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Role of crop residues in improving soil fertility and succeeding crops

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Abstract
Bio-degradation of crop residues *viz*; wheat trash, paddy trash, and cane trash employing urea and *Trichoderma* species have been studied under field condition. Application of 40 kg urea and 10 kg carrier based *Trichoderma harzianum* on these crop residues elevated assimiable nitrogen, phosphorus, potash and sulphurcontent of the soil with increase in the organic carbon at 60 days of their incorporation on the crop residues. Decomposition of the crop residues involved narrowing down of the C:N ratio by urea nitrogen followed by microbial decomposition by the *Trichoderma* fungus and thus elevation in the soil accessible nutrients and its health. The higher yield of paddy after wheat trash decomposition, yield of wheat after paddy trash, and yield of ratoon cane after plant cane trash decomposition owing to 40 kg urea and 10 kg *Trichoderma* species usage itself delineates the better soil physico-chemical, microbial and nutritional conditions. Additionally, their *in-situ* incorporation in the soil makes a fruitful and easy management of the crop residues, which is a concern for the succeeding crops, apart from saving the environment being intoxicated due to residues burning hazards.

Keywords: Crop residues, sugarcane trash, wheat trash, paddy trash, *Trichoderma*, soil, decomposition

Introduction

Crop residues are an important renewable source that can be managed to conserve soil fertility status, non-renewable soil and water resources, sustain crop productivity and substituting a part of fertilizer requirement. Residue amendments have potentials to restrict soil erosion, control weeds and plant diseases, exert good impact on soil structure, nutrient recycling, and soil water and soil temperature conservation. Recycling of organic waste by the process of composting in agriculture brings in the much needed organic matter to the soil and improves the overall soil fertility and soil productivity (Chukwuka and Omotayo, 2008; Ansari, 2011).

In our country crop residues or straw are mostly used ascattle feed while in developed countries they are mostly burnt in the field itself. Presently in our country also due to the advent of combine harvesters the crop residues like wheat, cane leaf and paddy straw are getting customary to be burnt in the field (Gupta *et al*. 2004) [14]. Biomass burning of agricultural field residue (stalks and stubble) during wheat and rice harvesting periods, in the Indo-Gangetic plains, is an important source of atmospheric pollution in this region (Kirkby, 1999; Venkataraman *et al*. 2006; Sindhu and Beri, 2008) [16, 44, 37].

Burning of the crops residues in the field results in atmospheric pollution, exert deleterious effect on the soil micro flora and loss of plant nutrients and organic matter (Rasmussen, 1980; Sharma and Mishra, 2001) [27, 33]. The magnitude of C and nutrient loss (N & P: 25%, K: 20% and S: 5 to 60%) during burning is influenced by the quantity of residue burned and the intensity of the fire (Sharma and Mishra, 2001; Dobermann and Fairhurst, 2002) [27, 6]. Consequently, regional climate, and consequently crop output (Auffhammer *et al*. 2006) [2], and the health (Long *et al*. 1998) [19] of the population are adversely affected. Crop residues have got good manurial values since it contains about 0.5% nitrogen, 0.6% phosphorus and 1.5% potassium. About 330 mt of crop residues are produced every year in India and if 1/3rd of these can recycle *in-situ* this can add 2.47 mt of NPK in the soil annually. In an future projection about 496 mt of crop residues estimated to be during 2025 and if 33% of these residues are tapable *in-situ* there could be an availability of 3.39 mt of NPK along with increase in organic carbon, soil physico-chemical and biological activities and their conservation.

The practice of burning the sugarcane residues to facilitate harvest and transport operations has been widespread.

Due to environmental, agronomic and economical reasons, the manual harvest of sugarcane has been gradually replaced by mechanical harvest with maintenance of the dry leaves and tops on the field, in a system called green cane management. The mulch formed influences the whole production process of sugarcane, influencing yields, fertilizer management, soil erosion and soil organic matter dynamics. The effects of sugarcane trash maintenance on the soil have been studied with focus on root growth and turnover (Ball-Coelho *et al*. 1992), soil nitrogen dynamics (Meier *et al*. 2006) [23], soil erosion (Sparovek and Schnug, 2001) [40], soil temperature and water content (Dourado *et al*. 1999) [7], soil bulk density (Tominaga *et al*. 2002) [43], soil aggregate stability (Graham *et al*. 2002) [13], soil carbon sequestration (Cerri *et al*. 2004; Resende *et al*. 2006) [28], and allelopathic effects (Sampietro *et al*. 2006; Viator *et al*. 2006) [30, 45].

In northern India three major crops *viz*; wheat, paddy and cane produce huge amount of residues which are generally burnt in the field nowadays leading to environmental pollution and thus becoming a great concern to the environmentalists. Their *in-situ* decomposition not only restricts the environmental pollution but elevate also the chemical and biological structure of the soil. Since residues contain high organic carbon their incorporation merely in the soil will led to more time span for proper decomposition thus some facilitator has to be incorporated with residues. It has been established that residues contain high C/N ratio which create problems in decomposition and so N as urea (40 kg/ha) is applied on the field on residues to narrow down C/N ratio which in turn become easy access to the microbial decomposition (Singh, 1991; Shen *et al*. 1993) [35]. In addition straw decomposition can be accelerated further by inoculation with microorganisms *viz*; *Trichoderma* species, *Aspergillus awamori*, *Paecilomyces fusisporus* (Goyal and Sindhu, 2011) [11]. These lignolytic and cellulolytic, saprophytic micro-organisms would be of immense importance in decomposing N as high as 12 mg/g straw (Lynch and Harper, 1985) [20].

In an extensive study under pit condition it has been found that *Trichoderma* exhibit great potentials to decompose paddy, wheat and cane trash with elevation in nutrients status of the compost (Sharma *et al*. 2011) [31]. Apart from its decomposing characteristics it acts as bio-pesticide against many fungi and micro-organisms and thus saves from different crop diseases (Benitz *et al*. 2004) [3].

Keeping that in view it was thought plausible to conduct an experiment to recycle wheat trash, paddy trash and cane trash *in situ* utilizing *Trichoderma* micro-organisms in field condition to restrict these residues burning in the field which not only check the environmental pollution but exert beneficial effect on soil physical, chemical and biological conditions and evaluate the impact of decomposed residues on soil fertility status and succeeding crops thereafter.

Materials and Methods

A field experiment was conducted in randomised block design for consecutive three years at the experimental farm of UP Council of Sugarcane Research Shahjahanpur (GSSBRI Seorahi), to evaluate the effectiveness of *Trochoderma* fungi in decomposing post harvested wheat trash, paddy trash and cane trash *in situ*. Experimental protocol (treatments) consisted of *Trochoderma* alone, 10 kg/ha, 20 kg urea alone/ha, 40 kg urea alone/ha, 10 kg *Trichoderma*+20 kg urea/ha, 10 kg *Trichoderma*+40 kg urea/ha and control (without any treatment). The field with respective crop residues *viz*. wheat trash, paddy trash and cane trash was irrigated 48 hrs before application of *Trichoderma* decomposer. Prior to decomposer application urea doses were top dressed on the residues in the field. Carrier based 10 kg *Trichoderma harzianum* was mixed with 40 kg of press mud cake and left overnight moistening with 20% water and applied in the field by broadcasting and field was ploughed thoroughly. Under wheat trash (C: 47.15%, N: 1.10%, P: 0.081%, K: 1.31%, S: 0.315%, C/N: 42.73) decomposition experiment treatments were applied *in situ* on the wheat trash residues left after combine harvesting of wheat and similarly after combine harvesting of paddy the same treatments were applied on paddy trash residues (C: 42.38%, N: 1.00%, P: 0.080%, K: 1.42%, S: 0.331%, C/N: 42.38). Likewise same treatments were applied on the cane trash (C: 45.15%, N: 0.55%, P: 0.085%, K: 0.64%, S: 0.279%, C/N: 82.10) left after harvesting of plant cane. The soil conditions were almost similar for all these experiments. Experimental soils exhibited alkaline in nature and had pH: 8.10-8.21, EC: 0.10-0.19 dsm^{-1}, $CaCO_3$: 22.0-32.2%, Organic carbon: 0.39-0.60%, available P: 6.90-10.86 ppm, available K: 22.0-35.0 ppm, and available S: 3.10-8.83 ppm. Soil samples from each treatments were collected at 30 and 60 days after decomposer application and analysed for organic carbon, available P, available K, available S and their pH values through standard procedures (Singh *et al*. 1987) [38].

The paddy planting was done in the field after wheat trash management and wheat crop was sown in the field after paddy trash management during appropriate succeeding seasons, maintained as per standard agronomic practices and yield data in each treatment were recorded for the both crops. Similarly ratoon cane crop was maintained in the field for the cane trash experiment and yield data as well as cane juice analysis were done at harvesting period.

Results and Discussions

The year wise and mean analytical results of the three years regarding soil organic carbon, available phosphorus, potash and sulphur, soil pH values at 30 and 60 days have been presented in the Tables 1-5. Table 6 delineates the yield of paddy after wheat trash, yield of wheat after paddy trash, yield of ratoon cane after cane trash bio-degradation and ratoon cane juice quality at harvest.

The mean results indicated that application of increasing doses of urea on any of the crop residues increased significantly the soil organic carbon, available P, K and S with highest at 60 days after application *viz*. 0.71%, 12.6 ppm, 33.89 ppm and 14.55 ppm over control *viz*. 0.61%, 10.73 ppm, 29.0 ppm and 9.20 ppm, respectively (Tables 1-4). Additionally, *Trichoderma harzianum* incorporation on either of the crop residues further accentuated the bio-degradation process as indicated by elevation of organic carbon-0.70%, available P: 12.09 ppm, available K: 33.08 ppm and available S: 13.17 ppm over control *viz*. 0.64%, 11.37 ppm, 30.26 and 10.97 ppm, respectively (Tables 1-4). It has been elucidated earlier that bare incorporation of residues in the soil may result into adverse effect on the soil available nutrients due to immobilization of nutrients by the presence of wide C/N ratio residues un- accessible to microbial population present in the soil. On the other hand nitrogen application on the residues narrows down the C/N ratio which ultimately becomes easy access for the microbial population and thus decomposition of the residues resulting into increased organic matter and available nutrients (Mandal *et al*. 2004). Sharma *et al*. (2011) [31] in a composting experiment under pit condition observed that concomitant application of *Trichoderma* species hastened the process of press mud cake (PMC), wheat trash, paddy trash and cane trash bio-degradation and produced a compost having elevated level of accessible N, P, K and S (Saha *et al*. 1995) [29]. This lignolytic and cellulolytic saprophytic micro-organism *viz*. *Trichoderma* species feed on the carbon of these bio molecules for its survival and growth lowering down the carbon content of these residues and leaving behind the P, K and S and thus increase in the level of these nutrients in the soil. Crop residues like wheat trash paddy trash and cane trash are lignocellulosic materials which are resistant initially to microbial degradation due to high C:N ratio. Treatment of crop residues with urea solution at the commencement of the experiment certainly narrowed down the C:N ratio and seems essential for hastening the decomposition. The inoculation by *Trichoderma* species further accentuated the decomposition process and thus substantially lowering of the C:N ratio (Goyal and Sindhu 2011) [11]. It is likely that a two step process for degradation would have followed as the primary stage to narrow down C/N ratio of residues by application of urea, hydrolysis of micro-molecules by acid /base reaction of the urea followed by secretion of the extracellular-enzymes for breaking down polymers as well as sequestration of the carbon from the residues resulting into its decomposition (Michael *et al*. 1989; Sreeniwas and Narayanasamy 2003) [24, 41].

Among the residues wheat trash was more prone to decompose followed by cane trash and paddy trash as elevated soil organic carbon, available P and S were observed due to wheat trash and cane trash incorporation at 60 days after treatment, while more soil K content was noted due to paddy trash incorporation (Table 1-4). Rice crop residues are highly siliceous and thus its low degradation. Similar findings were observed by Sharma *et al*. (2011) [31] under pit condition experimentation in which K was found elevated when paddy trash was composted. Garnier *et al*. (2003) [10] have studied wheat straw decomposition and Findeling *et al*. (2007) [8] have simulated rye and rape residue decomposition. Ma *et al*. (1999) [21] comparing the performance of different methods in the simulation of decomposition of wheat, corn, millet, sorghum and sunflower residue. Previously reported the decomposition of wheat and barley straw under field condition (Christensen, 1985) [5]. The decomposition of sugarcane trash was previously reported (Thorburn *et al*. 2001; Galdos *et al*. 2010) [42, 9].

The length of the period allowed for decomposition of crop residues before the sowing/planting of the next crop effects the agronomic response to applied residues. Houng and Hwa (1975) [15] found that when rice straw was allowed to decompose for 4 or more weeks before sowing, there was no adverse effect on germination of rice seeds. In many other studies, crop residues were allowed to decompose for 2 or more weeks before rice transplanting to avoid the adverse effects of phytotoxicity and N immobilization on crop growth (Ali *et al*. 1995; Lanjewar *et al*. 1992; Wu *et al*. 1997) [1, 18, 46]. Sharma and Mitra (1990) observed that rice yields were increased significantly when rice straw was applied 30 days before transplanting, and rice straw also exhibited a favorable residual effect on the yield of the second rice crop as well as wheat field (Sharma, 2001; Mishra *et al*. 2001b; Singh *et al*. 2004) [34, 25, 14].

A close view of table- 5 depicted that slight lowering of the soil pH value happened when 40 kg of urea and 10 kg of *Trichoderma* species/ha was applied on the residues indicated that production of organic acids such as formic, acetic, propionic, iso-butyric and iso-valeric which decreases soil pH value (3.95–6.65) and increased almost linearly (Simandi *et al*. 2005; Graham *et al*. 1986) [12]. Organic acids accumulate around straw only in the early stages of the decomposition and if straw breakdown could be accelerated by inoculation with micro-organisms or other means, the acid production danger would be reduced (Kumari *et al*. 2008; Rashid *et al*. 2004) [17, 26]. Among these residues cane trash was effective more to decrease the soil pH.It is evident that calcareous soils are having more pH value *viz*. <8.0 and thus availability of nutrients *viz*. phosphorus, zinc and boron becomes meagre reflecting decrease in productivity of the pulses crops. Lowering of the pH value by repeated treatment of these residues *in situ* might be beneficial in this soil for production of pulses crops.

The mean value of the yield of paddy after wheat residue treatment, wheat after paddy residue treatment and ratoon cane after cane trash treatment indicated that 40 kg urea + 10 kg *Trichoderma harzianum* treatment resulted highest yield of these crops which are owing to the higher available nutrients upon decomposition of these residues. Noremarkable change was noted in the juice quality of ratoon cane.

Table 1: Effect of crop residues management on soil organic carbon.

Treatments	Soil organic C%							
	30 Day				60 Day			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Residue								
Wheat trash	0.63	0.60	0.51	0.58	0.73	0.70	0.66	0.70
Cane Trash	0.73	0.63	0.56	0.64	0.79	0.65	0.65	0.70
Paddy Trash	0.61	0.57	0.55	0.58	0.63	0.60	0.56	0.60
Urea kg/ha								
0	0.57	0.53	0.52	0.54	0.64	0.60	0.59	0.61
20	0.69	0.62	0.54	0.62	0.73	0.68	0.63	0.68
40	0.71	0.65	0.56	0.64	0.78	0.71	0.65	0.71
Decomposer kg/ha								
0	0.64	0.58	0.53	0.58	0.68	0.64	0.61	0.64
10	0.67	0.62	0.55	0.61	0.76	0.70	0.64	0.70
CD at 5%								
Urea	0.021	0.014	0.012		0.014	0.010	0.016	
Residue	0.040	0.014	0.012		0.029	0.010	0.016	
Decomp	nil	0.012	0.010		0.024	0.008	0.013	
RxD	0.030	0.021	0.016		nil	0.014	0.022	
RxDxU	nil	0.034	Nil		nil	0.024	Nil	

Table 2: Effect of crop residues management on soil available phosphorus.

Treatments	Soil available P (ppm)							
	30 Day				60 Day			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Residue								
Wheat trash	11.06	9.93	14.87	11.95	12.54	11.63	15.71	13.29
Cane Trash	11.61	11.40	8.33	10.54	12.19	12.09	9.91	11.40
Paddy Trash	10.10	9.31	8.12	9.18	11.79	10.57	9.05	10.48
Urea kg/ha								
0	7.75	8.50	9.49	8.58	11.04	10.51	10.63	10.73
20	11.82	10.55	10.48	10.95	12.36	11.51	11.78	11.88
40	12.61	11.55	11.41	11.86	13.24	12.22	12.33	12.60
Decomposer kg/ha								
0	10.57	9.64	10.10	10.10	11.79	11.07	11.26	11.37
10	11.88	10.78	10.82	11.16	12.67	11.75	11.84	12.09
CD at 5%								
Urea	0.41	0.75	0.71		0.33	0.82	0.89	
Residue	0.41	0.75	0.71		0.33	0.82	0.89	
Decomp.	0.33	0.61	0.59		0.27	0.67	Nil	
RxD	0.57	nil	Nil		nil	Nil	Nil	
RxDxU	0.98	1.84	Nil		nil	Nil	Nil	

Table 3: Effect of crop residues management on soil available potash.

Treatments	Soil available K (ppm)							
	30 Day				60 Day			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Residue								
Wheat trash	28.18	26.53	35.52	30.08	30.15	29.21	39.67	33.01
Cane Trash	25.88	25.80	25.69	25.79	27.18	26.76	26.54	26.83
Paddy Trash	43.66	28.78	26.25	32.90	45.30	32.64	27.59	35.18
Urea kg/ha								
0	29.76	25.17	27.53	27.49	31.43	26.87	28.73	29.00
20	33.30	27.31	29.40	30.00	34.48	30.12	31.76	32.12
40	34.66	28.67	30.53	31.29	36.71	31.64	33.31	33.89
Decomposer kg/ha								
0	31.15	26.18	28.44	28.59	32.56	28.02	30.21	30.26
10	34.00	27.87	29.86	30.58	35.85	31.06	32.32	33.08
CD at 5%								
Urea	1.94	0.57	0.83		1.45	1.06	1.36	
Residue	1.94	0.57	0.83		1.45	1.06	1.36	
Decomp.	1.59	0.47	0.67		1.18	0.86	1.1	
RxD	nil	nil	Nil		nil	1.49	1.93	
RxDxU	nil	nil	Nil		nil	2.59	Nil	

Table 4: Effect of crop residues management on soil available sulphur.

Treatments	Soil available S (ppm)							
	30 Day				60 Day			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Residue								
Wheat trash	7.97	6.96	7.73	7.56	13.19	11.63	11.54	12.12
Cane Trash	11.22	10.89	10.57	10.89	13.44	12.99	12.13	12.85
Paddy Trash	8.65	6.89	6.92	8.15	13.50	11.36	8.82	11.23
Urea kg/ha								
0	7.21	5.88	6.83	6.64	9.75	9.05	8.80	9.20
20	9.66	8.79	8.57	8.84	13.79	12.53	11.06	12.46
40	10.97	10.03	9.83	10.28	16.63	14.39	12.64	14.55
Decomposer kg/ha								
0	7.88	6.46	7.45	7.26	11.84	10.99	10.08	10.97
10	10.67	10.04	9.36	10.02	14.95	12.98	11.58	13.17
CD at 5%								
Urea	0.49	0.59	1.06		0.92	0.69	1.06	
Residue	0.49	0.59	1.06		nil	0.69	1.06	
Decomp.	0.41	0.49	0.85		0.75	0.57	0.87	
RxD	0.71	nil	Nil		1.31	Nil	Nil	
RxDxU	1.22	1.47	Nil		2.26	1.69	Nil	

Table 5. Effect of crop residues management on soil chemical reaction.

Treatments	Soil pH value							
	30 Day				60 Day			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Residue								
Wheat trash	8.19	8.18	8.17	8.18	8.18	8.12	8.13	8.15
Cane Trash	8.17	8.13	8.13	8.14	8.07	8.08	8.12	8.09
Paddy Trash	8.07	8.22	8.19	8.16	8.04	8.14	8.13	8.10
Urea kg/ha								
0	8.16	8.18	8.18	8.17	8.09	8.12	8.14	8.12
20	8.17	8.19	8.16	8.17	8.11	8.10	8.12	8.11
40	8.10	8.15	8.14	8.13	8.10	8.12	8.11	8.11
Decomposer kg/ha								
0	8.17	8.19	8.18	8.18	8.11	8.12	8.13	8.12
10	8.12	8.16	8.15	8.14	8.09	8.10	8.12	8.10

Table 6: Effect of crop residues management on the yield of succeeding crops as well as quality of ratoon cane.

Treatments	Paddy yield after wheat trash (q/ha)				Wheat yield after paddy trash (q/ha)			
	Year				Year			
	I year	II year	III year	Mean	I year	II year	III year	Mean
Urea kg/ha								
0	40.83	36.18	43.85	40.28	19.72	26.25	19.00	21.65
20	43.88	38.60	46.75	43.07	20.72	27.32	20.40	22.81
40	45.43	42.12	48.20	45.38	21.55	28.65	21.25	23.82
Decomposer kg/ha								
0	42.81	38.21	45.10	42.04	20.25	26.28	19.37	22.14
10	44.22	39.72	47.33	43.75	21.08	28.05	20.80	23.31
	Ratoon yield after cane trash (mt/ha)				**Sucrose% in ratoon cane juice**			
Urea kg/ha								
0	67.29	57.21	59.04	61.18	17.57	14.80	15.28	15.88
20	68.42	63.40	61.08	64.30	17.85	14.63	15.62	15.96
40	71.36	65.18	61.96	66.16	18.04	14.88	15.82	16.24
Decomposer kg/ha								
0	68.23	60.69	59.82	62.91	17.85	14.75	15.52	16.04
10	69.82	63.18	61.57	64.85	17.79	14.79	15.62	16.06

Conclusion

Thus finding of this study revealed that application of urea followed by *Trichoderma* species on moist crop residues left after combine harvesting in the field exhibited in elevating soil organic matter, available nutrients, physico-chemical conditions of the soil and yield of the succeeding crops. An assessment of farmer straw management practices is an important part of developing fertilizer recommendations. The major impact of straw removal is on the soil K balance. Complete straw removal over several cropping seasons without replenishing soil K with mineral fertilizer is likely to lead to increased incidence of K deficiency. Additionally meaningful management of these organics safeguards the environment being intoxicated by hazardous burning impacts and increases the soil health for sustainable crop production. This process could be used to build scenarios in order to evaluate the long term impact of best management practices on soil quality, aiming at environmental and agronomic sustainability.

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