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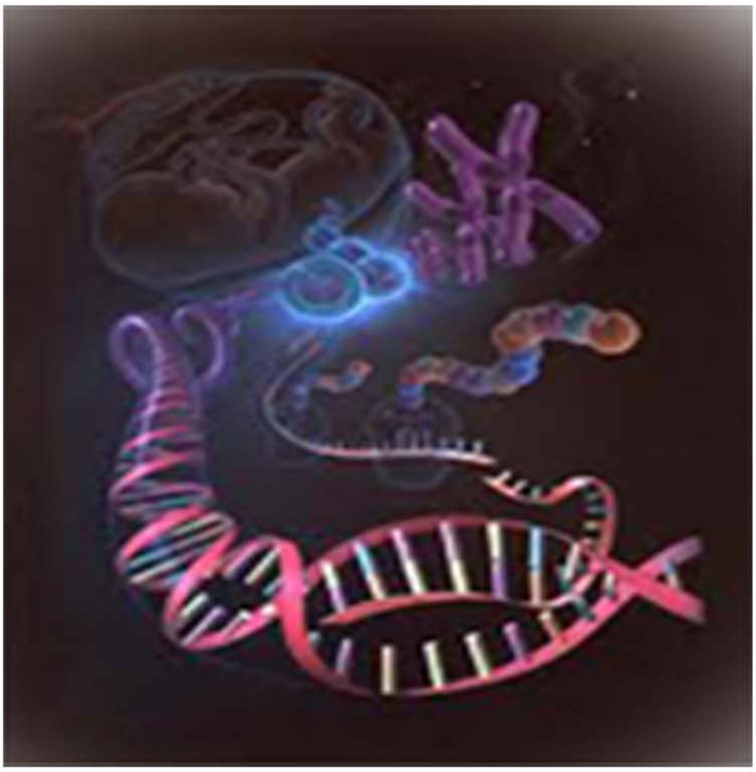

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Research Paper

RICE RESIDUES: FROM WASTE TO WEALTH THROUGH ENVIRONMENT FRIENDLY AND INNOVATIVE MANAGEMENT SOLUTIONS, IT'S EFFECTS ON SOIL PROPERTIES AND CROP PRODUCTIVITY

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Rice residues are important natural resources, and recycling of these residues improves the soil physical, chemical and biological properties.Management of rice straw is a major challenge as it is considered to be a poor feed for the animals due to high silica content.A field experiment was conducted over 03 years to review the potential of rice residues and its management options, residue effects on soil properties and crop productivity. A rice-wheat sequence that yields 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat removes more than 300 kg N, 30 kg P and 300 kg K ha^{-1} from the soil. Farmers need to manage 7 t ha^{-1} of rice residues and overcome the problems for planting wheat. The result showed that before wheat planting, burning results huge losses of N (up to 75%), P (25%), and K (21%) and by incorporation of residues of both crops in rice–wheat rotation increased the available N, P and K contents in soil over removal and burn of residues.Surface retention of residues increases soil N, P and K uptake by 14.6, 28.5 and 17.7 %.Total system productivity increased by 10.9-15.8% in residue retention with permanent wide beds planting, and zero tillage planting system over conventional.Residue management practices affect soil physical properties viz. soil moisture, aggregate formation and bulk density. Extensive tillage with its associated high costs can be reduced by the use of zero-tillage or permanent raised beds with residue retention is needed to insure production sustainability. Thus, if residues are managed properly, then it can warrant the improvements in soil properties and the sustainability in crop productivity.

Keywords: Rice residue, Burning, Incorporation, Retention, Soil properties, Crop productivity

INTRODUCTION

Crop residues, in general are parts of the plants left in the field after crops have been harvested and threshed. These materials at times have been regarded as waste materials that require disposal, but it has become increasingly realized that they are important natural resources and not wastes. The recycling of crop residues has the advantage of converting the surplus farm waste into useful product for meeting nutrient requirement

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of crops.It also maintains the soil physical and chemical condition and improves the overall ecological balance of the crop production system. A decline in land productivity, particularly of the rice–wheat (RW) system, has been observed over the past few years in the northern and north-western IGP despite the application of optimum levels of inputs under assured irrigation (Paroda 1997). Reflecting this, the fertiliser recommendation has been revised upwards for both rice and wheat crops. Agriculture in western Uttar Pradesh has, until now,been focused on achieving food security through increased area under high-yielding varieties of rice and wheat, expansion of irrigation and increased use of external inputs like chemical fertilisers and pesticides (Ladha et al.,2000;Naresh et al.2011). The support price system for rice and wheat crops, coupled with subsidies on fertilisers and irrigation water, made the RW system the most profitable option. This enabled rice and wheat crops, covering an estimated area of around 10 million hectares (Mha), to emerge as the major cropping system in the IGP, leading to the Green Revolution. These two crops together contribute more than 70% of total cereal production in India from an area of around 25 Mha under wheat and about 40 Mha under rice. The small states of Punjab and Haryana contribute 20% of the total national grain production and 50% and 85% of the government procurements of rice and wheat,respectively (Singh, 2000). With unabated increases in population, more and more land will be required for urbanisation, and productivity needs to be increased to meet the rising domestic and industrial demand.

With the introduction of combine harvesters, more than 75% of the rice area is harvested mechanically in north-western parts of the Indo-Gangetic Plains (IGP). Most of the farmers remove wheat straw for feeding the animals. Combine harvester leaves behind a swath of loose rice residues, which interfere with operations of the seed drill used for planting wheat.To avoid this problem farmers resort to burning of crop residue,which not only lead to loss of huge biomass but also cause environmental pollution.So there is a need to adopt ways and means to manage this valuable resource. Removal of crop residues, especially of wheat and scented rice,is a loss of organic sources for soil health but is necessary to feed livestock and sustain mixed farming.Incorporation is a better option but it requires large amounts of energy and time; leads to temporary immobilisation of nutrients, especially nitrogen;and the C:N ratio needs to be corrected by applying nitrogen at the time of incorporation (Pathak and Sarkar 1994). Farmers resort to burning as it is an easier disposal option and allows a shorter turnaround time between crops than incorporation,which is especially important between rice harvest and wheat sowing. Incorporation is also a more costly operation and,until recently,surface retention was not a viable option due to the lack of suitable machines able to seed into the loose residues left after combine harvesting.However, two machines are now available (Figures 1 and 2) that are capable of seeding into full, surface-retained rice residues.

Conservation tillage and mulch farming techniques have proven useful in the highly erodible soils of the western Uttar Pradesh keeping in mind both socioeconomic and biophysical factors, there is a need to develop conservation tillage systems for a wide range of rice based cropping systems, soils, and agro-ecological environments. Different residue

Figure 1: Happy Seeder for Seeding into Loose Residues

Figure 2: Rotary Disc Drill For Seeding into Loose Residues

management technologies or strategies need to be developed at a regional level to fit different rice-based cropping systems and to accommodate the management diversity required within a single farming enterprise. In this paper,crop residue potential particularly of rice crop, its management practices, zero and reduced tillage options and soil properties associated with rice residue management etc., were discussed.

MATERIALS AND METHODS

The experiment was conducted at the research farm ($29^0$01'N, $77^0$45'E, and 237 m above mean sea level) of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (Uttar Pradesh), during 2008–09 to 2010-11 in a randomised complete block design with three replicates, commencing with kharif in 2008. The plots consisted of ten layout or crop establishment straw treatments. The sites, treatments are briefly summarised in Table 1 for convenience. The climate of the area is semiarid,with an average annual rainfall of 765 mm (75-80% of which is received during July to September), minimum temperature of 4^0C in January, maximum temperature of 41 to 45^0C in June,and relative humidity of 67 to 83% throughout the year.In general the soils of the experimental sites was silty loam in texture with medium fertility status. The particle size distribution of 0-20 cm soil layer is 68.3 % sand,17.4 % silt and 14.7 % clay.The soil samples were taken at 0-15 cm soil layer from top of the beds in permanent beds and within the row in flats.The bulk density of 1.54 Mg m^{-3}, weighted mean diameter of soil aggregates 0.58 mm, infiltration rate 58.3mm hr^{-1}, cone index 2.45, total C 8.3 g kg^{-1}.

Rice residues in wheat (+R): Rice residues (partiall anchored, partially loose) amounting to 6 t ha^{-1} were retained in the +R treatments. In the raised beds the rice residues were cut at ground level and removed before sowing, then spread uniformly as mulch after sowing. In the flat plots wheat was direct drilled into the rice residues using a double-disc drill.

Pusa Basmati-1 rice variety was seeded on 1^{st},3^{rd} and 8^{th} June in direct-seeded plots, where as transplanting was done on 22^{nd}, 24^{th} and 29^{th}June in 2008, 2009 and 2010, respectively. Rice was seeded in flat beds as well as in raised beds after seed priming (soaking seeds in water for 12 hr's followed by air drying.A seed rate of 25 kg and 20 kg ha^{-1} was used for direct-seeded rice on flat and raised beds, respectively. 'PBW 343' wheat was seeded on 7^{th}, 9^{th} and 11^{th} Nov. 2008, 2009 and 2010, respectively. A seed rate of 80 kg ha^{-1} was used in treatments where wheat

Table 1: Treatments in the Replicated Experiment in Rice-Wheat Cropping System

Kharif Seaso			Rabi season		
	Layout	Abbrevations		Layout	Abbrevations
T_1	Conventional till (puddled) transplanted rice with sesbania	CT-TPR +S	T_1	Zero till direct seeded Wheat planted by turbo happy seeder	ZT-HS
T_2	Direct seeded rice on permanent wide beds with Sesbania	PWB- DSR+S	T_2	(Reshape shallow plow) Zero till direct seeded Wheat on wide beds+incorparate residue	WBedZT-DSW +RI
T_3	Direct seeded rice on permanent wide beds without sesbania	PWB - DSR	T_3	Zero till direct seeded Wheat on Permanent wide beds + residue burn	WBedZT-DSW+ RB
T_4	Transplanted rice on permanent wide beds with Sesbania	PWB -TPR+S	T_4	Zero till direct seeded Wheat on Permanent wide beds+partial removal of residue	WBedZT-DSW+PRR
T_5	Transplanted rice on permanent wide beds without sesbania	PWB - TPR	T_5	Zero till direct seeded Wheat on Permanent wide beds + retain residue	WBedZT-DSW+RR
T_6	Reduced till (non puddled) dry drill seeded rice with *Sesbania*	RT-DSR +S	T_6	Zero till direct seeded Wheat on Conventional till beds + incorporate residue	F Bed CT-DSW +RI
T_7	Reduced till (non puddled) dry drill seeded rice without sesbania	RT-DSR	T_7	Zero till direct seeded Wheat on Zero till flat beds + burn residue	F Bed ZT-DSW +RB
T_8	Zero till unpuddled transplanted rice with sesbania	ZT-TPR +S	T_8	Zero till direct seeded Wheat on Zero till flat beds + partial removal of residue	F Bed ZT-DSW+ PRR
T_9	Zero till unpuddled transplanted rice without sesbania	ZT-TPR	T_9	Zero till flat beds + retain residue	F Bed ZT-DSW +RR
T_{10}	Conventional till (puddled) transplanted rice	CT- TPR	T_{10}	Conventional tillage practices broadcast wheat	CT- BCW

was seeded on beds, and 100 kg ha^{-1} was used in the rest of the treatments. The multi crop zero till cum raised bed planter with enclined plate seed metering device machine was calibrated every time before seeding to adjust the seeding rate.

For rice, 120 kg N, 60 kg P_2O_5, 40 kg K_2O, and 20 kg $ZnSO_4$ ha^{-1} and for wheat 150 kg N, 60 kg P_2O_5, 40 kg K_2O ha^{-1} was applied. Half dose of N and full doses of P, K, Zn was applied as basal and remaining N was applied in two equal splits in rice and in wheat, 80% N was applied as basal and remaining N was applied at full bloom stage. The crop was maintained weed free using following practices-for rice crop weeds that germinate prior to seeding of rice and wheat in zero till plots were killed by spraying glyphosate @ 900 g a.i. ha^{-1}. The plots are then kept weed-free throughout the growing season. Butachlor @ 1300 g a.i. ha^{-1} at 2 days after transplanting (DAT) in case of transplanted rice followed by a spray application of bispyribac sodium (Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAT for narrow and broad leaf weeds, and pendimethalin @ 1000 g a.i. ha^{-1} at 2 DAS in direct seeded rice were applied for controlling grassy weeds followed by a spray application of bispyribac sodium (Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAS for narrow and broad leaf weeds. Additionally,1 hand-weeding in transplanted rice and 2 hand- weeding in direct seeded rice was done to keep the plots weed-free. For wheat crop grassy weeds were controlled by spraying of sulfosulfuron @ 35 g a.i. ha^{-1} at 30-45 DAS, and broad leaf weeds using 2,4-D @ 500 g a.i. ha^{-1} at 35 DAS.

The beds were reshaped prior to wheat sowing using the bed-planter drawn by a four-wheel tractor. The bulk density was determined with the core sampler at the 5 cm intervals up to 20 cm soil depth.The samples were collected and oven dried at 105^{0}C for 24 hrs and bulk density was deremined on the basis of oven dried soil. The large clods were collected from the each plot after harvest of the crop and oven dried. Large clods are broken to small pieces ranges >4.75 to >8mm size. Water stable soil aggregates were determined by using the wet sieve procedure (Yoder method). Infiltration rate was measured using double ring infiltrometers in each plot after harvest of the crop. The initial infiltration rate was measured after 5,15,30,45,60 min interval and steady state infiltration was measured after 24 h. Soil resistance was measured almost near to field capacity with the help of manual cone Penetrometer by using the 2 cm^2 cone. Soil resistance readings were recorded at the interval of every 5 cm up to 45 cm soil depth and in a replication of three in each plot after harvest of the crop.

RESULTS AND DISCUSSION

Residue Management Effects on Soil Properties

Soil Physical Properties

Residue management practices affect soil physical properties such as soil moisture content, aggregate formation, bulk density and soil porosity. Soil from permanent raised beds with full residue retention had significantly higher mean weight diameter (MWD) compared to conventional tilled flat beds (Table 3). The effect of plant residue removal on soil structure in permanent raised beds was very clear as the MWD decreased with decreasing amounts of residues retained. Soil aggregation refers to the cementing or binding together of several primary soil particles into secondary units. A lower aggregation results in a reduction of the infiltration and storage capacity of the soil by forming a relatively impermeable soil layer by sealing of pores (Naresh *et al.*, 2010). The furrows in permanent raised beds are more compacted as all traffic is always concentrated in the furrows. However, in order to take advantage of the active water harvesting system by installing furrows and ridges it is probably more desirable to have slow infiltration rates in the furrow in order to let the water slowly infiltrate to the plant root zone, rather than let it escape to deeper layers due to cracks in the soil. At initial time bulk density of surface layers remains lower under residue retained bed planting than under conventional tillage. This is because top of beds remains loose. The lower bulk density means more porosity especially in upper surface. The cone index was increased significantly under all the tillage and crop establishment techniques but the extent of

Table 2: Initial Soil Properties of the Experimental Site in 2008

Depth (cm)	Bulk density (Mg m^{-3})	P^H	Water stable aggregates > 250 μm	Soil Organic Carbon (%)	Avail.N (kg ha^{-1})	Avail.P (kg ha^{-1})	Avail.K (kg ha^{-1})
0-10	1.53	7.85	52.8	0.51	70.9	27.9	56.8
10-20	1.55	7.83	51.9	0.46	64.6	25.8	52.1
20-30	1.56	7.85	49.1	0.43	42.3	21.4	46.7
30-60	1.58	7.97	42.9	0.40	31.8	19.3	40.4
60-90	1.59	8.06	38.7	0.36	22.1	17.8	32.7

Table 3: Soil Physical Characteristics After 3 Years in Tilled and Permanent Beds and Different Residue management in 0-20cm

Crop Establishment	Bulk density (Kg m^{-3})	Infiltration rate (mm/hour)	Cone index (Kg/cm^2)	MWD (mm)	Field Capacity (% Moisture)		Permanent Wilting Point (% Moisture)	
					0-5 cm	5-20 cm	0-5 cm	5-20 cm
T_1	1.57	62.2	5.81	0.40	29	30	11	10
T_2	1.54	81.4	3.40	0.46	30	32	11	11
T_3	1.58	78.6	6.79	0.41	28	30	10	09
T_4	1.55	82.3	4.79	0.43	31	32	12	11
T_5	1.54	84.7	2.51	0.45	33	34	13	12
T_6	1.61	72.4	6.57	0.37	29	31	12	11
T_7	1.63	69.5	7.60	0.34	28	29	10	09
T_8	1.57	73.4	5.59	0.38	29	30	12	11
T_9	1.59	76.9	4.63	0.42	30	31	13	10
T_{10}	1.69	55.7	8.49	0.29	29	31	10	09
Initial	1.53	50.3	2.79	0.23	-	-	-	-
C D at 5%	0.23	13.58	0.83	0.09	-	-	-	-

increase was more under conventional tillage systems. The soil organic carbon content in top soil (0-15cm) was increased significantly due to raised bed planting compared to flat sowing planting mostly because of localized deposition of more fertile top soil on beds under altered land configuration than flat planting (Walker *et al.*, 2003).

Available nitrogen, phosphorus and potassium status of soil analyzed after harvest of wheat showed significant variation due to different treatments (Table 4). Maximum available N, content in soil was recorded in residue retained while P and K content in soil was recorded under residue incorporation.

Table 4: Effect of Crop Residue Management For 03 Years in Rice-wheat Rotation on Physicochemical Properties of the Soils

Parameters	Retained	Incorporation	Removed	Burnt
P^H	7.95	7.35	7.40	7.65
Water stable aggregates >250 µm	57.4	56.9	46.3	38.2
Organic Carbon (%)	0.53	0.58	0.43	0.47
Avail.N (kg ha^{-1})	89.0	83.0	32.0	21.0
Avail.P (kg ha^{-1})	39.0	42.0	21.0	29.0
Avail.K (kg ha^{-1})	67.0	69.0	48.0	55.0

Soil Chemical Properties

No-tillage systems significantly increase the organic matter content of the upper few cm of soil. During the initial years of no-till management, the build-up of organic matter results in the immobilization of nutrients, especially N. This is in contrast to the mineralization of nutrients that is encouraged by the decline of soil organic matter under conventional tillage. Eventually,when soil organic matter stabilizes at a new higher level,nutrient mineralization rates under no-till increase.Higher moisture and lower oxygen levels may also stimulate denitrification. These processes sometimes result in the need for greater levels of N fertilization for optimum yields during the early years of no-till management. In an 3 year field experiment shows that incorporation of residues of both crops in rice–wheat rotation increased the available P and K contents in soil over removal and burn of residues. The increase in K availability in the soil was small. In no-tillage systems, nutrient elements tend to accumulate in the upper few cm of soil as they are added to the soil surface through crop residues and chemical fertilizers. However, research indicates that because of the surface mulch, crop roots have no trouble obtaining nutrients from the near-surface soil layers. Without tillage to mix the soil, the acidifying effects of nitrogen oxidation, residue decomposition, and rainfall are concentrated in the upper few centimeters of soil. Result has shown that if these organic residues are returned to the soil, soil pH can be increased due to the decarboxylation of organic anions on decomposition by micro-organisms and the pH of which may drop more rapidly than that of the whole plough layer in conventional systems.

Crop Yields

The various tillage and crop establishment techniques had a significant effect on rice yield (Table 5). Yield were similar when rice was conventionally puddled transplanted T_1 transplanted on wide raised beds T_4 and unpuddled transplanted in slits after no tillage T_8. This indicated that puddling of soil,for which normally a large amount of water and labour are required can be avoided without any penalty in rice. Treatments T_8 and T_9 were at par with each other, however,they recorded higher grain yield over T_6 and T_7 treatments which recorded lowest grain yield (4.15 & 4.05 tha^{-1}).

The wheat grain yield t ha^{-1} resource conserving technologies when practiced as such which includes sowing earlier than conventional tillage resulted in higher wheat yield over conventional tillage over all treatments. Treatment T_5 was found significantly superior to all the treatments, and recorded maximum grain yield. Grain yield increased significantly within various resource conserving technologies with residue retained. Treatment T_4 was significantly superior to the remaining treatments. T_2,T_1,T_9,T_8 and T_6 were at par with each other, however, they recorded significantly higher grain yield over T_{10} treatment which recorded lowest grain yield. Under all the tillage and crop establishment techniques, there was yield advantage with surface residue retention compared to removal. The crop residues retained as surface mulch (partially anchored and partially loose) @ 6.0 mg ha^{-1} that helped in regulating the soil temperature, moisture and more response was mainly due to the aberration in weather conditions during the crop growth period.

Total System Productivity

The retention of residue increased productivity rapidly, starting from the second crop cycle.We believe this is an important findings because, if

Table 5: Productivity of Rice-Wheat Systems Under Various Residue Management and Crop Establishment Techniques

Crop Establish-ment	Grain yield t ha^{-1}								
	2008-09			2009-10			2010-11		
	Rice	Wheat	RW System	Rice	Wheat	RW System	Rice	Wheat	RW System
T_1	4.75	5.15	9.90	4.95	5.20	10.15	5.35	5.25	10.60
T_2	4.20	5.15	9.35	4.30	5.25	9.55	4.50	5.35	9.85
T_3	4.35	5.35	9.70	4.45	5.30	9.75	4.65	5.27	9.92
T_4	4.55	5.25	9.80	4.75	5.30	10.05	5.15	5.45	10.60
T_5	5.05	5.45	10.50	5.15	5.55	10.70	5.45	5.60	11.05
T_6	4.05	5.05	9.10	4.25	5.15	9.40	4.40	5.30	9.70
T_7	4.15	5.20	9.35	4.40	5.10	9.50	4.55	5.05	9.60
T_8	4.25	5.15	9.40	4.55	5.20	9.75	4.85	5.35	10.20
T_9	4.30	5.25	9.55	4.60	5.30	9.90	4.65	5.45	10.10
T_{10}	5.35	4.73	10.08	5.15	4.65	9.80	4.95	4.35	9.30
C D at 5 %	0.92	0.51	-	0.85	0.46	-	0.63	0.49	-

repeated on farmers fields, farmers will quickly realize the benefits and be more interested in adopting the technology. Total system productivity increased by 10.9-15.8% in residue retention with permanent wide beds planting, and zero tillage planting system over conventional (Table 5). Total system productivity of rice-wheat (R-W) was 11.05 t ha^{-1}yr^{-1}. For both crops the highest system yields occurred in full straw retained, but the differences between residue removal and full residue retained were always significant for both the crops. Lower system productivity also occurred from residue removal due to reduced crop growth.Yields tended to be lower in with lower levels of residue retention for both crops.

CONCLUSION

The intelligent management and utilization of crop residues is essential for the improvement of soil quality and crop productivity under rice-based cropping systems of the semi-arid. Crop residues, usually considered a problem, when managed correctly can improve soil organic matter dynamics and nutrient cycling, thereby creating a rather favourable environment for plant growth. Crop residues contain large quantities of nutrients, and thus the return of crop residues to the soil can save a considerable quantity of fertilizers. The most viable option is to retain residue in the field; burning should be avoided. The major issue is adapting drills to sow into loose residues. Strategies include chopping and spreading of straw during or after combining or the use of disc-type trash drills.

The important conditions that influence crop residue decomposition under field conditions were temperature, moisture, aeration, and N application. Several other factors, such as residue quality, tillage, and soil properties, also affect microbial decomposition of crop residues.There are several options for management of rice residues: burning, incorporation, surface retention etc. Every management options have its advantages as well as disadvantages.Strategies include chopping and spreading of straw during or after combining or the use of disc-type trash drills.Now it is the location, soil and situation, which will govern the practice to be selected of course,intensive research is required to solve this problem of managing rice residues. Sometimes surface retention may be the best option in many situations.

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