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Integrated use of crop residues and fertilizers for sustainability of potato (*Solanum tuberosum*) based cropping systems in Bihar

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ABSTRACT

A field experiment was conducted at Patna for 4 years (2002-03 to 2005-06) on a fixed site to study the effect of crop residues(CR) recycling along with 2 levels of recommended dose of NPK fertilizers (RDF) i.e. RDF and 125% RDF in two potato (*Solanum tuberosum* L.) based cropping systems [potato-onion (*Allium cepa* L.)-rice (*Oryza sativa* L.) and potato-wheat (*Triticum aestivum* L. emend. Fiori & Paol)-rice]. Incorporation of CR has improved the mean rice equivalent yields of system by 7.86% as compared to their removal (24.15 t/ha). Incorporation of CR decreased the bulk density and increased infiltration rate, water holding capacity, microbial population, soil fertility than the initial values as compared to no residue treatment after four years of study. Increasing levels of RDF also increased the yield but did not show any significant effect on soil physico-chemical properties. Incorporation of residues along with RDF improved the crop productivity in both the cropping systems and was at par with 125% RDF. The residue incorporation with NPK fertilizer resulted in the highest yield, nutrient uptake, improved residual soil fertility and soil microorganism status and ultimately high benefit: cost ratio.

Key words: Crop residues, Onion, Potato, Rice, Rice equivalent yield, Wheat

Cultivation of two or more crops in a year involves heavy removal of plant nutrients and decreasing inputs of organic materials in intensive agriculture have led to deterioration in soil health resulting in decline in soil organic matter, soil fertility and productivity. Recent diagnostic survey indicates that in many intensively cultivated areas, farmers have resorted to use of greater than the recommended dose of fertilizer (RDF), particularly N to maintain crop productivity (Dwivedi *et al*., 2001). Therefore, it is necessary to judiciously manage the inflow of organic sources of nutrients and their interaction with fertilizers for improving soil fertility and sustaining productivity of crops. The recycling of crop residues adds organic matter as well as mineral matter to the soil. While the nutrient input improves soil fertility, the organic matter plays a vital role in improving soil physical properties and provides more favorable environment for root growth. Potato (*Solanum tuberosum* L) produces almost 2-3 times more dry matter and edible energy/unit area and time than cereal crops like wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) and thus augments the productivity of any potato based cropping systems. However, potato crop requires high fertilizer inputs. Application of chemical fertilizers along with organic manures increases the recovery of nutrients considerably from the applied fertilizers (Singh *et al*., 1997). Therefore, the present study was undertaken to study the effect of recycling of crop residues on productivity and soil fertility in two potato based cropping systems.

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MATERIALS AND METHODS

The field experiment was carried out at Central Potato Research Station, Patna, Bihar, for four consecutive years from 2002-03 to 2005-06 on a permanent layout in split plot design replicated thrice. The treatments consisted of two cropping systems viz. C_1=potato-onion-rice (a popular cropping system for the region) and C_2=potato-wheat -rice (new cropping system for the region) as main plot treatments and two levels of recommended dose of NPK fertilizer (RDF) viz.100 and 125% applied to all the crops in the system with or without *in situ* residue incorporation of previous crop as four sub plot treatments. The soil was sandy clay loam in texture with pH 7.1, bulk density 1.43 g/cc, organic carbon 0.40% and available N, P and K of 186.6, 20.1 and 233.6 kg/ha, respectively.

The experiment started with potato crop. Short duration early bulking potato 'Kufri Ashoka' was planted during 20-23 October, at a spacing of 60 cm x 20 cm using 3.0-3.5 t/ha of tubers of 40-50 g size as planting material. In potato-wheat-rice system, harvesting of potato was done at

70 days after planting (DAP) i.e. during last week of December. After the harvest of potato, wheat was sown next day. 'PBW-226' wheat suitable for late sowing was sown with a seed rate of 120 kg/ha in rows 20 cm apart. In potato-onion-rice system, fully matured crop of potato was harvested at 90 DAP and onion seedlings 'Agri-Found Light Red' was transplanted during 3-6 February at a spacing of 20 cm x 10 cm. During *kharif*, 21-day old seedlings of short duration and early maturing rice 'Prabhat' was transplanted between 12-15 July at a spacing of 20 cm x 15 cm and was harvested during 15-18 October in all the four years. The RDF for rice and wheat was 120-26.4-50, and for potato and onion was 150-26.4-66.7 kg N-P-K/ha, respectively. The crops were raised under irrigated condition with recommended package of practices. The residues were incorporated *in situ* immediately after the harvest of potato, wheat/onion and rice crop with potato haulms in wheat /onion, wheat straw /onion shoot in rice and rice straw in potato. The crop residues (CR) before incorporation into the plots were chopped by chaff cutter into small pieces of about 5 cm length and spread across the plots and incorporated by spade digging to 10-15 cm depth. The quantity of residues incorporated from each crop and nutrient added thereby is given in Table 1. Potato produce of each plot was graded into large (>75 g), medium (25-75 g) and small (<25 g) size tubers, and weighed separately. The yield of all the crops was converted into rice equivalent yield (REY) based on prevailing market price for comparison of treatments. The returns were calculated on yearly basis and then averaged. Benefit: cost ratio (B: C ratio) of systems was expressed as ratio of net return and cost of cultivation. The change in soil fertility status was monitored after four crop cycles i.e. after completion of experimentation. The soil samples were analyzed for organic carbon, available N, P, and K by standard methods.

RESULTS AND DISCUSSION

Potato

Growth attributes of potato (plant height, canopy cover and emergence %) were not significantly influenced by cropping systems (Table 2). However, the grade wise tuber yields as well as total tuber yield was significantly influenced by cropping systems. Tuber production was significantly higher in potato – onion – rice (C_1) system in comparison to potato – wheat – rice (C_2) and this was because of longer potato crop duration (full maturity at 90 days) in former than the later cropping system. Significantly higher tuber yield of large and medium grade tubers of potato was recorded at 125% RDF over 100% RDF and this trend was maintained only in system C_1 where full matured crop was harvested. In cropping system C_2 where potato was harvested at 70 days, the yield difference between RDF and 125% RDF was not significant. The total tuber yield increased significantly with incorporation of CR except in the first year when there was no application of residue in potato crop as the experiment started from potato (Table 2). Incorporation of CR showed higher tuber yield with 125% RDF than with RDF. Addition of CR and its subsequent decomposition improved the organic matter status and soil health and released nutrients through out the crop growth period that helped to increase the growth and yield attributing characters of potato which ultimately resulted in higher potato tuber yield as compared to no residue treatment (Sood and Sharma, 2002).

Wheat/onion

Wheat grain yield as well as onion bulb yield was significantly higher with 125% RDF than with RDF (Table 3). Further, the yield of crops with application of 125% RDF was at par with RDF + CR incorporation. *In situ* incorporation of CR significantly increased the grain yield of wheat and bulb yield of onion. Highest yield of wheat and onion was recorded with 125% RDF + CR. Addition of CR and subsequent decomposition released nutrients in the crop cycle that helped to realize higher value of yield attributing characters and ultimately resulted in higher grain yield of wheat (Singh and Yadav, 2006) and bulb yield of onion as compared to fertilizers alone treatments.

Table 1. Biomass production and nutrient addition through crop residues (pooled data of 4 years)

Treatment	Biomass(t/ha)			Nutrient accumulation (kg/ha)								
				Potato haulms			Onion tops/wheat straw			Rice straw		
	Potato haulms	Onion tops/wheat straw	Rice straw	N	P	K	N	P	K	N	P	K
Potato-onion-rice												
RDF	10.6	10.7	4.46	20.4	1.6	18.9	10.7	1.5	15.0	18.6	2.5	43.4
125% RDF	12.5	11.9	4.68	23.6	1.8	22.4	11.8	1.8	16.2	20.4	2.8	45.7
Potato-wheat-rice												
RDF	11.4	4.41	4.71	21.2	1.7	20.4	16.6	1.0	50.7	20.6	2.9	45.9
125% RDF	14.6	4.85	4.78	25.1	1.9	26.2	18.4	1.2	55.6	22.4	3.2	47.6

Rice

Rice grain yield was significantly higher in potato-wheat-rice system as compared to potato-onion-rice system. The incorporation of wheat straw produced higher rice grain yield as compared to onion residue incorporation. It might be due to low residue load produced by onion (Narang *et al*., 1999). The increasing fertility level as well as residue incorporation increased the grain yield of rice significantly. On an average application of 125% RDF produced 0.4 t/ha more rice yield than RDF. Application of 125% RDF significantly increased the vegetative growth and yield attributing components (Table 4), which resulted in increased photosynthetic area as well as sink area, that ultimately resulted in higher grain yield (Das *et al*., 2003). Incorporation of CR increased the grain yield of rice significantly over its removal. Rice yield obtained with RDF

Table 2. Effect of crop residue incorporation and levels of NPK on growth, yield components and yield of potato in potato based cropping system (pooled data of 4 years)

Treatment	Plant height at 55 DAP (cm)	Canopy cover at 55 DAP (%)	Grade wise tuber yield (t/ha)			Total tuber yield (t/ha)			
			Large (>75g)	Medium (25-75g)	Small (<25g)	2002-03	2003-04	2004-05	2005-06
Cropping system									
Potato-onion-rice	48.3	90.6	4.91	19.64	2.49	26.45	26.93	27.29	27.48
Potato-wheat-rice	49.1	90.1	2.30	15.79	2.40	20.35	20.46	20.54	20.60
SEm±	0.8	1.0	0.18	0.24	0.40	0.48	0.51	0.45	0.52
CD (P=0.05)	NS	NS	1.06	1.24	NS	2.80	3.10	2.90	3.20
Fertility level+ Residue									
RDF	45.5	85.8	2.76	16.72	2.53	22.52	22.27	21.81	21.42
RDF+CR	48.9	91.0	3.67	17.77	2.35	22.63	23.43	24.37	24.73
125% RDF	49.2	90.8	3.72	18.00	2.45	24.20	24.25	24.05	24.15
125% RDF+CR	51.2	94.0	4.27	18.36	2.47	24.27	24.84	25.44	25.87
SEm±	0.7	0.7	0.16	0.21	0.32	0.40	0.39	0.39	0.49
CD (P=0.05)	2.1	2.3	0.55	0.67	NS	1.30	1.20	1.10	1.50

CR, Crop residue; DAP, Days after planting

Table 3. Effect of crop residue incorporation and levels of NPK on yield attributes (pooled data of 4 years) and yield of wheat/onion in potato based cropping system

Fertility level + residue	Wheat							
	Yield attributes				Grain yield (t/ha)			
	Spike/m length	Grains/spike	1,000 grain weight (g)	Biological yield (t/ha)	2002-03	2003-04	2004-05	2005-06
RDF	56	31	40.8	7.28	3.31	3.24	3.05	2.96
RDF +CR	61	33	41.4	8.08	3.36	3.56	3.81	3.93
125% RDF	62	34	41.3	8.22	3.64	3.59	3.61	3.60
125% RDF + CR	66	37	42.2	8.77	3.69	3.88	4.02	4.09
SEm±	1	1	1.0	0.18	0.05	0.06	0.07	0.09
CD (P=0.05)	4	3	NS	0.67	0.21	0.23	0.26	0.31

Fertility level + residue	Onion							
	Yield attributes				Bulb yield (t/ha)			
	Equatorial diameter of bulb(cm)	Polar diameter of bulb (cm)	100 bulb weight (kg)	Biological yield (t/ha)	2002-03	2003-04	2004-05	2005-06
RDF	4.83	4.33	3.64	31.8	22.40	21.90	21.30	20.80
RDF +CR	5.05	4.22	4.20	34.4	22.64	23.66	23.95	24.39
125% RDF	5.00	4.77	4.16	34.5	23.54	23.48	23.46	23.44
125% RDF + CR	5.11	4.56	4.84	36.4	23.82	24.31	24.66	25.03
SEm±	0.03	0.07	0.04	0.6	0.62	0.32	0.30	0.36
CD (P=0.05)	0.10	NS	0.22	1.9	NS	1.20	1.10	1.30

+ CR was at par with that obtained with 125% RDF. Highest grain yield of rice was recorded with 125% RDF + CR incorporation. Addition of CR improved the soil health, thus increased the effective tillers and grains/panicle, which ultimately led to increase in grain yield. Crop residues on decomposition released nutrients to soil slowly throughout the growth period of rice plants causing better uptake of nutrients which resulted in increasing the value of plant growth and yield attributing characters of rice (Das *et al.*, 2003).

Rice equivalent yield (REY) of system

On the basis of four year pooled data, potato-onion-rice system produced significantly higher REY (35.5%) over potato-wheat-rice system (Table 5). This higher REY was due to higher yield of potato and onion in potato-onion-rice system. Application of 125% RDF produced 10.16% higher REY over RDF. Similarly REY was 7.69% higher with *in situ* residue incorporation over its removal. Our results corroborate the findings of Singh *et al.* (1997). The REY was significantly higher with 125% RDF + residue incorporation over rest of the treatments. This trend was observed in all the four years.

Economics

On the basis of four year pooled data, potato-onion-rice gave Rs 22,151/ha higher net return as compared to potato-wheat-rice sequence (Table 6). This was due to high yield of potato and onion in the system as well as better price of onion. Addition of crop residue increased the yield of economic produce of the crops of the system and thus increased the returns. Similarly application of 125 % RDF increased the net return and benefit: cost ratio over RDF, as it increased the yield of all the crops in the rotation. The highest net returns in both the cropping systems were achieved when residues were incorporated along with 125% RDF to the crops in the system. Sole application of 125% RDF gave net return at par with RDF + CR incorporation. Similar trend was also observed in relation to benefit : cost ratio.

Nutrient uptake

Total uptake of nutrients (N, P and K) was significantly influenced by cropping systems, fertilizer levels and crop residue incorporation (Table 6). The highest uptake of nutrients was recorded in potato-onion-rice-cropping system due to higher dry matter production in the system.

Residue incorporation increased the N, P and K uptake by 19.9, 4.9 and 20.4 kg/ha over its removal. The increased availability of N, P and K due to decomposition of crop residue might have increased their uptake. Increasing levels of RDF application influenced the total NPK uptake of cropping systems with the highest uptake values under 125% RDF. Application of 125% RDF increased the N, P and K uptake by 19.6, 3.3 and 21.4 kg/ha, respectively, over RDF. Higher NPK content at higher level of NPK application together with higher dry matter production resulted in higher NPK uptake. These results support the findings of Das *et al*. (2003). The nutrient uptake with the sole application of 125% RDF was at par with CR + RDF. The total uptake of NPK was maximum in 125% RDF + CR treatment. The increase is attributed to the fact that combined application of fertilizer and residues might have enhanced the decomposing process of residues, thereby releasing the nutrients in quicker time on one hand and reduced the immobilization effect on crop growth on the other hand.

Table 4. Effect of crop residue incorporation and levels of NPK on growth and yield attributes (pooled data of 4 years) and yield of rice in potato based cropping system

Treatment	Plant height (cm)	Effective tillers/m^2	Grains/ panicle	Test weight (g)	Biological yield (t/ha)	Rice grain yield (t/ha)			
						2002-03	2003-04	2004-05	2005-06
Cropping system									
Potato-onion-rice	88.0	248.2	114.9	25.3	8.13	3.67	3.67	3.71	3.68
Potato-wheat-rice	92.6	254.4	120.4	25.5	8.51	3.79	3.84	3.89	3.96
SEm±	0.6	1.8	0.7	0.4	0.74	0.16	0.14	0.17	0.18
CD (P=0.05)	3.9	NS	4.1	NS	NS	NS	NS	NS	NS
Fertility level + Residue									
RDF	82.3	221.4	102.4	25.0	7.48	3.52	3.43	3.21	3.01
RDF +CR	91.1	258.7	119.6	25.4	8.49	3.67	3.81	3.96	4.15
125% RDF	93.5	254.6	121.4	25.3	8.37	3.81	3.77	3.83	3.78
125% RDF + CR	94.3	270.4	127.1	26.0	8.95	3.92	4.02	4.20	4.34
SEm±	0.5	1.5	0.6	0.3	0.42	0.14	0.11	0.13	0.16
CD (P=0.05)	2.9	4.4	3.7	0.9	1.02	NS	0.20	0.40	0.50

Effect on physico-chemical properties of soil

The physical properties like bulk density, and infiltration rate and organic carbon of soil improved in both the cropping systems over the initial value, the highest increase being seen in potato-wheat-rice system (Table 6). The improvement could be due to addition of greater organic matter through root-shoot biomass of crops.

The soil bulk density (0-20 cm depth) decreased while the infiltration rate increased significantly with the incorporation of crop residue over no residue. Addition of CR and its subsequent decomposition of added organic matter to the soil and thus mass/ unit volume of soil reduced and the porosity of the soil increased thereby increasing the infiltration rate of soil. Decrease in bulk density with addition of crop residue was also reported by Kumar and Goh (2000).

Potato-wheat-rice recorded higher organic carbon content, available N, P as compared to potato-onion-rice system after four years of study. An increase of 4.3%, 6.69 % and 11.80% in organic carbon content, available N and P was observed in potato-wheat-rice over potato-onion-rice system.

Organic carbon (OC), available N, P and K, and microbial population in the soil increased substantially due to residue incorporation compared to its removal. The increase was higher (13.3%) when residue was incorporated

Table 5. Effect of cropping system and levels of NPK + crop residue incorporation on rice equivalent yield of potato based cropping system

Treatment	Rice equivalent yield (t/ha)														
	Year														
	2002-03			2003-04			2004-05			2005-06			Pooled		
	C_1	C_2	Mean	C_1	C_2	Mean	C_1	C_2	Mean	C_1	C_2	Mean	C_1	C_2	Mean
RDF	27.53	19.93	23.73	27.01	19.66	23.34	26.16	19.04	22.60	25.45	18.57	22.01	26.54	19.30	22.92
RDF+CR	27.83	20.47	24.15	28.71	21.23	24.97	29.77	21.90	25.84	30.32	22.55	26.44	29.16	21.54	25.35
125% RDF	29.18	21.73	25.45	29.21	21.56	25.39	29.12	21.56	25.34	29.07	21.60	25.34	29.14	21.61	25.38
125% RDF+CR	29.36	22.08	25.72	30.20	22.52	26.36	31.07	23.02	27.04	31.69	23.38	27.53	30.58	22.75	26.66
Mean	28.47	21.06		28.78	21.24		29.03	21.38		29.13	21.53		28.85	21.30	
SEm± for (S)		0.54			0.49			0.55			0.52			0.38	
CD (P=0.05)		3.20			2.90			3.40			3.30			2.24	
SEm± for (F)		0.39			0.38			0.32			0.30			0.32	
CD (P=0.05)		1.17			1.14			1.04			1.04			1.11	
SEm± for (S x F)		0.41			0.39			0.34			0.33			0.41	
CD (P=0.05)		1.48			1.39			1.26			1.28			1.42	

C_1, Potato-onion-rice cropping system; C_2, Potato-wheat–rice cropping system; S, Cropping system; F, Fertility levels+residue

Table 6. Effect of crop residue incorporation and levels of NPK on economics, nutrient uptake, and soil physico-chemical properties in potato based cropping systems (pooled data of 4 years)

Treatment	Cost of cultivation (Rs/ha/ year)	Net return (Rs/ha/ year)	Nutrient uptake (kg/ha/year)			Bulk density (g/cc)	Infiltration rate (cm/hr)	Organic carbon (%)	Available nutrient (kg/ha)			Microbial population (Log Cfu/ g soil)
			N	P	K				N	P	K	
Cropping system												
Potato-onion-rice	69,316	74,944	218.2	34.5	257.4	1.36	1.97	0.45	195.2	23.6	253.1	8.70
Potato-wheat-rice	53,714	52,793	205.2	34.9	242.6	1.34	1.99	0.49	208.3	26.3	254.1	8.72
SEm±			1.4	0.6	1.4	0.01	0.02	0.01	0.6	0.1	0.9	0.11
CD (P=0.05)			9.1	NS	8.3	NS	NS	NS	3.6	0.5	NS	NS
Fertility level + Residue												
RDF	59,637	54,955	191.0	30.8	228.3	1.39	1.85	0.44	194.3	22.4	248.5	8.17
RDF+CR	61,002	65,742	212.8	35.3	250.3	1.33	2.08	0.49	205.1	25.4	255.1	9.19
125% RDF	62,086	64,799	212.5	33.7	251.2	1.37	1.87	0.45	197.5	24.7	251.4	8.22
125% RDF+CR	63,336	69,977	230.5	39.0	270.1	1.31	2.11	0.51	210.1	27.2	259.4	9.26
SEm±			1.2	0.6	1.3	0.01	0.03	0.01	1.3	0.3	1.3	0.18
CD (P=0.05)			3.6	1.8	4.2	0.02	0.12	0.02	4.1	0.8	4.5	0.64
Initial						1.43	0.94	0.40	186.6	20.1	233.6	7.85

Sale price: Potato(early), Rs 3,100/t; Potato(late), Rs 2,500/t; Onion, Rs 2,500/t; Wheat, Rs 6,600/t and Rice, Rs 5,000/t

with 125% RDF. Das *et al.* (2003) also reported increased OC in the soil following residue incorporation. Decomposition of CR might have improved the microbial activity leading to increased N_2 fixation and reduced N losses in residue incorporated plots by forming organo-mineral complexes. The increase in available P might be due to solublizing action of certain acids and displacement of phosphate by organic anions formed during the decomposition of organic residues. These results corroborate the findings of Kachroo *et al*. (2006). The residue incorporation improved the microbial population in the soil substantially, being highest with the treatment receiving 125% RDF. Residue incorporation provides a stable supply of carbon and energy for micro-organisms and thus increased the microbial population (Dobbermann and Fairhurst, 2002).

Thus it was concluded that incorporation of crop residues along with chemical fertilizers in potato-onion-rice cropping system is best for productivity and profitability of system and for enhancing the soil fertility.

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