Plant, Soil and Environment, 69, 2023 (7): 333–343 *Original Paper*

https://doi.org/10.17221/68/2023-PSE

Influence of 11 years of crop residue management on rice productivity under varied nitrogen levels in the rice-wheat cropping system

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Citation: Gupta R.K., Sraw P.K., Kang J.S., Kaur J., Kalia A., Sharma V., Manhas S.S., Al-Ansari N., Alataway A., Dewidar A.Z., Mattar M.A. (2023): Influence of 11 years of crop residue management on rice productivity under varied nitrogen levels in the rice-wheat cropping system. Plant Soil Environ., 69: 333–343.

Abstract: The present study compares the six crop residue management techniques in main plots (since 2008) and three split nitrogen (N) levels, i.e., 75, 100 and 125 kg N/ha in subplots for rice crops for two years, i.e., 2019 and 2020, in sandy loam soil under field conditions. This experiment evaluated the long-term effect on rice productivity, soil organic carbon content and nutrient requirement in rice-wheat cropping system. The results revealed that different crop residue management practices and N levels significantly influenced rice growth, yield and yield attributes and improved nutrient uptake by grain and straw. Maximum grain yields of 20.8% and 17.8% higher over the conventional (no straw) treatment during 2019 and 2020, respectively, were recorded where the rice and wheat residue was retained or incorporated. The rice grain yield without residue responded significantly up to 125 kg N/ha. Whereas, with rice and wheat residue, rice grain yield did not respond to the application of N beyond 75 kg N/ha during both years.

Keywords: environmental pollution; nitrogen uptake; climate change; *Oryza sativa* L.; paddy straw

The rice-wheat system is labour, water and energy intensive and is becoming less economical due to depleting natural resources. The novel constraints of soil health deterioration, weed shift and climate change further aggravate the problem. As an agrarian state in North-western plains of India, Punjab includes a substantial land area (2.6 million hectares) under the rice-wheat cropping system. On an annual average, 55 million tons of crop residue is generated through this cropping system, of which more than 22 million tons of agri-residue is contributed only from rice (Gupta et al. 2020). Rice straw management has always been challenging. Although, the straw generated by the cultivation of wheat is removed from the combine harvested fields for its utilisation as animal feed. However, more than 80% of rice straw is burnt in the field due to its low economic value and other issues such as labour scarcity, interference with the sowing of

https://doi.org/10.17221/68/2023-PSE

subsequent crops and the short time window for rice straw management before the sowing of wheat (Singh and Sidhu 2014). Rice straw is considered inferior for milch animals due to its high silica content and limited alternative uses. Therefore, farmers usually find on-farm burning as the most common viable option to eliminate residues within a short time window. Furthermore, on-farm residue burning decreases the biotic stresses like crop weeds and pest inoculum, encouraging farmers to choose crop residue burning as the quickest and easiest solution for crop residue management (Junpen et al. 2018).

Despite the positive effects of burning crop residue in terms of saving time, energy, labour and biotic stresses, it has posed numerous ill effects on soil, human health and the environment. The on-farm burning of crop residues has emerged as a significant source of particulate matter and greenhouse gases (such as carbon dioxide (70%), methane (0.66%), carbon monoxide (7%) and N_2O (2.09%)) (Samra et al. 2003, Dutta et al. 2022), affecting the atmospheric chemistry at global and regional levels and leading to serious health issues (Singh et al. 2008). In Punjab, rice residue burning causes an average loss of 35 kg N, 3 kg P and 2.7 kg S/ha (Dutta et al. 2022, Parihar et al. 2023). Reports further suggested that around 40% of absorbed N, 30–35% of absorbed P, 80–85% of absorbed K and 40–50% of absorbed S remain accumulated in vegetative tissues of the crop plants, part of which otherwise get lost with the burning of crop residues (Kumar et al. 2019, Dutta et al. 2022, Parihar et al. 2023). Apart from the nutrient losses, the heat generated due to burning also kills the environment-friendly beneficial soil microbes (Samra et al. 2003). In crux, the removal and burning of crop residues engender massive loss in terms of soil nutrient pool and biodiversity, eventually affecting the nutrient inputs along with significant effects on long-term soil fertility and productivity (Singh and Sidhu 2014).

Such a scenario suggests the necessity of farming appropriate, user-friendly and cost-effective measures for managing rice residue. In recent years, several crop residue management strategies have evolved. These alternate strategies include the surface retention of rice straw and sowing subsequent wheat with a happy seeder or zero tillage, mulching in other crops, *in-situ* incorporation, baling and bioenergy generation (Singh and Sidhu 2014, Gupta et al. 2022). Among these crop residue management options, more emphasis is laid on the *in-situ* retention of crop residues due to its crucial role in sustaining the productivity of rice-wheat systems across the Indo-Gangetic Plains (Singh et al. 2005). In this context, minimum or zero till drilling of wheat seems potent; however, it is associated with the constraints of straw accumulation, poor traction of drive and requirement of frequent lifting, affecting the seedling establishment and seed depths (Thind et al. 2019).

On the other hand, *in-situ* incorporation of crop residues before wheat alters the soil microclimate, microbial population and activity and causes subsequent nutrient transformations in soil (Kumar and Goh 1999). According to Singh et al. (2008), the immediate incorporation of wheat and rice residue with high C/N before planting causes N immobilisation, eventually causing reductions in the yield of subsequent crops due to nitrogen deficiency. The net supply of nitrogen from crop residues relies on the type of residues, environmental conditions and the period from the incorporation of residues to the sowing of the subsequent crop for the process of decomposition (Singh and Sidhu 2014). The decomposition requires an average period of more than a year for completion (Singh et al. 2005). The higher C/N ratio can also be rectified through an additional dose of nitrogen fertiliser at the time of incorporation (Singh et al. 2008). The study by Singh and Sharma (2000) also supported this remediation and reported successful mitigation of yield depreciation by adding rice residue with the application of 20 to 40 kg N/ha. Another study further reported the positive effects of long-term incorporation of rice residue on soil organic matter build, which enhanced the readily mineralised organic soil N and supported the potential for reducing fertiliser N rates for an optimal yield of succeeding crops (Bird et al. 2001). Therefore, plenty of published literature documenting the positive impacts of residue management on rice's soil characteristics and yield attributes can be retrieved. However, the working hypothesis for the present investigation has been formulated to recognise the residual and interactive effects of long-term, i.e., eleven years of rice/wheat crop residue incorporation through various residue management practices with different levels of nitrogen fertiliser application on grain productivity of rice cultivated under rice-wheat (RW) cropping system.

MATERIAL AND METHODS

Site description and soil characteristics

A field experiment was initiated on sandy loam soil in 2008 at Research Farm, Department of Agronomy,

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Punjab Agricultural University (PAU) Ludhiana, Punjab, India. The experimental site is geographically located at 30°54'N latitude and 75°48'E longitude with an altitude of 247 m a.s.l. The soil physical and chemical attributes of the experimental field soil were obtained at the start of the experiment. International Pipette Method (Piper 1966) was used to determine the textural class of the experimental field. The soil texture of the experimental site was confirmed by mechanical soil analysis. The bulk density was determined by using the core sampler method (Blake 1965). The data on various physico-mechanical properties of soil has been presented in Table 1.

For chemical analysis, composite soil samples were collected from 0–15, 15–30 and 30–45 cm soil depth; shade dried, were ground and sieved through a 2 mm sieve. The various chemical properties analysed were soil pH, electrical conductivity (EC), organic carbon (OC) and available (N, P and K) before sowing of the crop in the experimental field. The detail of various chemical properties of the experimental field depicted is given in Table 1.

Climate and weather data during the study

The experimental site was in the central plain regions of Punjab under the Trans-Gangetic agro-climatic zone of India. Sub-tropical and semi-arid climates characterise the region. It experiences a hot and dry summer from April to June, hot and humid weather (July–September), winter (November–January) and mild weather during February and March.

The meteorological data recorded during the growth period of the crop (Figure 1) showed that the mean weekly maximum and minimum temperatures during 2019 ranged from 30.2 to 43.0 °C and 19.2 to 28.5 °C. In 2020, corresponding values ranged from 29.6 to 42.1 °C and 14.9 to 28.0 °C, respectively. The maximum and minimum mean weekly temperatures of 43.0 °C and 19.2 °C were recorded from 04 to 10 June 2019 and 08 to 14 October 2019, respectively. In contrast, in 2020, maximum and minimum mean weekly temperatures of 42.1 °C and 14.9 °C were recorded on 21 to 27 May 2019 and 15 to 21 October 2020, respectively.

Experimental design and crop management

A long-term field experiment established in 2008 at Research Farm, Department of Agronomy, PAU Ludhiana, was modified in 2019 in which crop residue management (CRM) main plot treatments were split into subplots to accommodate varied nitrogen (N) levels. This was performed to investigate the effect of crop residue management practices and nitrogen

Table 1. Physicomechanical and chemical properties of soil of the experimental field

Soil separate	0–15 cm	15–30 cm	30–45 cm	Method of estimation
Sand (%)	69.8	69.6	67.9	
Silt (%)	18.1	19.1	19.4	Piper (1966)
Clay (%)	12.2	12.5	13.2	
Textural class	sandy loam	sandy loam	sandy loam	
Bulk density (g/cm^3)	1.38	1.54	–	Blake (1965)
Chemical properties				
pH	7.11	7.21	7.28	Beckman's glass electrode pH meter (Jackson 1967)
EC (dS/m)	0.27	0.28	0.26	Solubridge conductivity meter (Jackson 1967)
OC (%)	0.57	0.51	0.40	Walkley and Black rapid titration method (Walkley and Black 1934)
Available N (mg/kg)	129.5	122.6	117.1	Modified alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (mg/kg)	12.0	10.8	8.61	0.5 mol/L sodium bicarbonate extractable method (Olsen et al. 1954)
Available K (mg/kg)	133.7	121.6	112.8	1 mol/L ammonium acetate extractable K method (Jackson 1967)

EC – electrical conductivity; OC – organic carbon

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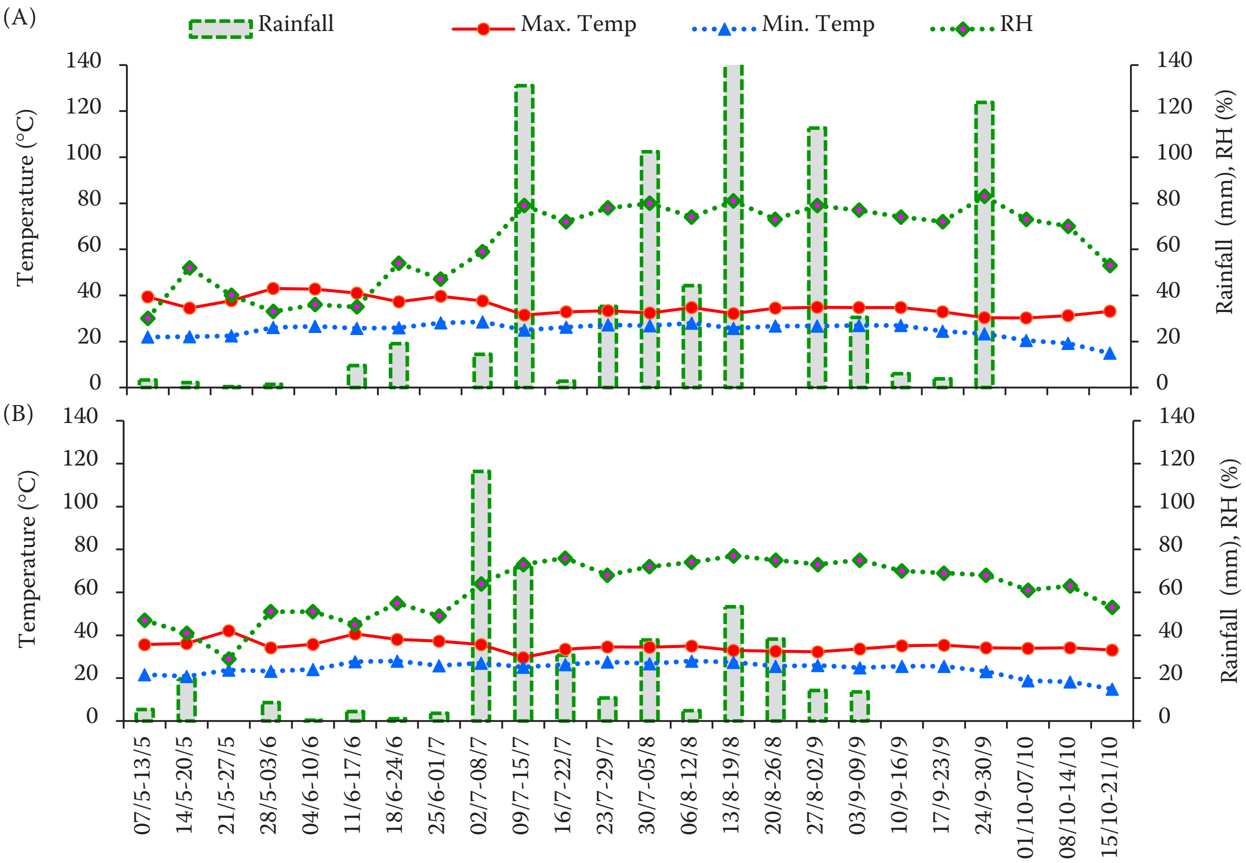

Figure 1. Weekly mean meteorological data during crop season in (A) 2019 and (B) 2020. RH – relative humidity

rates on growth, yield, nutrient uptake, and soil health in cropping rice-wheat system. The experiment was assessed in a split-plot design comprised of six CRM techniques in the main plot and three N-levels *viz*. 75, 100 and 125 kg N/ha in sub-plots (Table 2) with three replications. The size of the

Table 2. Details of treatments

Main plots: crop residue management practices (6)		
	Summer	Winter
T_1	transplanted paddy (after removing the wheat straw)	zero tillage sowing of wheat (after removing the paddy straw)
T_2	transplanted paddy (after removing the wheat straw)	conventional tillage sowing of wheat (after removing paddy straw)
T_3	transplanted paddy (after removing the wheat straw)	conventional tillage sowing of wheat (with paddy straw)
T_4	transplanted paddy (after removing the wheat straw)	zero tillage sowing of wheat (with paddy straw)
T_5	transplanted paddy (with wheat straw)	zero tillage sowing of wheat (with paddy straw)
T_6	transplanted paddy after burning wheat straw	zero tillage wheat after partial burning of paddy straw
Subplots: nitrogen levels		
N_1	75 kg N/ha	
N_2	100 kg N/ha	
N_3	125 kg N/ha	

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main plots was 16.5 × 2.5 m, which were later split into three subplots (N levels), each of size 5 × 2.5 m with 0.75 m buffers. The rice cultivar PR 127 was sown in the nursery (seed rate of 20 kg/ha) in the second fortnight of May during both years. Before sowing, seeds were soaked overnight in water consisting of 60 g Sprint 75 WS (carbendazim + mancozeb). Three seedlings per hill were transplanted following row-to-row and plant-to-plant spacing of 20 cm and 15 cm, respectively, in the second fortnight of June during both years of study. Nitrogen was applied as per treatments, i.e., 75, 100 and 125 kg N/ha through urea in three equal splits, i.e., $1/3^{rd}$ within the first week of transplanting, $1/3^{rd}$ three weeks after transplanting and the remaining $1/3^{rd}$ after six weeks after transplanting. Before puddling, a full dose of phosphorus (30 kg P/ha) and potassium (25 kg K/ha) was applied. Zinc sulphate heptahydrate (21% Zn, 62.5 kg/ha) was applied two weeks after transplanting. For weed management, RifitPlus 37 EW (Pretilachlor, 1.875 L/ha) was applied by mixing with sand in standing water within two days of tranplantation. The field was continuously ponded with irrigation water for two weeks after tranplantation. Afterwards, the field was irrigated within two days after ponded water had infiltrated the soil. Chlorpyriphos (2.5 L/ha) was sprayed in 250 L of water to control the leaf folder and stem borer. Two sprays of Tilt 25 EC (Propicanazole, 500 mL/ha) were applied to protect the crop from brown leaf spots and sheath blight. The net plots were harvested manually within the second fortnight of October for both years of investigation. The harvested crop was tied in bundles, labelled, and threshed manually after sun drying.

During the summer (rainy) season, wheat straw was removed in T_1 to T_4 treatments; however, in the T_5 treatment, wheat straw was incorporated in soil with a disc harrow, and it was burnt in the T_6 treatment before rice tranplantation. During the winter, wheat was sown with zero-till drill after removing paddy straw or partial burning of paddy straw in T_1 and T_6 treatments, respectively. In T_2, wheat was sown after removing the paddy straw in the prepared seed bed with a conventional seed drill. In the T_3 treatment, paddy straw was incorporated into the soil with a disc harrow, and sowing was done with a conventional seed drill after preparing the seed bed. In T_4 and T_5, wheat sowing was done with Turbo Happy seeder directly in the standing stubbles and loose paddy straw.

Plant and soil analysis studies

Plant biometric attributes. Effective tillers (ear-bearing tillers) were recorded from two sites in one-meter row length from each plot and converted into the number of effective tillers per m^2. Five representative fully developed panicles were selected from each treatment and threshed manually to obtain the data on the number of grains per panicle. Afterwards, grains per panicle were counted manually, averaged, and expressed as the number per panicle. A sample of one thousand grains was taken from the produce of each plot and weighed and expressed in grams. The total produce obtained from each net plot was weighed after threshing, and grain yield was calculated as t/ha.

Soil analysis

Soil organic carbon. The composite soil samples were collected from 0–15 cm soil depth, dried in the shade, were ground and sieved through a 2 mm sieve. The organic carbon (OC) was determined by Walkley and Black's rapid titration method (Walkley and Black 1934).

Plant analysis

Nitrogen, phosphorous and potassium content in grain and straw. Each treatment's grain and straw samples were ground to determine N, P and K content. For N content determination in grain and straw, 0.5 g sample of each of grain and straw were wet digested separately for every treatment in 10 mL of concentrated H_2SO_4 and digestion mixture having selenium dioxide, copper sulphate, potassium sulphate and mercuric oxide. Kjeldahl's method, proposed by Piper (1966), was used for analysing nitrogen.

To determine P and K content, a 0.5 g ground sample (grain and straw each) was wet digested in a di-acid mixture of nitric (HNO_3) and perchloric acid ($HClO_4$) in the ratio of 4:1 as per Piper (1966). The vanado-molybdate phosphoric acid colourimetric method in nitric acid, outlined by Jackson (1967), was used to determine P content. The intensity of the yellow colour was measured by a visible spectrometer (Spectronic-20, Bausch and Lomb, Bridgewater, USA) at 470 nm wavelength. The K content of both grains and straw samples was determined with a flame photometer.

Nutrient (N, P and K) uptake by grain. For calculating the uptake of N, P and K by grain, the percentage

https://doi.org/10.17221/68/2023-PSE

of the nutrient content of grain was multiplied by the respective grain yield, and uptake was expressed in kg/ha.

Data analysis

Data was analysed with two-way ANOVA by applying the Split Plot design in SAS software (version 9.1, Cary, USA). The comparison of means for the treatments was made by using *LSD* (least significant difference) (P < 0.05). The normality of the data150 was evaluated through the Shapiro-Wilk test (Tondey et al. 2022) in SAS software (version 9.1, Cary, USA). Since no significant difference in the results was observed, the data were pooled over two years.

RESULTS AND DISCUSSION

Yield attributes

Effective tillers and grains per panicle with incorporation/retention of both crop residues were significantly higher than residue removal or burning treatments. The addition and retention of crop residue improved the availability of nutrients throughout the growing season, reducing tiller mortality. The ANOVA table indicating the relative effect of crop management methods and nitrogen level has been presented in Table 3. The sub-treatment nitrogen levels also significantly influenced the effective tillers and grains per panicle. The highest number of effective tillers and grains per panicle were registered in the N_3 (125 kg N/ha) treatment, which was significantly superior to N_2 and N_1 treatments. The influence of different crop residue management practices and N levels was found to be non-significant on 1 000 grain weight (Table 4). Other researchers (Okonji et al. 2011, Nandan et al. 2018) have also documented similar results.

Grain yield

During both years, rice grain yield significantly responded to various crop residue management practices, nitrogen levels and their interaction (Tables 4 and 5). The maximum increase of 20.8% during 2019 and 17.8% in 2020 was recorded in T_5, where the crop residue was retained from both crops (rice and wheat) compared to the conventional practice (T_2). The second maximum increase of 11.2% and 10.8%

Table 3. Analysis of variance (degree of freedom and *F*-value) of yield attributes and yield of rice

Source	*df*	*F*-ratio							
		effective tillers (number/m^2)	grains/ panicle (pcs)	1 000 grain weight (g)	grain yield (t/ha)	soil organic carbon (%)	N uptake by grain	P uptake by grain	K uptake by grain
2019									
Main	5	7.81*	18.8*	2.21^{ns}	35.9*	–	43.6*	44.2*	95.7*
Sub	2	15.6*	26.6*	0.57^{ns}	37.1*	–	52.6*	42.6*	73.4*
Main × sub	10	0.51*	3.73*	0.10^{ns}	3.00*	–	2.05^{ns}	2.85*	2.20^{ns}
2020									
Main	5	8.01*	23.6*	2.85^{ns}	44.0*	25.1*	64.0*	43.5*	124.1*
Sub	2	15.6*	27.8*	0.69^{ns}	21.0*	0.37^{ns}	44.4*	46.6*	57.9*
Main × sub	10	0.63^{ns}	3.75*	0.21^{ns}	1.93^{ns}	1.98^{ns}	1.9^{ns}	2.01^{ns}	1.52^{ns}
Pooled data over two years									
Year	1	914.3*	0.00*	0.00*	198.6*				
Main	5	15.8*	41.6*	5.03*	78.3*				
Year × main	5	0.06^{ns}	0.79^{ns}	0.00^{ns}	0.67^{ns}				
Sub	2	31.1*	54.3*	1.30^{ns}	54.8*				
Year × sub	2	0.05^{ns}	–0.02^{ns}	–0.05^{ns}	0.14^{ns}				
Main × sub	10	1.09^{ns}	7.46*	0.26^{ns}	4.59*				
Year × main × sub	10	0.06^{ns}	0.01^{ns}	0.04^{ns}	0.12^{ns}				

ns – not significant; *Values are statistically significant at P = 0.05. *df* – degree of freedom

https://doi.org/10.17221/68/2023-PSE

Table 4. Effect of crop residue management practices and nitrogen levels on yield attributes and yield of rice in rice-wheat system

Treatment	Effective tillers (number/m^2)			Grains/panicles (pcs)			1 000 grain weight (g)			Grain yield (t/ha)		
	2019	2020	pooled	2019	2020	pooled	2019	2020	pooled	2019	2020	pooled
Crop residue management (CRM)												
T_1	283	292	287.5	108	109	109	22.6	22.6	22.6	5.59	5.98	5.79
T_2	284	296	290.4	113	111	112	22.6	22.6	22.6	5.72	6.11	5.91
T_3	302	312	307.5	117	118	118	23.2	23.3	23.2	6.36	6.77	6.56
T_4	302	313	307.5	116	117	117	23.2	23.4	23.3	6.35	6.76	6.55
T_5	324	338	331.4	123	124	123	23.3	23.5	23.4	6.91	7.20	7.06
T_6	290	299	294.5	113	112	113	22.8	22.9	22.8	6.02	6.21	6.14
LSD (P = 0.05)	17	19	12.1	3.6	3.6	2.4	ns	ns	0.5	0.26	0.23	0.16
Nitrogen levels (N)												
N_1	284	294	289.1	112.4	112.6	113	22.9	22.9	22.9	5.81	6.18	6.00
N_2	301	311	305.8	115.4	115.7	116	23.0	23.1	23.0	6.21	6.56	6.39
N_3	309	320	314.5	117.4	117.4	117	23.0	23.1	23.1	6.45	6.77	6.61
LSD (P = 0.05)	9	10	6.6	1.4	1.4	1.0	ns	ns	ns	0.16	0.19	0.12
CRM × N	ns	ns	ns	ns	ns	2.3	ns	ns	ns	0.38	ns	0.29

LSD – least significant difference; ns – not significant

was recorded in the T_3 main treatment, which was statistically at par with the T_4 but significantly different from the rest of the treatments. The interaction of various crop residue management practices with nitrogen levels showed significant variation. The grain yield of rice transplanted without crop residue responded up to 125 kg N/ha and 100 kg N/ha, where rice was transplanted with only rice residue retention/incorporation. However, the grain yield of rice transplanted with rice and wheat residue did not respond beyond 75 kg N/ha during both years of the experimental study. The results further state that an average yield increment of 4.0% and 10.4% can be achieved by managing rice residue alone or both rice and wheat residue (T_5), and 25 kg N/ha can also be saved compared to the conventional practice.

Table 5. Interactive effect of crop residue management practices and nitrogen levels on grain yield (t/ha) of rice in rice-wheat system

Treatment	Nitrogen levels (kg N/ha)					
	2019			2020		
	75	100	125	75	100	125
Crop residue management practices (CRM)						
T_1	5.00	5.60	6.17	5.53	6.00	6.42
T_2	5.19	5.76	6.20	5.61	6.12	6.59
T_3	6.02	6.48	6.57	6.46	6.89	6.96
T_4	6.05	6.41	6.60	6.39	6.91	6.99
T_5	6.84	6.93	6.97	7.19	7.21	7.20
T_6	5.62	6.03	6.41	5.78	6.22	6.63
LSD (P = 0.05)	CRM × N = 0.38			CRM × N = ns		

*The *LSD* (least significant difference) values indicate interaction among crop residue management practices and nitrogen levels. ns – not significant

https://doi.org/10.17221/68/2023-PSE

Similarly, an average grain yield increment of 9.3% can be achieved by saving 50 kg N/ha in T_5 treatment over the conventional practice (T_2), where no residue is retained. Incorporation/retention of crop residues boosted crop growth in terms of plant height and yield attributes (effective tillers, number of grains per panicle and 1 000 grain weight) by enhancing the soil OC and status of the available nutrient pool, thereby recording the higher yield levels. Elemental N plays an active role in increasing cellular growth through cell division and cell enlargement and increases crop productivity by enhancing photosynthetic surfaces (as evidenced by high leaf area index (LAI)), dry matter accumulation, and sink growth. The results align with the findings of Sidhu et al. (2007) and Okonji et al. (2011) in rice.

Soil properties and nutrient uptake

Soil organic carbon. The soil OC was observed with residue retention/incorporation compared to removal or burning under the RW cropping system during both years of experimentation (Table 6). Higher soil OC was recorded in treatments in the year 2020, comprising the retention of single as well as both crops residue. Systems with beneficial effects on soil organic carbon (SOC) are believed to be pivotal for soil health and sustainability (Khokhar et al. 2022). Retention of crop residues from both of the crops, i.e. rice and wheat, in T_5 treatment registered with the highest SOC (0.67% and 0.69%), which was at par with single crop residue retention treatments T_3 and T_4 but numerically higher over residue burning (T_6) or residue removal treatments (T_1 and T_2). Crop residue retention/incorporation helped to reduce nutrient loss and improved the organic matter through carbon transformation processes resulting in the formation of C-intermediates and thereby enhancing the soil OC. The reduction in the SOC due to intensive tillage may be attributed to the disturbance of aggregates that rendered soil microbes to exhibit increased soil C-mineralisation (Xue et al. 2015). Furthermore, no crop residue incorporation besides the removal of residues in the residue removal treatment also exhibited low SOC contents. The application of N did not significantly influence the SOC content.

Nutrient (N, P and K) uptake by grain. Crop residue management practices and nitrogen levels significantly affected N, P and K uptake by grain (Table 7). Significantly higher N uptake by grain was recorded in the T_5 treatment (99.1 and 103.6 kg/ha), significantly superior over the rest of the crop residue management treatments. The N uptake by grain in T_3 and T_4 was mutually at par and was significantly higher over the residue removal treatments. It might be due to improvement in the SOC under residue retention/incorporation treatments which thereby stabilises soil structure and provides the congenial environment for root proliferation. Residue retention/incorporation improved the availability of nutrients to plants and positively affected N concentration and its uptake by grain. Other researchers have also presented the beneficial effect of crop residue on N uptake (Kumar et al. 2018). The N uptake by grain was also significantly affected by the rising nitrogen levels from 75 to 125 kg/ha. Significantly higher N uptake by grain was reported under N_3, which was 19.8% and 5.9% higher than under N_1 and N_2 in 2019; however, the corresponding values were 18.8% and 5.4% in 2020, respectively.

The data of P uptake by rice grain revealed that the highest P uptake (23.6 and 24.8 kg/ha) was recorded

Table 6. Effect of crop residue management practices and nitrogen levels on soil organic carbon (SOC) after the rice harvest in rice-wheat system

Treatment	Soil organic carbon (%)	
	2019	2020
Crop residue management practices (CRM)		
T_1	0.44	0.45
T_2	0.42	0.43
T_3	0.61	0.63
T_4	0.62	0.63
T_5	0.67	0.69
T_6	0.48	0.49
LSD (*P* = 0.05)	–	0.09
Nitrogen levels (N)		
N_1	0.54	0.55
N_2	0.53	0.55
N_3	0.55	0.56
LSD (*P* = 0.05)	–	ns
Interaction	–	ns

*The year 2019 SOC data depicts the average values but the ANOVA analysis and *LSD* (least significant difference) values for this parameter could be obtained as it failed the normal distribution. The year 2020 data was normally distributed, and the *LSD* values have been included. However, the interactions between crop residue management practices and nitrogen levels were non-significant. ns – not significant

https://doi.org/10.17221/68/2023-PSE

Table 7. Effect of crop residue management practices and nitrogen levels on nutrient uptake by rice grain in rice-wheat system

Treatment	Nutrient uptake by grain (kg/ha)					
	2019			2020		
	N	P	K	N	P	K
Crop residue management practices (CRM)						
T_1	69.6	16.2	15.4	74.7	18.1	16.5
T_2	71.8	16.8	15.7	76.6	18.9	16.8
T_3	90.3	20.3	21.0	96.4	22.2	22.9
T_4	87.3	20.0	20.4	93.6	22.0	22.4
T_5	99.1	23.6	24.2	103.6	24.8	26.3
T_6	78.8	18.0	17.7	80.7	19.3	18.3
LSD (*P* = 0.05)	5.4	1.3	1.1	4.7	1.2	1.1
Nitrogen levels						
N_1	74.6	17.3	16.9	79.3	18.4	18.1
N_2	84.4	19.5	19.3	89.4	21.4	20.8
N_3	89.4	20.7	21.0	94.2	22.9	22.6
LSD (*P* = 0.05)	3.0	0.8	0.7	3.3	1.0	0.9
CRM × N	ns	1.9	ns	ns	ns	ns

*The *LSD* (least significant difference) values indicate interaction among crop residue management practices and nitrogen levels. ns – not significant

in T_5 (both rice and wheat residue retention/incorporation treatment) in 2019 and 2020, respectively, which was significantly better than the rest of the treatments. The P uptake by grain with single residue retained treatments (T_3 and T_4) was mutually at par and significantly higher over without residue treatments (T1 and T2) during both years of study. Increased uptake of nutrients under residue-treated plots as compared to residue removal or burning has also been documented by Dotaniya (2012) and Kachroo et al. (2006). Similarly, maximum P uptake by straw was reported in the T_5 treatment (15.5 and 16.8 kg/ha in 2019 and 2020, respectively) and was significantly superior to the rest of the crop residue management treatments. These results are in accordance with the findings of Dotaniya (2012) and Meena et al. (2016). During both years, varied nitrogen rates significantly affected P uptake by rice grains. The maximum P uptake by rice grain was observed with N_3 level, i.e. 18.5 and 19.9 kg/ha, significantly better than the rest of the N rates during 2019 and 2020, respectively.

The highest K uptake by grain (23.6 and 24.8 kg/ha) was reported in T_5 (with both crop residues) in 2019 and 2020, respectively, significantly better than the rest of the crop residue management treatments. The second improvement in K uptake by grain was observed with T_3 and T_4 (single residue), which was 33.7% and 29.9% and 36.3% and 33.3% higher over T_2 treatment (conventional practices) during 2019 and 2020, respectively. Similar results were also observed by Dotaniya (2012) and Kachroo et al. (2006). Among the nitrogen levels, maximum K uptake by rice grain was reported with N_3 (18.2 and 19.5 kg/ha), significantly better than the rest of the N rates during 2019 and 2020, respectively. The lowest K uptake was found in N_1, which was significantly lower over N_2 and N_3 during both the years of study.

Different crop residue management practices and N rates significantly affected growth, yield attributes and rice yield. The grain yield of transplanted rice obtained with both residues was 20.8% and 17.8% higher over conventional practice (without residue) during 2019 and 2020, respectively. The grain yield of rice without residue responded up to 125 kg N/ha and responded up to 100 kg N/ha with single rice residue retention/incorporation. The grain yield of rice with rice and wheat residue did not respond to the application of N beyond 75 kg N/ha during both years of study. Residue retention/incorporation significantly influenced SOC and N, P and K uptake by grain.

https://doi.org/10.17221/68/2023-PSE

Acknowledgement. The authors extend their appreciation to the Deanship of Scientific Research, King Saud University, for funding through the Vice Deanship of Scientific Research Chairs, Research Chair of Prince Sultan Bin Abdulaziz International Prize for Water.

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Received: February 18, 2023
Accepted: June 16, 2023
Published online: July 17, 2023