_2O /ha were applied through urea, DAP and MOP. The recommended dose of N and P was applied in all the treatments and the dose of K was adjusted as per treatment. *Trichoderma viridae* @ 5.0 kg/ha culture was mixed with biocompost and applied in furrow at the time of planting. The experiment was laid down in RBD with four replications. Plot size was 9.24 m x 5.40 m. Test crop was sugarcane (cv. B.O.147). Half of N and whole P were applied through inorganic fertilizer at the time of planting of sugarcane and the rest half N was top dressed at the time of earthing up. The cane height, cane girth and cane yield data was recorded at the harvesting stage. The quality data was recorded for brix, pol and purity per cent, as described by Chen James (1985). Commercial Cane Sugar per cent (CCS%) was calculated. Sugar yield (CCS t/ha) was obtained by multiplying cane yield (t/ha) with CCS%. The plant samples were analyzed for N, P and K by the standard procedure at harvest stage. The uptake of nutrients by plant was calculated. The experimental soils (0-30 cm depth) were collected at the time of harvesting of ratoon crop (2nd cycle) and analyzed for various physico-chemical properties using standard procedures. Soil samples were analyzed for pH and EC in 1:2 soil suspension ratios. The organic carbon was estimated by method of Walkley and Black (1934) [36]. The available N was determined by using alkaline permanganate method (Subbiah and Asija 1956) [33], available P by method described by Olsen *et al.* (1954) [22] and available K was determined flame photometrically as described by Jackson (1973) [14]. The soil physical properties were analyzed by method described by Blake (1965) [4]. The available micronutrients cations were analysed method describe by Lindsay and Norvell (1978) [20]. The quality of juice was determined using procedure outlined by Spencer and Meade (1964) [31]. Soil microbial colonies were determined using the methods of plate culture count as described by Li *et al.* (2008) [19]. The data obtained were analyzed statistically.

Results and discussion

Effect on NMC and cane yield

The pooled data (Table 1) indicated that application of inorganic fertilizer along with BC with *Trichoderma* significantly increased NMC and cane yield of sugarcane. The treatment T_2 receiving 100% NPK + BC along with *Trichoderma* produced highest NMC (99.1 x10^3/ha) and yield (83.7 t/ha) of plant crop which was found at par with treatment T_3 receiving 100% NP +75% K through inorganic fertilizer +25% K through biocompost. Similarly, residual effect of treatment T_2 was also pronounced on NMC (94.0 x 10^3/ha) and yield (79.5 t/ha) of ratoon crop. The result indicated that application of K through both from organic and inorganic sources along with *Trichoderma* were found beneficial for obtaining higher yield of plant and ratoon crop. However, difference in yield was non-significant between treatment T_4 and T_5 receiving lower dose of inorganic fertilizer as K. The result clearly indicated that substitution of 25% K through BC along with *Trichoderma* was superior in increasing cane yield of plant and ratoon crop. *Trichoderma viride* has strong capacity to mobilize and take up soil nutrient specially K which may promote the growth of the plant (Benitez *et al.,* 2004) [2]. Efficacy of *Trichoderma* for improving the growth and yield of several crop plants has been established by several workers (Harman *et al.,* 2004, Srivastava *et al.,* 2006) [12, 32]. Singh *et al.* (2010) [28] observed that *T. harzianum* enhanced the availability and uptake of nutrients. Increased nutrition may directly link with cane yield.

Sugar yield

The integrated effect of BC and inorganic fertilizer along with *Trichoderma* significantly improved sugar yield in plant cane and ratoon crop (Table 1). The highest sugar yield was recorded in treatment T_2 (10.12 t ha^{-1}) which was found at par with T_3 and T_4 and lowest was observed in control (7.25 t ha^{-1}). The application of 100% NPK + BC @ 5 t/ha + *Trichoderma* was found effective in improving sugar yield maximum to the tune of 39.6 per cent in plant crop which was found at par with plots receiving 100% NP +75% K through IF + 25% K through BC + *Trichoderma.* The residual effect of treatment receiving organic and inorganic fertilizer in combination with *Trichoderma* was also pronounced on sugar yield of ratoon crop (9.32 t ha^{-1}). Hari and Srinivasan (2005) [11] evaluated the response of sugarcane varieties and nitrogen fixing diazotrophs viz., *Azotobacter*, *Azospirillum* and *Gluconacetobacter* under different levels of fertilizer nitrogen and reported significant improvement in the yield and sugar content of bio-fertilizer inoculated sugarcane plants compared to un inoculated control. Thakur and Singh (1996) [34] reported that the use of different bio-fertilizers like *Azotobacter*, *Azospirillum* and Phosphorus fixing bacteria (*Bacillus megatherium*) alone or in combined use of these micro-organisms significantly increased the sugar yield.

Table 1: Effect of integrated use of inorganic and organic fertilizer with *Trichoderma* on NMC, yield and sugar yield of sugarcane plant- ratoon system (pooled data of two years)

Treatments	NMC (000/ha)		Yield (t/ha)		Cane yield Response over control (%)		Sugar yield (t/ ha)		Sugar Yield response over control (%)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
T_1: RDF(Control)	70.0	60.1	62.0	60.4	-	-	7.25	6.40	-	-
T_2: 100% NPK + BC @ 5 t/ha + *T richoderma*	99.1	94.0	83.7	79.5	35.00	31.62	10.12	9.32	39.59	45.63
T_3: 100% NP +75% K through IF + 25% K through BC + *Trichoderma*	92.0	90.5	79.6	77.9	28.39	28.97	9.51	9.14	31.17	42.81
T_4: 100% NP + 50% K through IF + 50% K through BC+ *Trichoderma*	86.1	85.1	72.5	69.3	21.77	14.74	8.12	7.90	12.00	23.44
T_5: 100% NP + 25% K through IF + 75% K through BC + *Trichoderma*	77.2	74.6	68.6	66.2	10.65	9.60	7.97	7.72	9.93	20.63
SEm ± CD (P= 0.05)	5.57	5.39	3.92	3.82	-	-	0.26	0.28	-	-
	18.40	16.12	12.93	10.20	-	-	0.87	0.91	-	-

BC; Biocompost, RDF; N_{150} P_{85} K_{60}, IF-Inorganic fertilizer

Nutrient uptake

The nutrient uptake by plant and ratoon (Table 2) significantly increased due to application of organic manure and *Trichoderma* along with inorganic fertilizer over control. The highest uptake was recorded in treatment T_2 receiving 100% NPK + BC @ 5 t/ha along with *Trichoderma* and lowest in control. The combined use of BC along with *Trichoderma* and inorganic fertilizer resulted higher uptake of nutrient in T_2 to T_4 treatments. The data further revealed that among major nutrients relatively higher K uptake was recorded which was followed by N and P. The higher cane yield coupled with integration of nutrients through organic and inorganic sources resulted more nutrients uptakes (Bhalerao *et al.* 2006) [3]. Singh *et al.* (2007) [27] also indicated a positive balance of soil N, P and K in the plots treated with bio-manures in multi-ratooning sugarcane system. Improvement in the cane yield at all nitrogen levels due to the application of FYM and bioagents clearly indicated the role of improved availability of P and K in these treatments. Shukla *et al.* (2008) [25] also indicated the role of *Trichoderma* and *Gluconacetobacter* in improving sugarcane ratoon yields due to improved soil carbon and nitrogen status. Overall inclusion of BC and bio-agents *Trichoderma* for nutrient mobilization has proved be to beneficial for sugarcane productivity and saving K fertilizer; consequently, the amount of K-fertilizer could be reduced and these beneficial bioagents should be recommended for their use in integrated nutrient management.

Table 2: Effect of integrated use of inorganic and organic fertilizer with *Trichoderma* on NMC, yield and sugar yield of sugarcane plant- ratoon system (pooled data of two years)

Treatments	Uptake of macro nutrient (kg/ha)						Uptake of micro nutrient (g/ha)					
	Plant			Ratoon			Plant			Ratoon		
	N	P	K	N	P	K	Zn	Fe	Mn	Zn	Fe	Mn
T_1: RDF(Control)	140.0	13.06	149.3	125.5	10.71	133.9	44.24	553.8	197.9	39.83	495.6	187.5
T_2: 100% NPK + BC @ 5 t/ha + *Trichoderma*	191.5	17.88	204.6	176.8	16.66	195.3	53.14	678.4	240.2	51.56	657.5	232.9
T_3: 100% NP +75% K through IF + 25% K through BC + *Trichoderma*	184.5	17.25	196.5	174.4	16.08	193.4	51.68	658.4	232.6	50.50	642.9	227.2
T_4: 100% NP + 50% K through IF + 50% K through BC+ Trichoderma	171.5	15.93	181.1	170.0	15.40	178.9	48.10	610.6	215.9	45.82	580.7	215.4
T_5: 100% NP + 25% K through IF + 75% K through BC + *Trichoderma*	163.1	15.69	175.5	150.5	14.71	163.7	44.72	566.4	201.5	41.13	521.2	182.1
SEm ± CD (P= 0.05)	7.64	0.76	6.42	6.62	0.75	9.30	2.73	4.51	2.91	1.90	12.31	12.8
	25.32	2.52	21.28	19.42	2.57	28.57	7.37	13.85	8.95	5.24	36.83	36.5

BC; Biocompost, RDF; N_{150} P_{85} K_{60}, IF-Inorganic fertilizer

Soil properties

Addition of organic manure with *Trichoderma* in combination with inorganic fertilizer significantly improved the soil fertility in terms of organic carbon and availability of macro and micro nutrients (N, P, K, Zn, Cu, Mn and Fe) with significant reduction in bulk density of post-harvest soil (Table 3). The application of organics in combination with inorganic fertilizer and *Trichoderma* significantly decreased pH and lowest being in T_2 (8.07) receiving 100% NPK + BC @ 5 t ha^{-1} along with *Trichoderma* and highest in control (8.20). In contrast, significant increase in EC was recorded in biocompost treated plot with maximum increase in T_2 (0.45dS m^{-1}). The reduction in pH might be due to production of weak organic acids due to decomposition of biocompost followed by increase in salt content of soil due to mineralization, which increase EC of soil. Bhalerao *et al.* (2006) [3] also reported that the soil pH reduced while EC increased due to application of bio-compost. There was significant effect of treatments receiving BC on organic carbon and available N, P_2O_5, K_2O and micro nutrient content of soil after harvest of crop over control. The highest organic carbon was observed in T_2 over control. The treatments varied significantly for available nutrients with N (230.4 to 258.7 kg ha^{-1}), P_2O_5 (22.30 to 39.10 kg ha^{-1}) and K_2O (118.7 to 146.5 kg ha^{-1}). The buildup of soil available nutrient could be attributed to greater multiplication of microbes due to addition of biocompost, which helps in mineralization as well as solubilization of native nutrients. The data also indicated that cations especially Ca^{2+}+Mg^{2+} content of soils significantly increased in treatments of biocompost. This might be resulted due to solubilization of nutrients by complexation of nutrients by humic and fulvic acid present in bio-compost (Prasad and Sinha 1984) [23]. The result also indicated that application of only inorganic fertilizer (T_1) was not effective for maintenance of soil fertility in sugarcane plant as reflected from initial value. Soil available nutrients and organic carbon sustained in all the organic manure and *Trichoderma* treated plots. The bulk density of post-harvest soil varied significantly (1.34 to 1.38 g/cm^3) with addition of organic manure and *Trichoderma* (Table 3). The reduction in bulk density resulted in increased pore space of soil with increasing level of organic manure. The maximum reduction (1.34 g/cm^3) unit in bulk density was recorded in treatment T_2 as compared to control. Beneficial effect of BC in improvement of physical and chemical condition of soil may be attributed to improvement in organic matter status in biocompost treated soil resulted in improved soil fertility (Sharma *et al*. 2006; Sinha *et al*. 2014; Jha *et. al*. 2015) [24, 29, 16]. Higher soil organic matter following the application of manure like sulphitation press mud has been reported by Dee *et al*. (2003) [9] under sugarcane growing conditions which often witness a loss of soil organic matter under conventional agriculture (Haynes and Hamilton, 1999) [13]. Slow release of nutrients in the presence of FYM/biocompost improves the soil fertility compared to chemical fertilizer applications (Chowdhary *et al.*, 2004) [6] and the use of bioagents by immobilization retain soil nutrients in the plant-soil system and reduces leaching losses (Kennedy *et al*., 2004) [17]. Increased soil carbon due to application of bioagents and FYM sustains soil health for a longer period than the chemical fertilization (Jeyabal and Kuppuswamy, 2003; Amlinger *et al*., 2003) [15, 1]. The application of FYM/biocompost along with recommended rates of chemical fertilizers have been advocated for accumulation and sequestration of C, improved biological activity and soil fertility (Zaller and Kopke, 2004; Dwivedi and Dwivedi, 2007) [39, 10] and enrichment with bioagents increased the efficiency of different organic amendments (Jeyabal and Kuppuswamy, 2003) [15].

Table 3: Effect of integrated use of inorganic and organic fertilizer with *Trichoderma* on NMC, yield and sugar yield of sugarcane plant- ratoon system (pooled data of two years)

Treatment	pH	EC dS/m)	Organic Carbon (g/kg)	Bulk density (g/cm^3)	Ca^2 + Mg^+ (m/L)	Available Nutrients (kg/ha)			Soil Micro Nutrients (ppm)			
						N	P_2O_5	K_2O	Zn	Cu	Mn	Fe
T_1: RDF(Control)	8.20	0.33	4.6	1.38	10.60	230.4	22.30	118.7	0.68	0.76	4.0	6.7
T_2: 100% NPK + BC @ 5 t/ha + *Trichoderma*	8.07	0.45	6.9	1.34	12.27	258.7	39.10	146.5	0.86	0.85	5.4	9.6
T_3: 100% NP +75% K through IF + 25% K through BC + *Trichoderma*	8.10	0.40	6.7	1.35	11.70	254.8	33.50	142.4	0.83	0.82	4.9	8.8
T_4: 100% NP + 50% K through IF + 50% K through BC+ Trichoderma	8.13	0.43	5.8	1.36	10.96	248.4	27.96	131.3	0.81	0.79	4.6	8.7
T_5: 100% NP + 25% K through IF + 75% K through BC + *Trichoderma*	8.14	0.46	5.7	1.36	10.93	238.4	26.60	129.8	0.73	0.78	4.4	8.2
SEm $\pm$ CD (P= 0.05)	0.02	0.02	0.1	0.02	0.26	7.08	0.50	3.53	0.05	0.01	0.08	0.23
	0.06	0.05	0.3	NS	0.85	21.47	1.67	10.70	0.14	0.03	0.26	0.77

BC; Biocompost, RDF; N_{150} P_{85} K_{60}, IF-Inorganic fertilizer

Microbial populations

The microbial population viz. bacteria, actinomycetes and fungi significantly increased (Table 4) with addition of organic manure and *Trichoderma* over control. The highest population of bacteria (39.5 x 10^6), actinomycetes (18.31 x 10^4), fungi (21.80 x 10^5) were observed in treatment T_2 receiving 100% NPK + BC @ 5 t/ha along with *Trichoderma* and lowest in control. These results explained the improvement in microbial population of soil due to application of organics. Kumar *et al* (2015) [18] also observed that in both plant and ratoon crops enumeration of *Azotobacter*, PSB, fungi, bacteria, actinomycetes in rhizosphere indicated that the population of all the groups was higher when bio-fertilizers were applied in combination with inorganic fertilizers. Microorganisms utilized organic carbon as a source of energy, nutrient and for nourishment which resulted in proliferation of soil microorganism. The increased activity of microflora in organic manure and *Trichoderma* treated soil may be due to high organic matter build up with application of organic manure.

Table 4: Effect of integrated use of inorganic and organic fertilizer with *Trichoderma* on NMC, yield and sugar yield of sugarcane plant- ratoon system (pooled data of two years)

Treatments	Microbial population					
	Bacteria (10^6cfu g^{-1})	Population increase over control (%)	Actinomycetes (10^5cfu g^{-1})	Population increase over control (%)	Fungi (10^4cfug^{-1})	Population increase over control (%)
T_1: RDF(Control)	23.7	-	11.90	-	12.70	-
T_2: 100% NPK + BC @ 5 t/ha + *Trichoderma*	39.5	66.67	18.31	53.78	21.80	71.65
T_3: 100% NP +75% K through IF + 25% K through BC + *Trichoderma*	36.6	54.43	15.50	30.25	20.60	62.20
T_4: 100% NP + 50% K through IF + 50% K through BC+ *Trichoderma*	34.8	46.84	13.80	15.97	16.90	33.07
T_5: 100% NP + 25% K through IF + 75% K through BC + *Trichoderma*	32.2	35.86	13.60	14.29	15.61	22.83
SEm $\pm$ CD (P= 0.05)	0.61 2.06	-	0.45 1.52	-	0.42 1.43	-

BC; Biocompost, RDF; N_{150} P_{85} K_{60}, IF-Inorganic fertilizer

Conclusion

The application of *Trichoderma* inoculated biocompost substitute 25% recommended dose of potassium in sugarcane plant-ratoon system. Thus, application of 100% NP +75% K through chemical fertilizer + 25% K through biocompost along with *Trichoderma* improved soil fertility, bulk density and microbial population which in turn helped in getting better sugarcane production system in calcareous soil.

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