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On-farm Rice Straw Management: Effects on Crop Productivity and Environment

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Abstract: *The rice-wheat (RW) is the principal cropping system in South Asia that occupies about 13.5 million hectares in the Indo-Gangetic Plains (IGP), of which 10 million hectares are in India. This cropping system is predominantly practiced in Punjab, Haryana, Bihar, Uttar Pradesh and Madhya Pradesh, and contributes to 75% of the national food grain production. RW system occupies about 2.65 M ha in Punjab. Both wheat and rice straws constitute more than 90% of the crop residues produced in the state. Paddy straw alone constitutes more than 22 M t of the total residues produced in the state (Yadvinder-Singh et al 2010). While, at present 75-80% of wheat straw is collected by the farmers after combine harvesting using straw combine and often fed to animals, rice straw is considered poor feed for animals due to high silica content. About 80% of total rice straw (18 mt) and 20-25% of wheat straw is burnt in-situ annually in Punjab. Burning is the normal and easiest method of crop residue management because residues interfere with tillage and seeding operations for the next crop. Despite the ban imposed by the district magistrates of various districts, burning of residues has been doing great damage to the environment. The field burning of crop residues is a major contributor to reduced air quality (particulates, greenhouse gases), and human respiratory ailments in intensive rice-production areas. Burning means a complete waste of organic matter, N and S, and partial loss of P and K. In view of the serious problems associated with the burning of paddy residues, efforts are needed to find means and ways to efficiently utilize the huge amount of surplus residues produced in the state for maintaining soil health, human and animal health, and increasing farmer's profits. It is estimated that about 40 percent of the nitrogen (N), 30 to 35 percent of the phosphorus (P), 80 to 85 percent of the potassium (K), and 40 to 50 percent of the sulphur (S) taken up by rice remains in rice straw at crop maturity.*

There exist several options for managing crop residues. These can be removal from the field, left on the soil surface, incorporation into the soil, composted or used as mulch for succeeding crops or converted in to biochar for its subsequent application in the soil. Each of the above mentioned options of crop residue management in RW system leads to the saving of huge quantity of nutrients besides improving the soil and crop productivity.

IN-SITU INCORPORATION

The incorporation of rice residue before wheat planting is challenging for farmers because of the short interval between rice harvest and wheat planting. The incorporation of crop residue with high C–to–N ratio into soil typically results in microbial N immobilization and a temporary decrease in plant-available N. This initial period of several weeks of net N immobilization is followed by net N mineralization (Yadvinder-Singh *et al.*, 2005). The duration of net N immobilization and the net supply of N from crop residue to a subsequent crop depend upon decomposition rate, residue quality, and environmental conditions.

Studies showed no significant wheat yield increase upon rice residue incorporation in wheat when fertilizer N was applied at rates sufficient to meet the crop requirements for supplemental N (Yadvinder-Singh *et al.*, 2004; Bijay-Singh *et al.*, 2008). A 7-year study by Yadvinder-Singh *et al.* (2004)

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demonstrated that rice and wheat productivity were not adversely affected when rice residue was incorporated for at least 10 d and preferably 20 d prior to establishment of the succeeding crop (Table 1). This study showed that rice residue decomposition of about 25% during the pre-wheat fallow period was sufficient to avoid any detrimental effects on wheat yields. Under laboratory conditions no immobilization of fertilizer N was observed when paddy residues were incorporated at 20 d or more before fertilizer application. Recovery efficiency of N was decreased by the application of starter-N (Table 1). Paddy straw incorporated in wheat did not show a residual effect on the succeeding rice crop. Another long-term study conducted by Sidhu and Beri (2005) showed that in 4 out of 11 years wheat yield was significantly higher under straw incorporation at 20 days before sowing wheat compared to straw burning. Yadvinder-Singh *et al.* (2005) and Bijay-Singh *et al.* (2008) have concluded based on a review of literature that application of rice residue to wheat typically has small effect on wheat yields during the short term of 1 to 3 years. From a 4-year study, Gupta *et al.* (2007) reported that incorporation of paddy straw showed no effect on wheat yield during the first three years but wheat yield increased significantly in the 4th year compared with removal or burning of straw (Table 2). Long-term incorporation of rice residue can increase readily mineralized organic soil N, suggesting potential after several years for reducing fertilizer N rates for optimal rice yield.

The incorporation of paddy straw is likely to be more beneficial in soils with heavy texture than in coarse-medium in texture due to improvement in soil-water relationships and in the areas where irrigation water is brackish in nature or soils are sodic in nature. A 5-year study by Beri *et al.* (2002) showed that drilling or broadcast application of 50% N of the recommended 120 kg N ha^{-1} at sowing of wheat and top dressing of remaining 50% N at first post-sowing irrigation produced the maximum wheat yield than applying 50% or whole of the N at paddy straw incorporating (Table 3). Application of first half N dose at pre-sowing irrigation also proved inferior to its application at wheat sowing. Thus, in general, paddy straw can be managed *in situ* successfully by allowing sufficient time between the incorporation and sowing of the wheat crop.

However, this practice is not popular among farmers because of high incorporation costs and energy and time intensive. The technology for the incorporation of paddy straw involves use of straw chopper followed by rotavator and allowing residue to decompose for 15-20 days and involves additional cost of Rs. 1000/acre.

Table 1
Effect of long-term (7 years) paddy straw management on wheat, recovery efficiency (RE) of N and its residual effect in the following rice in the rice-wheat system (Yadvinder-Singh *et al.*, 2004)

Treatment to wheat	*Wheat yield (t ha^{-1})*	*RE in wheat (%)*	*Rice yield (t ha^{-1})*
Paddy straw- removed	4.94a	52bc	6.19b
Paddy straw -Burned	5.10a	56ab	6.25b
Paddy straw incorporated- 40 days	5.17a	54ab	6.34b
Paddy straw incorporated- 20 days	5.22a	56ab	6.29b
Paddy straw incorporated -10 days	4.95a	53ab	6.33b
Paddy straw incorporated -20 days + 25% N at incorporation	4.97a	49c	6.29b

Table 2
Effect of residue management on grain yield of wheat in the rice-wheat system (Gupta *et al.*, 2007).

Straw management	*Grain yield (t ha^{-1})*			
	2001-02	*2002-03*	*2003-04*	*2004-05*
Paddy straw- removed	4.9	3.8	3.7	4.1
Paddy straw -Burned	5.0	3.8	4.0	4.6
Paddy straw- incorporated	4.8	4.3	4.5	5.1
Both Paddy straw and Wheat straw incorporated	5.2	4.2	4.4	4.8
LSD ($P \leq 0.05$)	NS‡	NS	NS	0.5

Table 3
Effect of N and paddy straw management on grain yield of wheat (mean for 5 years) at Ludhiana (Sidhu and Beri *et al.*, 2005)

Treatment				*Grain yield (t ha^{-1})*
Paddy straw management	*Time and method of N application (kg ha^{-1})* At straw incorporation/ pre-sowing irrigation	*At sowing*	*At first irrigation*	
Burnt	0	60- broadcast	60-top dressed	4.61
Incorporated	0	60- broadcast	60- top dressed	4.79
Incorporated	120-broadcast	0	0	3.63
Incorporated	60- broadcast	0		4.13
Incorporated	0	60- drilled	60-top dressed	4.91
Incorporated	60-broadcast at pre-sowing irrigation	0	60- top dressed	4.11

Note: Paddy straw was incorporated at 20 days before sowing of wheat

RICE RESIDUE MANAGEMENT IN WHEAT USING HAPPY SEEDER

In 2006, Punjab Agricultural University has recommended the use of Happy Seeder for direct sowing of wheat into rice residues avoiding burning and environmental pollution. Continuous retention of rice residue by using Happy Seeder for sowing of wheat should improve soil fertility as well as physical and biological properties of the soil. It is likely that regular retention of rice straw on fields will also increase crop productivity and reduce the fertilizer requirement compared to conventional rice-wheat system. Yadvinder- Singh *et al.* (2009) conducted a 3-year field experiment on rice straw management in RW system on two soil types. Rice straw retained at surface as mulch-ZT using Happy Seeder. Four rates of N were: 0 (control), 90, 120 and 150 kg N ha^{-1} were applied in the sub-plots. Amount of rice residue returned to wheat ranged from 8.8 to 9.8 Mg ha^{-1} during 3 years of study. In the sandy loam, wheat grain yield was not affected by different straw and tillage management treatments in the first year (2004–2005) but it was higher in straw mulch-ZT than all the other treatments in 2005–2006 (Table 4). During 2006–2007, wheat yield was higher in straw burnt-CT compared with straw burnt-ZT and straw incorporation-CT but it was similar to straw mulch-ZT treatment. On average for 3 years, wheat grain yield trend on sandy loam soil was as follows: straw mulch-ZT = straw burnt-CT > straw burnt-ZT = straw incorporation-CT.

In silt loam soil, wheat grain yield was lower in straw incorporation-CT than in all the other treatments but it was highest in straw burnt-CT in 2004– 2005 (Table 4). In 2005–2006, straw mulch-ZT out yielded the all the other treatments and wheat yield again was the lowest in straw incorporation-CT treatment (Table 4). The study showed that the effects of straw and tillage management on wheat yield depended on soil type. While straw burnt-ZT produced lowest yield on sandy loam, straw incorporation-CT performed poor on silt loam. Wheat yield was lower in 2005–2006 compared with other years on both soils and was possibly due to unusually warm temperature in February 2006 coinciding with grain filling stage.

Based on average for 3 years, application of 150 kg N ha^{-1} compared with no-N control increased the grain yield of wheat by about 104% on sandy loam and141% on silt loam. In 2005–2006, in both types of soils, response to N application rate varied with tillage and straw management as suggested by significant tillage and straw management by N rate interaction (Table 5). For example, in sandy loam soil, N response was observed up to 120 kg ha^{-1} in plots where residues were retained (straw incorporated-CT and straw mulch-ZT) and up to 150 kg N ha^{-1} in straw burnt treatments (straw burnt-ZT and -CT). In silt loam soil, in contrast to sandy loam soil, response to applied N was observed up

Table 4
Effect of rice straw management, tillage system and N fertilizer on grain yield (t ha^{-1}) of wheat on two soils (Yadvinder-Singh *et al.* 2009)

Treatment		*Sandy loam*			*Silt loam*		
		2004-05	*2005-06*	*2006-07*	*2004-05*	*2005-06*	*2006-07*
	Grain yield (t ha^{-1})						
	Straw management						
	Straw burned-CT	4.09	4.14	3.96	3.63	3.45	3.16
	Straw burned-ZT	4.08	3.87	3.64	3.33	3.36	3.25
	Straw incorporated-CT	4.03	4.11	3.66	3.12	3.33	3.15
	Straw mulch-ZT	4.15	4.40	3.83	3.32	3.59	3.11
	LSD (0.05)	NS	0.26	0.21	0.20	0.11	NS
(B)	N rates (kg ha^{-1})						
	0	2.24	2.79	2.10	1.59	1.94	1.74
	90	4.38	4.23	3.83	3.37	3.44	3.38
	120	4.81	4.67	4.35	4.00	3.99	3.64
	150	4.91	4.84	4.81	4.44	4.36	3.91
	LSD (0.05)	0.30	0.24	0.30	0.21	0.24	0.22
	Interaction	NS	0.48	NS	NS	0.47	NS

to 150 kg N ha^{-1} in straw retained treatments (straw incorporated-CT and straw mulch-ZT) and up to 120 kg N in which residues were burnt (straw burnt-ZT and -CT) (Table 5). In sandy loam soil, when no N was added, yield of straw mulch-ZT was higher than straw incorporation-CT and yields of both the treatments were similar at all N levels (Table 5). At 120 kg N ha^{-1}, straw burnt-ZT treatment produced lower yield than straw incorporation and straw mulch plots. At 150 kg N ha^{-1}, straw burnt-CT wheat produced higher yield than straw burnt-ZT but the yields were on a par with straw incorporation and straw mulch treatments. In silt loam soil, at 90 kg ha^{-1}, wheat grain yield was lower in straw

Table 5
Effect of rice straw management, tillage system and N fertilizer on grain yield (t ha^{-1}) of wheat on two soils during 2005–06 (Yadvinder-Singh *et al.* 2009)

	Straw management	*Levels of N (kg ha^{-1})* 0	90	120	150	*Mean*
		Grain yield (t ha^{-1})				
(A)	Sandy loam					
	Straw burned-CT	2.48	4.33	4.73	5.03	4.14
	Straw burned-ZT	2.68	3.94	4.30	4.54	3.87
	Straw incorporated-CT	2.40	4.35	4.80	4.89	4.11
	Straw mulch-ZT	3.58	4.30	4.84	4.90	4.40
	Mean	2.79	4.23	4.67	4.84	
	LSD (0.05): Main-0.26; Sub-0.24; Main× sub-0.48					
(B)	Silt loam					
	Straw burned-CT	2.14	3.59	4.00	4.06	3.45
	Straw burned-ZT	1.70	3.56	3.99	4.20	3.36
	Straw incorporated-CT	2.02	3.07	3.93	4.31	3.33
	Straw mulch-ZT	1.90	3.55	4.03	4.87	3.59
	Mean	1.94	3.44	3.99	4.36	
	LSD (0.05): Main-0.11; Sub-0.24; Main× sub-0.47					

incorporation-CT than all the other treatments (Table 5). Grain yield of wheat at 0 and 120 kg N ha^{-1} was, however, similar under all the straw-tillage system treatments. At 150 kg N ha^{-1}, straw mulch-ZT had the highest wheat yield than the other treatments.

Yadvinder-Singh *et al.* (2015) conducted several on-farm and on-station field experiments in 2007-2008 to 2012-2013 to evaluate N management practices for ZT wheat sown into rice residues using Happy Seeder. There was no significant increase in across-farm average grain yield in response to applied nitrogen above the recommended rate (120 kg N ha^{-1}) and there was no interaction between years and treatments (Table 6). Wheat yield was similar for CT and Happy Seeder sown wheat at the recommended fertilizer rate. It indicates that wheat established with ZT and rice residue did not require more than 120 kg N ha^{-1}, the rate recommended for a conventional RW system. Sidhu *et al.* (2015) conducted 106 on-farm trials on wheat sown into rice residues with the 9-row Turbo Happy Seeder during 2007-08 to 2009-10 and showed that grain yield of wheat obtained with 9-row Turbo Happy Seeder was similar to or higher than yield with straw burning and conventional tillage prior to sowing.

Table 6
Response of wheat sown into rice residues to fertilizer N application in on-farm trials during 2007–2010 (Yadvinder-Singh *et al.* 2015)

Nitrogen rate (kg ha^{-1})	*Average grain yield (Mg ha^{-1})*		
	2007-08 (n=5)	*2008-09 (n=3)*	*2009-10 (n=3)*
90	-	-	3.25
120	4.34	4.73	3.65
150	4.44	4.90	3.78
180	4.48	4.97	-
120(FP)	-	-	3.54
LSD (0.05)	NS	NS	0.26

(FP)- Farmer's practice, conventional tillage after burning of rice residues

Use of rice straw as biochar

Biochar, a co-product of thermochemical conversion of lignocellulosic materials into advanced biofuels, may be used as a soil amendment to enhance the sustainability of biomass harvesting. Application of synthetic biochar in soil may provide a novel soil management practice because of its potential to improve soil fertility, enhance soil carbon content, mitigate greenhouse gas emissions, reduce leaching of nutrients and chemicals, increase fertiliser use efficiency, and enhance agricultural productivity. Surplus rice residue available in the NW India could potentially be pyrolysed to produce bioenergy, thereby reducing field burning and the use of fossil fuels, and the biochar by-product could be used as soil amendment. The major distinction between biochar and charcoal (or char) is that the former is produced with the intent to be added to a soil as a means of sequestering carbon and for enhancing soil quality.

A simple technology has been developed by PAU Ludhiana to convert rice straw in to biochar using modified kiln which can process 0.7 t of rice straw in to 0.5 t of biochar. The cost of kiln is approximately Rs.30000/-. In one month it can convert 5 t of rice straw in to 3.5 t of rice straw biochar. Out of the options available for incorporation of rice straw into soils, conversion of rice straw in to biochar and its subsequent application to the soil is the eco-friendly, technically sound and economically viable technology. Haefele *et al.* (2011) concluded that biochar from rice residues can be beneficial in rice-based systems but the actual effects on soil fertility, grain yield, and soil organic carbon will depend on site-specific conditions. Biochar offers significant prospects for sequestering about 40-50% of original biomass carbon in soil in a chemically altered form that is biologically stable but remaining physically and chemically active. Due to its greater stability against microbial decomposition and its superior ability to retain nutrients compared to other forms of soil organic matter, applying biochar to soil also offers a significant potential for mitigating climate change and enhancing environmental quality. Currently, very little research has been done on various aspects of biochar application in different cropping systems in India. Results from a 3-yr field study conducted at Punjab Agricultural University, Ludhiana showed that application of biochat at the rate 5 t/

ha each to both rice and wheat in rice-wheat system increased yields of rice and wheat by 10 to 15 per cent compared to no biochar at recommended rates of fertilizer application. It also helped in saving fertilizer nitrogen to the extent of 30 to 35 percent. There was a significant improvement in the physical, chemical and biological properties of the soil under study.

Impact of open burning Vs straw management practices on environment

Open burning of rice straw in the fields

In the state of Punjab, 18 m tons out of 22 m tons of rice straw is burnt annually in the open fields. One ton of rice straw contains 6.2 kg N, 1.1 kg P_2O_5, 18.9 kg K_2O, 1.35 kg S and 400 kg Carbon plus other micro nutrients. It is estimated that in Punjab alone, about 1.5 lakh tonnes of N and S in the rice residues is lost during burning, costing more than Rs. 150 crores at the prevailing prices. In north-west India some 70 to 80 million tons of rice and wheat straw are burned annually, releasing approximately 140 million tonnes of CO_2 (carbon dioxide) to the atmosphere, in addition to CH_4 (methane), N_2O (nitrous oxide) and air pollutants. About 75% of greenhouse gases (GHG) emissions from agro-residues burning are CH_4 and the remaining one-fourth was N_2O. Burning has to be discouraged in view of its harmful effects on environment and soil productivity. Besides substantial loss of plant nutrients and environmental hazards, it has important implications on human health also. A study conducted by Institute of Social and Economic Change revealed that approximately Rs. 7.6 crores are spent annually on ailments caused by the burning of rice residues.

In-situ incorporation of rice straw

Generally incorporation of rice straw is done 20-25 days before sowing of wheat crop. It is done by chopping, mould ploughing and then followed by another ploughing for the preparation of land for sowing. The cost of various operations to be carried out to prepare one acre of land comes out to be Rs.2500 to Rs. 3000. If we calculate for the Punjab State, it comes out to be Rs. 2000/- crores. Besides this huge amount it will also burn 161 million litres of diesel oil as fuel required to carry out these operations. This will emit 0.42 m tons of CO_2 in to the atmosphere. In addition to this the decomposition of the incorporated rice straw will also be contributing to the environmental pollution.

Retention rice residues by using Happy Seeder

The use of Happy Seeder for the sowing of wheat in the rice residues is relatively environmental friendly technology. It helps saving huge amount of funds and diesel oil required by other technologies of sowing wheat. It will also help in cutting the cost of fertilizer nitrogen and phosphorus after 2-3 years of continuous sowing with Happy Seeder in the same fields. In spite of 40 per cent subsidy on its purchase by the state Government, its adoption is limited only to less than 3 per cent.

Conversion of rice straw in to biochar

The emission of gases coming out during this process is reduced to 30 to 40 percent compared to open field burning thus reducing the environmental pollution to 60 to 70 per cent. The advantage of this technology is that almost 40-50 % of the carbon incorporated in the soil is in recalcitrant form and can stay in the soil for thousands of year and thus will not return to the atmosphere as CO_2.

CONCLUSIONS

Burning of rice straw in the open fields results in the environmental pollution, loss of nutrients and is harmful to soil, animals and human health. Therefore burning has to be discouraged in view of its harmful effects on environment and soil productivity. Wheat can be sown into rice residues using the Happy Seeder. Continuous incorporation of crop residues for 4 years significantly increased the wheat yield over straw removal, particularly under limited P supply situations. Besides saving nitrogen in-field retention of rice residues will help in improving soil health and reduce environmental pollution from rice straw burning. The results indicate that biochar amendments have the potential to substantially improve the quality, fertility status and productivity of the agricultural soils. Due to relatively stable biological state of biochar, its production for soil application has been proposed as a way of diverting waste biomass carbon from a rapid to a slow carbon-cycling pool in soil.

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