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RESEARCH ARTICLE

Effect of conservation tillage and phosphorus levels on weed growth and wheat productivity in rice-wheat cropping system

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ABSTRACT

A field study was conducted during 2019-20 and 2020-21, to assess the effect of crops residue management, tillage and phosphorus on weeds growth and wheat productivity in rice-wheat cropping system. The weed density and biomass were significantly lower under zero-tillage (ZT) wheat grown in sequence with puddled transplanted rice (PTR) and rice residue retention as compared to rice residue removal or burning. Wheat plant height and tillers density were significantly influenced by residue management. Highest grain yield of wheat was attained in ZT-wheat with rice residue retention and in sequence with PTR with wheat residue. Wheat grain yield was 17.3 and 15.8% higher than conventional tillage-wheat without rice residue, and 12.8 and 11.7% higher in comparison to ZT-wheat grown after partial burning of rice residue, during 2019-20 and 2020-21, respectively in sequence with PTR without wheat residues. Wheat growth and yield enhanced significantly with increase in phosphorus (P) level from 0 to 60 kg/ha, across the residue management practices but weed density and biomass were unaffected. ZT-wheat with rice residue grown in sequence with PTR with wheat residues did not respond to phosphorus application and recorded similar yield with all tested doses of P. Thus, conservation tillage improved wheat productivity and reduced cultivation cost by reducing usage of fertilizers and herbicides.

Keywords: Conservation tillage, Crop residue, Phosphorus, Rice-wheat cropping system, Weed management, Wheat

INTRODUCTION

Rice-wheat system in Punjab covers 2.6 million ha with a crop residue production of 55 million tons, out of which more than 22 million tons contributed by rice (Gupta *et al.* 2020). Straw generated from wheat cultivation is removed from the combine harvested fields with the help of wheat straw combine for its utilization as animal feed. However, more than 80% of straw generated from rice fields is burned because of its low economic value, labour scarcity, interference with the sowing of subsequent crops and narrow window period before the sowing of wheat (Singh and Sidhu 2014). Heat generated from burning causes mortality of the environment friendly useful soil microbes in addition to release of green-house gases (GHG's) such as carbon dioxide (70%), carbon monoxide (7%), nitrous oxide (2.09%) and methane (0.66%) (Samra *et al.* 2003). Recent advancements in rice residue management have brought to light numerous residue management options *viz.*, surface retention of rice straw and zero-till sowing of subsequent wheat with happy seeder, mulching in other crops, *in-situ* incorporation; baling and bioenergy generation.

Conservation agriculture (CA) with reduced or zero-tillage (ZT) reduces operational cost, energy inputs, human labour, and conserves soil and water besides addition of organic matter in soil. Addition of rice residues in wheat alters soil microclimate, microbial populations and their activity and causes subsequent nutrient transformations in soil (Kumar and Goh 2000) particularly carbon, nitrogen and phosphorus mineralization (Gupta *et al.* 2022, 2024). Further, weeds are the major threat in wheat production (Gyawali *et al.* 2022) and account for 20-40% reduction in yield (Flessner *et al*. 2021, Oerke *et al*. 2012). Crop residue cover present at soil surface affects the germination of weed seeds and emergence by altering the soil seedbank environment (Buttar *et al.* 2022). The quality and quantity of crop residue affects weed emergence and dry matter accumulation (Kaur *et al*. 2021). Retention of crop residue on the soil surface along with zero tillage has suppressive effect on weed emergence and allows the crop to gain benefit over weeds. Thus, keeping in view the advantages of conservation agriculture along with residue retention, this study was conducted to evaluate the effect of crop residues, tillage and phosphorus levels on weeds growth and wheat productivity in rice-wheat cropping system.

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MATERIALS AND METHODS

A long-term field experiment was initiated in 2008 on residue management in rice-wheat system at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana (30°54'N, 75°48'E, 247 m average mean sea level), India. The present study was conducted during 2019-20 and 2020-21 in the same long-term experimental plot by retaining the main plots. The climate of the study site is sub-tropical and semiarid with dry and hot summer (April - June), moist weather from July - September and cool and dry winter (November to January). During cropping season (winter 2019-20), mean weekly maximum and minimum temperatures ranged from 10.3 to 35.5°C and 4.9 to 18.4°C while respective values ranged from 14.0 to 36.1°C and 3.5 to 17.9°C during 2020-21. The soil of the experimental site was sandy loam in texture (69.8% sand, 18.1% silt and 12.2% clay) with normal pH (7.16) and electrical conductivity (0.20 dS/m), low in soil organic C (0.33%) and medium in available N (285.1 kg/ha), available P (19.8 kg/ha) and available K (250.0 kg/ha). Experiment was laid out in split plot design, replicated thrice, by assigning six crop residue management practices in main plots and three phosphorus levels, *viz.* 0, 30 and 60 kg P/ha in sub plots. The main plot size was 15 m × 2.5 m and sub-plot size was10.0 m^2 (4.0 m × 2.5 m) with buffers of 0.75 m width. The details of treatments applied to rice and wheat crops grown in sequence are given in **Table 1**. In TPR WR_0-ZTW RR_0 treatment, wheat was sown with zero till drill after removing the paddy straw. In conventional tillage treatments (TPR WR_0- CTW RR_0 and TPR WR_0–CTWRR) with and without paddy straw, the conventional seed-cum-fertilizer drill was used for wheat sowing. In TPR WR_0– ZTWRR and TPR WR-ZTWRR treatments, sowing was done in standing rice stubbles with turbo happy seeder after uniformly spreading the loose rice residue. In TPR BWR - ZTW BRR, the loose rice straw was burnt before wheat sowing in standing rice stubbles. Wheat variety, *Unnat* PBW 343 was sown in the first week of November using seed rate of 100 kg/ha with row to row spacing of 22.5 cm. Wheat crop was fertilized with phosphorus (SSP-16% P), potash (MOP-60% K) and nitrogen (Urea-46% N). The entire recommended dose of P (as per treatment) and K and 1/3rd N was applied as basal dose by broadcasting method and remaining N was applied at CRI and late tillering stages in two equal splits. Weeds were controlled by using clodinafop 60 g/ha and metsulfuron-methyl 4 g/ha after 35 days of sowing (DAS) as tank mix in 375 litres of water during both the years of study. Plant density (number of plants/m^2) was recorded at 15 DAS from two spots in each treatment plot after complete emergence of crop. The data on weed density and biomass was recorded from each treatment at 30 (before herbicide application) and 100 DAS from two randomly selected spots with quadrat of 50 x 50 cm size. For taking biomass, weeds were removed from the ground level from the selected spots and were dried in oven at 60 ^{0}C until the constant weight. Wheat plant height was recorded at harvest and wheat tillers density at 90 DAS.Wheat grain yield was recorded from each net plot separately. Wheat root density was recorded, from different soil depth layers wise, at flowering stage. For root density, the plants were cut from the top and layer wise soil samples were taken using root sampling pipe. The sample of soil thus obtained was washed in running water in a thin nylon mesh of one mm sieve and dried in oven at 65 ^{0}C till the constant weight was attained. The root density was calculated by using the following formula

$$\text{Wheat root density (g/m}^3\text{)} = \frac{\text{Total root weight (g) in particular depth}}{\text{Total volume of soil (m}^3\text{) from which roots were collected}}$$

The data were analysed by undergoing analysis of variance (ANOVA) using CPCS1 software and the

Table 1. Details of treatments tested in rice (summer/*Kharif*) and wheat (winter/*Rabi* season) (in main plots)

Treatment	Rice	Wheat
TPR WR_0- ZTW RR_0	Transplanted puddled rice grown after complete removal of wheat residue (TPR WR_0)	Zero tillage wheat grown after complete removal of rice residue (ZTW RR_0)
TPR WR_0-CTW RR_0	Transplanted puddled rice grown after complete removal of wheat residues (TPR WR_0)	Conventional tillage wheat grown after complete removal of rice residues (CTW RR_0)
TPR WR_0-CTWRR	Transplanted puddled rice grown after complete removal of wheat residues (TPR WR_0)	Conventional tillage wheat grown with complete rice residues incorporation (CTW RR)
TPR WR_0-ZTWRR	Transplanted puddled rice grown after complete removal of wheat residues (TPR WR_0)	Zero tillage wheat grown with complete rice residues retention (ZTWRR)
TPR WR-ZTWRR	Transplanted puddled rice grown with complete retention of wheat residues (TPR WR)	Zero tillage wheat grown with complete rice residues retention (ZTWRR)
TPR BWR- ZTW BRR	Transplanted puddled rice grown after complete burning of retained wheat residues (TPR BWR)	Zero tillage wheat grown after partial burning of retained rice residues (ZTW BRR)

treatment means were compared at a significance level of 5% (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weeds

Major grassy weed in experimental field was *Phalaris minor* (11%), while the broad-leaved weeds included: *Rumex dentatus* (35%), *Medicago denticulata* (35%), *Chenopodium album* (6%), *Anagallis arvensis* (6%) and *Lepidium didymium* (7%). The crop residue management practices significantly affected the weed density and biomass (**Table 2**). In treatments where wheat was sown with happy seeder and straw was retained as mulch, significantly lower weed density and biomass was recorded as compared to residue removal/burnt or incorporation treatments. The effect of residue mulching on weed suppression was more prominent at early stages (30 DAS) as compared to late stage (100 DAS) as residue effect diminished in later stages due to its degradation with time. At 30 DAS, the weed density reduction of 35.7 and 32.5% was observed in wheat sown in rice residue retained plots followed by PTR with wheat residue (TPR WR- ZTWRR) and without wheat residue (TPR WR_0–ZTWRR) over residue removal (conventional practice, TPR WR_0-CTW RR_0), respectively. Residue retained as mulch in ZT delayed weed germination due to higher mechanical impedance and less exposure of weed seeds to solar light (Nichols *et al.* 2015). Significant reduction in weed biomass was recorded under ZT with residue retention. Similar results were also documented by Kaur *et al.* (2024), Sen *et al.* (2023) and Baghel *et al.* (2018). Weed density and biomass did not differ significantly with different phosphorus levels.

Wheat emergence and growth: Wheat sown under ZT with mulch treatments using happy seeder took a greater number of days to emerge (8-9 days) as compared to where crop was sown after preparing the seed bed (5-6 days). The overall number of plants/m^2 at 15 days was not significantly affected by residue management and phosphorus levels. Maximum tiller density was recorded at 90 DAS, thereafter; there was decline in tillers with advancement of crop age. It might be due to mortality of tillers at later stages of crop growth. Maximum plant height and tiller density was registered with treatment where residue of both crops was retained and it was significantly superior to rest of crop residue management practices. More tillers in residue retained plots as compared to conventional practice of residue removal was probably due to better soil heath, more availability of nutrients and better soil moisture (Kaur 2020, Gupta *et al.* 2022, Gupta *et al.* 2024). Taller plants and more tiller density under ZT wheat with residue retention treatments as compared to control was also reported by Kesarwani *et al.* (2017). Significant improvement in plant height and tiller density was recorded with 60 kg P/ha and lowest in control. Similar findings were also reported by Gupta *et al.* (2024), Ali *et al.* (2020) and Rafiullah *et al.* (2021). Harvest index was similar across all the treatments.

Table 2. Effect of crop residue management and phosphorus levels on weed density and biomass in wheat

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)			
	30 DAS		100 DAS		30 DAS		100 DAS	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Crop residue management practices								
TPR WR_0- ZTW RR_0	7.64 (58.0)	7.43 (55.0)	5.28 (27.0)	5.43 (28.5)	2.50 (5.3)	2.43 (5.00)	2.09 (3.23)	2.12 (3.30)
TPR WR_0-CTW RR_0	8.75 (76.5)	8.60 (73.7)	5.70 (31.7)	5.82 (33.0)	2.67 (6.4)	2.64 (6.10)	2.15 (3.65)	2.17 (3.73)
TPR WR_0-CTWRR	9.08 (82.0)	9.01 (80.8)	6.09 (36.2)	6.19 (37.4)	2.90 (7.5)	2.83 (7.10)	2.26 (4.10)	2.28 (4.20)
TPR WR_0-ZTWRR	5.95 (35.5)	5.77 (33.0)	4.80 (22.4)	4.85 (22.7)	1.97 (2.9)	2.00 (3.09)	1.97 (2.91)	1.99 (2.96)
TPR WR-ZTWRR	5.63 (31.5)	5.52 (29.9)	4.61 (20.3)	4.85 (22.5)	1.98 (3.0)	1.92(2.75)	1.97 (2.89)	1.99 (2.98)
TPR BWR- ZTW BRR	7.86 (60.7)	7.72 (59.6)	5.26 (26.9)	5.43 (28.7)	2.55 (5.4)	2.48 (5.19)	2.11 (3.46)	2.13 (3.53)
LSD (p=0.05)	0.69	0.85	0.49	0.42	0.28	0.30	0.11	0.12
Phosphorus levels (kg/ha)								
0	7.57 (58.4)	7.40 (56.3)	5.37 (28.2)	5.47 (29.2)	2.43 (5.1)	2.37 (4.83)	2.11 (3.48)	2.13 (3.57)
30	7.36 (55.2)	7.19 (53.0)	5.17 (26.2)	5.32 (27.7)	2.39 (5.1)	2.33 (4.60)	2.09 (3.41)	2.11 (3.49)
60	7.23 (53.3)	7.03 (51.0)	5.08 (25.3)	5.33 (27.7)	2.37 (4.8)	2.31 (4.49)	2.08 (3.34)	2.10 (3.43)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Data were subjected to square root transformation ($\sqrt{x+1}$). Original values are in parentheses.

TPR WR_0: Transplanted puddled rice (TPR) grown after complete removal of wheat residues (WR_0), TPR WR: Transplanted puddled rice (TPR) grown with complete retention of wheat residues (WR), TPR BWR: Transplanted puddled rice (TPR) grown after complete burning of wheat residues (BWR), ZTW RR_0: Zero tillage wheat (ZTW) grown after complete removal of rice residues (RR_0), CTW RR_0: Conventional tillage wheat (CTW) grown after complete removal of rice residues (RR_0), CTWRR : Conventional tillage wheat (CTW) grown with complete incorporation of rice residues (RR), ZTW RR: Zero tillage wheat (ZTW) grown with complete rice residues retention (RR), ZTW BRR: Zero tillage wheat (ZTW) grown after complete burning of rice residues (BRR).

More than 75% of roots mass was present in top soil layer (0-15 cm) irrespective of treatments. ZT treatments showed maximum root mass density than conventional practices. Maximum root mass density was found in double residue retention treatment. While, it was minimum under conventional practice. Higher root density in ZT with residue retention might be due to improvement in soil physical structure and greater retention of soil moisture which leads to better root growth. Lower root density under convention tillage sown wheat might be due to more compaction in these treatments. The compaction restricts root growth due to more resistance to root penetration (Data not given). Meena *et al.* (2015) and Mondal *et al.* (2019) also reported higher root mass densities under ZT with residue as compared to conventional tillage.

Wheat yield

Crop residue management practices and phosphorus levels caused significant variation in grain yield (**Figure 1**). The highest wheat grain yield was recorded from the plots where rice and wheat residue were retained in rice-wheat system (TPR WR-ZTWRR) which was statistically at par with treatment where rice residue was retained in wheat followed by transplanted rice without wheat residue (TPR WR_0– ZTWRR) and was significantly superior to residue removal (TPR WR_0- CTW RR_0) and burning (TPR BWR - ZTW BRR) treatments. The improvement in grain yield in TPR WR- ZTWRR was 17.3 and 15.8% and 12.8 and 11.7% over TPR WR_0-CTW RR_0 and TPR BWR - ZTW BRR during 2019-20 and 2020-21, respectively. Higher grain yield

Table 3. Effect of residue management practices and phosphorus levels on growth parameters of wheat

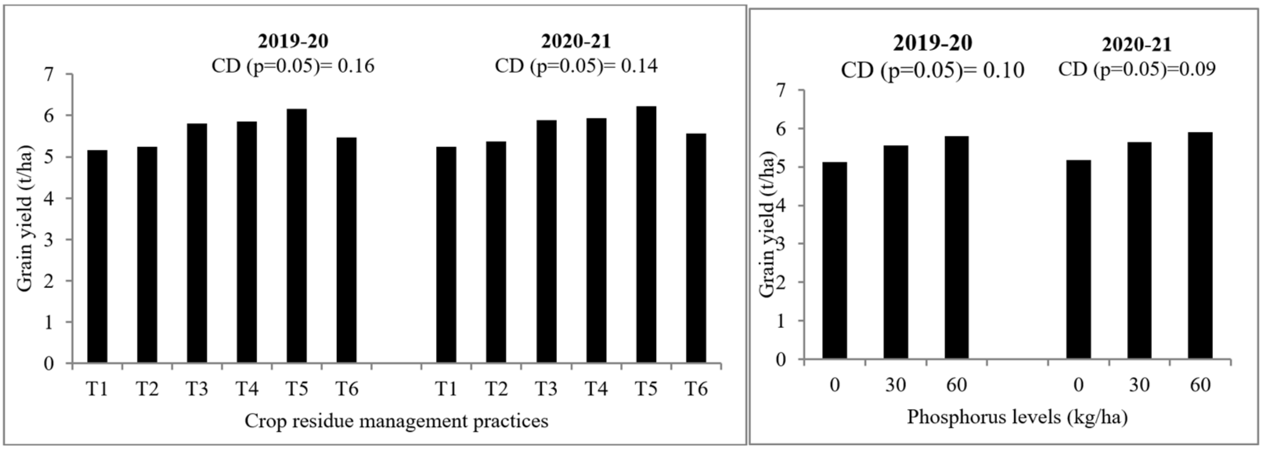
Treatment*	Days to emergence		Plant density at 15 DAS (no./m^2)		Plant height at harvest (cm)		Tiller density at 90 DAS (no./m^2)		Harvest index (%)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Crop residue management practices										
TPR WR_0- ZTW RR_0	7	7	155.8	164.5	75.9	77.0	364	370	42.7	42.4
TPR WR_0- CTW RR_0	5	5	164.5	172.2	76.4	79.7	366	372	42.4	42.7
TPR WR_0- CTWRR	6	6	165.0	175.2	89.1	90.9	388	395	43.8	43.1
TPR WR_0- ZTWRR	8	9	153.3	163.3	86.0	88.5	385	395	44.0	43.9
TPR WR- ZTWRR	9	8	157.3	165.2	94.4	96.6	402	410	44.2	43.6
TPR BWR - ZTW BRR	7	7	158.1	166.2	79.6	81.8	368	374	42.6	42.9
LSD (p=0.05)	-	-	NS	NS	5.2	5.3	20	17	NS	NS
Phosphorus levels (kg/ha)										
0	7	7	158.1	167.1	80.0	81.0	366	373	42.7	42.1
30	7	8	158.7	167.9	82.6	84.7	377	385	43.1	43.2
60	8	8	159.4	168.7	84.7	87.0	386	394	43.5	43.4
LSD (p=0.05)	-	-	NS	NS	2.5	2.6	8	8	NS	NS

*Refer Table 1 and 2 for details of treatments

Table 4. Effect of crops residue management and levels of phosphorus on wheat root mass density at flowering stage

Treatment*	Root mass density (g/m^3)							
	0-15 cm		15-30 cm		30-60 cm		60-90 cm	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Crop residue management practices								
TPR WR_0- ZTW RR_0	1740	1729	370	365	163	155	113	107
TPR WR_0- CTW RR_0	1625	1621	357	352	155	146	99.0	96.0
TPR WR_0- CTWRR	1660	1664	360	359	160	151	108	103
TPR WR_0- ZTWRR	1867	1851	385	380	165	160	118	114
TPR WR- ZTWRR	1902	1895	389	385	175	168	130	124
TPR BWR - ZTW BRR	1757	1750	342	329	165	157	109	107
LSD (p=0.05)	110	92	NS	NS	NS	NS	NS	NS
Phosphorus levels (kg/ha)								
0	1680	1660	343	320	164	165	113	109
30	1765	1748	353	331	167	168	115	113
60	1823	1813	357	334	170	169.	114	115
LSD (p=0.05)	53	47	NS	NS	NS	NS	NS	NS

*Refer Table 1 and 2 for details of treatments



T1=TPR WR_0 - ZTW RR_0; T2 = TPR WR_0- CTW RR_0T3 = TPR WR_0– CTWRR; T4 = TPR WR_0– ZTWRR; T5 = TPR WR- ZTWRR; T6 = TPR BWR - ZTW BRR

Figure 1. Grain yield of wheat influenced by crop residue management practices and phosphorus levels in rice-wheat system (refer Table 1 and 2 for details of treatments)

under residue retention treatments attributed to reduction in weed density, weed biomass and better growth parameters, increase in soil organic matter content, improved soil properties (physical, chemical and biological), availability of nutrients (Sraw 2022) and more retention of soil moisture etc. which ultimately led to better plant growth and increase in grain yield (Gupta *et al.* 2024, Korav *et al.* 2024, Gupta *et al.* 2022). Interaction effect of crop residue management practices and phosphorus levels on grain yield was found to be significant during both the years of the study. ZT-wheat with rice residue plots in sequence with PTR with wheat residues did not respond to phosphorus application and resulted into similar yield with 0, 30 and 60 kg/ha phosphorus..

It was concluded that ZT wheat with rice residue retention had substantially lower weed infestation which led to significant improvement in wheat growth and grain yield.

REFRENCES

Ali A, Asif M, Adnan M, Aziz A, Hayyat MS, Saleem MW, Hanif MS, Javed MA, Hassa W and Ali SM. 2020. Effect of different levels of phosphorus on growth, yield and quality of wheat (*Triticum aestivum* L.). *International Journal of Botany Studies* **5**: 64–68

Baghel JK, Das TK, Raj R, Paul S, Mukherjee I and Bisht M. 2018. Effect of conservation agriculture and weed management on weeds, soil microbial activity and wheat (*Triticum aestivum*) productivity under a rice (*Oryza sativa*)-wheat cropping system. *Indian Journal of Agricultural Sciences* **88** (11): 1709–1716. https://doi.org/10.56093/ijas.v88i11.84911.

Buttar G S, Kaur S, Kumar R and Singh D (2022) *Phalaris minor* Retz. infestation in wheat crop as influenced by different rice straw management practices usage in Punjab, India. *Indian Journal of Weed Science* **54**: 31–35.

Flessner ML, Burke IC, Dille JA, Everman WJ, VanGessel MJ, Tidemann B, Manuchehri MR, Soltani N, Sikkema PH. 2021. Potential wheat yield loss due to weeds in the United States and Canada. *Weed Technology* **35**: 916–923.

Gomez KA and Gomez AA. 1984. Statistical Procedures for Agricultural Research. 2nd ed. New York: John Wiley & Sons, Inc.

Gupta RK, Hans H, Kalia A, Kang JS, Kaur J, Sraw PK, Singh A, Alataway A, Dewidar AZ, Mattar MA. 2022. Long-term impact of different straw management practices on carbon fractions and biological properties under rice–wheat system. *Agriculture* **12**: 1733.

Gupta RK, Hussain A, Sooch SS, Kang JS, Sharma S and Dheri GS. 2020. Rice straw biochar improves soil fertility, growth, and yield of rice-wheat system on a sandy loam soil. *Experimental Agriculture* **56:** 118–131.

Gupta RK, Sraw PK, Kang JS, Kaur J, Sharma V, Pathania N, Kalia A, Al-Ansari N, Alataway A, Devidar AZ and Mattar MA. 2024. Interactive effects of long-term management of crop residue and phosphorus fertilization on wheat productivity and soil health in the rice–wheat. *Scientific Reports* **14**: 1399.

Gyawali A, Bhandari R, Budhathoki P and Bhattrai S. 2022. A review on effect of weeds in wheat (*Triticum aestivum* L.) and their management practices. *Food and Agri Economics Review* **2**: 34–40.

Kaur R, Deol JS, Kaur N and Kaur S.2024.Weed seed bank and dynamics in wheat as affected by sowing time and rice residue management methods. *Indian Journal of Weed Science* **56**: 24–29.

Kaur R, Kaur S, Deol JS, Sharma R, Kaur T, Brar AS, Choudhary OP. 2021. Soil properties and weed dynamics in wheat as affected by rice residue management in the rice–wheat cropping system in south Asia: A Review. *Plants* ***10:*** 953. https://doi.org/10.3390/plants10050953

Kaur S. 2020. *Long term effect of crop residue management on productivity and nitrogen requirement of wheat (Triticum aestivum* L.*) in rice-wheat cropping system under varied nitrogen levels*. M.Sc Thesis, Punjab Agricultural University, Ludhiana, Punjab, India.

Kesarwani A, Shukla R, Singh VP, Pandey DS, Pramanick B, Yadav SK and Rani M. 2017. *In-situ* rice residue management under rice-wheat cropping system and their influence on wheat productivity. *Journal of Pharmacognosy and Phytochemistry* **6**: 1422–1425.

Korav S, Yadav DB, Yadav A, Rajanna GA, Parshad J, Tallapragada S, Elansary HO and Mahmoud EA. 2024. Rice residue management alternatives in rice–wheat cropping system: impact on wheat productivity, soil organic carbon, water and microbial dynamics. *Scientific Reports* **14**: 1822.

Kumar K and Goh KM. 2000. Crop residue management: Effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Advances in Agronomy* **68**: 197.

Meena JR, Behera UK, Chakraborty D and Sharma AR. 2015. Tillage and residue management effect on soil properties, crop performance and energy relations in green gram (*Vigna radiata* L.) under maize-based cropping systems. *International Soil and Water Conservation Research* **3**: 261–272.

Mondal S, Chakraborty D, DAS TK, Shrivastava M, Mishra AK, Bandyopadhyaya KK, Aggarwala P and Chaudharie SK.2019.Conservation agriculture had a strong impact on the sub-surface soil strength and root growth in wheat after a 7-year transition period. *Soil &Tillage Research* **195**: 104385.

Nichols V, Verhulst N, Cox R and Govaerts. 2015. Weed dynamics and conservation agriculture principles: A review. *Field Crops Research* **183**: 56–68.

Oerke EC, Dehne HW, Schönbeck F and Weber A. 2012. *Crop production and crop protection: estimated losses in major food and cash crops*. Elsevier Science, Amsterdam. DOI: https://doi.org/10.11634/

Rafiullah, Khan MJ, Muhammad D, Mussarat M, Huma, Adnan M, Fahad S, Wahid F, Arif M and Amanullah J.2021. Foliar versus soil phosphorus (P) application for improving P use efficiency in wheat and maize in calcareous soils. *Journal of Plant Nutrition* **44***:* 1598–1610.

Ranaivoson L, Naudin K, Ripoche A, Rabeharisoa L, Corbeels M. 2018. Is mulching an efficient way to control weeds? Effects of type and amount of crop residue in rainfed rice based cropping systems in Madagascar. *Field Crops Research* **217**: 20–31.

Samra, JS, Bijay-Singh and Kumar K.2003.Managing crop residues in the rice-wheat system of the Indo-Gangetic plain. p. 173-195 In J.K. Ladha et al. (ed.) *Improving the productivity and sustainability of rice-wheat systems: Issues and impact*. ASA Spec Pub. 65. ASA, Madison.

Sen S, Das TK, Dass A, Kumar D, Bhatia A, Bhattacharyya R, Raj, Govindasamy P, Roy A, Gunturi A, Saha P and Sharma T. 2023. Tillage, residue, nitrogen and herbicides effects on weeds and greengram productivity and profitability in conservation agriculture-based maize-wheat-greengram system. *Indian Journal of Weed Science* **55**: 380–387

Singh Y and Sidhu HS.2014. Management of cereal crop residues for sustainable rice-Wheat production system in the Indo-Gangetic plains of India. *Proceeding of Indian National Science Academy* **80**: 95–114.

Sraw PK. 2022. *Long term impact of residue management on nutrient requirement in rice-wheat system*. Ph. D. Dissertation, Punjab Agricultural University, Ludhiana, Punjab, India.

Timsina J and Connor DJ. 2001. Productivity and management of rice-wheat systems: issues and challenges. *Field Crops Research* **69**: 93–132.