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Zinc uptake in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system under the influence of microbial consortia (Pusa decomposer) mediated *in situ* rice straw management options

S M MANU[1]*, Y V SINGH[1], Y S SHIVAY[1], KAPILA SHEKHAWAT[1], V K SHARMA[1], NAMITA DAS SAHA[2] and GOVINDARAJ KAMALAM DINESH[1,3]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2019–20 and 2020–21 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi to study the effect of various crop establishment methods and microbial consortia (Pusa decomposer) mediated *in situ* rice straw management options on zinc (Zn) concentration and uptake in rice (*Oryza sativa* L.) (cv. Pusa Basmati 1509) and wheat (*Triticum aestivum* L.) (cv. HD 2967). The experiment was laid out in split-plot design (SPD) with 3 replications having 2 main plot (main factor) treatments, viz. aerobic rice (AR); and conventional transplanted (CT) rice in wet season; and 7 sub-plot (sub-factor) treatments, viz. Clean cultivation (removal of paddy straw); Paddy straw incorporation (PSI); Paddy straw mulching (PSM); PSI + Pusa decomposer (PD); PSM + PD; PSI + urea @20 kg/ha; and PSI + PD + urea @10 kg/ha in dry season. Findings showed that, in rice the zinc concentration (18.51 and 20.30 mg/kg in grain; 57.02 and 57.81 mg/kg in straw) and uptake (78.38 and 89.81 g/ha in grain; 427.1 and 434.6 g/ha in straw) were significantly superior in CT rice than AR in main plots during both the years of experiments. However, sub-plot treatments were non-significant in the zinc concentration and uptake. In wheat, among *in situ* rice straw management options (sub-plots), paddy straw incorporation + Pusa decomposer + Urea @10 kg/ha treatment significantly resulted in higher Zn concentration (38.08 and 39.03 mg/kg in grain; 28.24 and 29.01 mg/kg in straw) and uptake (185.0 and 191.9 g/ha in grain; 234.2 and 242.6 g/ha in straw) compared to other treatments and control (clean cultivation). The principal component analysis revealed that Zn uptake positively correlated with straw and grain yields in rice and wheat. Thus, the same treatment was found to be a better option for higher Zn concentration and uptake in the rice-wheat cropping system.

Keywords: Aerobic rice, Paddy straw, Pusa decomposer, Wheat, Zinc uptake

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.*)* cropping system (RWCS) is a predominant agricultural practice in the Indo-Gangetic plains, covering 40% of the net sown area (Saurabh *et al*. 2021). Despite its significance, this system faces challenges related to nutrient intensity, efficiency and sustainability (Sandhu *et al*. 2020). Crop residue, a rich source of essential plant nutrients, is easily accessible to rice farmers and plays a vital role in maintaining agricultural ecosystem stability (Almagro *et al.* 2021). Rice, a global staple, produces a substantial amount of straw annually, constituting 50% of the total dry weight of the plant. In India alone, 686.0 million tonnes of dry matter is generated yearly from various crops, with 234.5 million tonnes as surplus crop residue (Cardoen *et al*. 2015). Rice residues contribute to 34% of India's total crop residues, but improper disposal, including burning in fields due to the absence of suitable alternatives, leads to the loss of macro and micronutrients. Rice and wheat crops together remove significant amount of essential elements, such as Zn, Fe, Mn, Cu, B, and Mo, from the soil (Dhaliwal *et al*. 2022). India produces a staggering 488 million tonnes of crop residue, having a micronutrient potential of about 35.4 thousand tonnes (Ravindra *et al*. 2019). Recycling crop residues can address this issue, with 50–80% of Zn, Cu, and Mn taken up by crops being recyclable through residue incorporation (Goswami *et al*. 2020). Long-term incorporation of crop residues enhances soil content of DTPA-extractable Zn, Cu, Fe and Mn. The addition of crop residues increases the diffusion coefficient of Zn, attributed to chelating agents released during decomposition, thereby elevating total diffusible Zn concentration (Yadvinder *et al*. 2005). This recycling of crop residues proves beneficial in addressing

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]ICAR-Central Tobacco Research Institute, Dinhata, West Bengal; [3]SRM College of Agricultural Sciences, Baburayanpettai, Tamil Nadu. *Corresponding author email: msmanusm12@gmail.com

micronutrient deficiencies, particularly in the case of Zn, as 50% of Indian soils are reportedly deficient in this element (Suganya *et al*. 2020). The present study offers significant insights into the impact of crop establishment methods and microbial consortia (Pusa decomposer) on *in situ* rice straw management, specifically focusing on Zn concentration and uptake in the RWCS.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2019–20 and 2020–21 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The total amount of rainfall received during the first (2019–2020) and second (2020–2021) cropping cycles of RWCS were 907.2 mm and 757 mm, respectively. The experimental site had sandy clay-loam soil with *p*H 7.97 and 0.42% organic carbon. Available N, P and K were 183, 16.6 and 262 kg/ha, respectively. The fertilizer dose of 120 kg N, 60 kg P_2O_5, and 60 kg K_2O was applied per ha. The experiment was conducted in a split-plot design (SPD) with 3 replications using the aromatic rice variety Pusa Basmati 1509 and wheat variety HD 2967. The treatments consisted of 2 main plot treatments, viz. aerobic rice (AR) (M_1); and conventional transplanted rice (CTR) (M_2); and 7 sub-plot treatments, viz. Clean cultivation (removal of paddy straw) (S_1); Paddy straw incorporation (PSI) (S_2); Paddy straw mulching (S_3); Paddy straw incorporation + Pusa decomposer (PD) (S_4); Paddy straw mulching + Pusa decomposer (S_5); Paddy straw incorporation + urea @20 kg/ha (S_6); and Paddy straw incorporation + Pusa decomposer + urea @10 kg/ha (S_7). The effects of these treatments were observed in seed drill and zero till sown wheat in *rabi* (winter) seasons. The 6 t/ha straw was either incorporated or mulched, and the recommended dose of Pusa decomposer was sprayed at 25 litre/ha (liquid formulation). The Zn concentration in dry matter was determined by wet-digestion method (using di–acid) as described by Prasad *et al.* (2006) using atomic absorption spectrophotometry. The Zn concentration was expressed as mg/kg. The Zn uptake was computed by multiplying with respective Zn concentration in grain and straw/stover with yields (grain and straw) of the respective crops and was expressed as Zn uptake in g/ha (Prasad and Shivay 2018). The total Zn uptake was determined by adding their uptake in grain and straw for the individual treatment. The data were recorded for different parameters and statistically analyzed using the analysis of variance technique (ANOVA) (Gomez and Gomez 1984). The Pearson correlation analysis was done to study the relationship between nutrient uptake by plants and yield parameters using R studio ver. 2023.03.0 + 386 (R Core Team 2013) and principal component analysis was done using Origin Ver. 2021 software package to study the trends (Paul *et al*. 2013).

RESULTS AND DISCUSSION

Zn concentration and uptake in rice: The results (Table 1) showes the impact of different crop establishment methods (CEM) and *in situ* rice residue management options (IRM) on zinc (Zn) concentration and Zn uptake in rice grain and straw for two consecutive years (2019–20 and

Table 1 Effect of crop establishment methods and *in situ* rice residue management options on zinc (Zn) concentration and Zn uptake in rice

Treatment	Zn concentration in grain (mg/kg)		Zn concentration in straw (mg/kg)		Zn uptake by grain (g/ha)		Zn uptake by straw (g/ha)		Total Zn uptake (g/ha)	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Crop establishment methods (CEM)										
M_1	18.11	19.21	56.12	56.62	63.05	70.54	383.8	392.3	446.85	462.88
M_2	18.51	20.30	57.02	57.81	78.38	89.81	427.1	434.6	505.47	524.38
SEm±	0.003	0.01	0.01	0.01	0.29	0.24	4.06	3.85	4.28	4.08
LSD (*P*=0.05)	0.020	0.07	0.06	0.08	1.74	1.45	24.69	23.42	26.07	24.85
In situ *rice residue management options (IRM)*										
S_1	18.30	19.75	56.56	57.21	68.26	77.48	394.2	401.8	462.49	479.30
S_2	18.31	19.75	56.56	57.21	69.90	79.32	398.0	407.7	467.92	487.02
S_3	18.31	19.75	56.56	57.21	70.62	80.09	401.3	409.0	471.94	489.08
S_4	18.31	19.75	56.57	57.21	71.79	81.33	405.1	412.8	476.91	494.17
S_5	18.31	19.75	56.57	57.21	70.88	80.35	403.7	411.4	474.57	491.74
S_6	18.31	19.75	56.57	57.21	70.28	79.69	418.4	426.2	488.64	505.90
S_7	18.32	19.76	56.57	57.22	73.28	82.99	417.4	425.2	490.66	508.22
SEm±	0.003	0.0009	0.00002	0.00002	1.01	1.10	1.25	1.32	1.81	1.89
LSD (*P*= 0.05)	0.009	0.002	0.00007	0.00007	2.94	3.21	3.65	3.84	5.28	5.53
I (CEM × IRM)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details are given under Materials and Methods. Straw incorporated/mulched@6 t/ha; Recommended dose of Pusa decomposer @25 litres/ha (liquid formulation); I, Interaction.

2020–21). The CEM significantly affected Zn concentration in grain and straw in both the years. Zn concentration in grain (18.51 and 20.30 mg/kg) and straw (57.02 and 57.81 mg/kg) of conventional transplanted rice (CTR) was higher than aerobic rice (AR) in both the years. Among IRM options, no significant difference was found regarding Zn concentration in grain and straw of rice in both the years. The interaction between the CEM and IRM was non-significant on Zn content. The CEM significantly affected Zn uptake in grain and straw in both the years. Zn uptake in grain and straw of CTR (78.38 and 89.81 g/ha in grain; 2425.6 and 2481.6 g/ha in straw) was significantly higher than AR (221.82 and 238.8 g/ha in grain; 427.1 and 434.6 g/ha in straw) in both the years. Consistently, CTR exhibited superior performance in total Zn uptake compared to AR, primarily attributable to higher zinc uptake in both grain and straw components. The comparatively higher zinc uptake in both grain and straw observed in 2020–21 compared to 2019–20 may be attributed to factors such as improved soil conditions and enhanced nutrient availability.

The increased availability of micronutrient (Zn) can be related to addition of organic matter as a crop residue. In addition to that, it is also because of Zn availability improved under low land conditions compared to high land (aerobic) conditions, this may be due to several factors including soil characteristics, efficient nutrient management, and microbial activity (Meena 2015). The plots with IRM practices recorded higher Zn uptake than control. Paddy straw incorporation (PSI) + Pusa decomposer (PD) + urea @10 g/ha treated plots recorded higher Zn uptake (73.28 and 82.99 in grain; 417.4 and 425.2 g/ha in straw) compared to other treatments. Total Zn uptake (490.66 and 508.22 g/ha) was statistically higher in the same treatment (PSI + PD + Urea). However, it was at par with PSI + Urea. PSI + PD (476.91 and 494.17 g/ha) were recorded higher than paddy straw mulching (PSM) and control. At the same time, PSI results were at par with PSM (471.94 and 489.08 g/ha) in the second season. The lowest value of total Zn was recorded in clean cultivation (462.49 and 479.30 g/ha) without adding crop residues. This can be attributed to the lack of organic matter as a crop residue mulch on the topsoil for nutrient cycling (Dinesh *et al*. 2023). Crop residue mulch plays a crucial role in nutrient availability and cycling in the soil (Goswami *et al*. 2020, Manu *et al.* 2023). There was no significant interaction between the CEM and IRM practices on Zn uptake in rice. AR typically exhibits higher zinc nutrient uptake and concentration than CTR due to differences in growth conditions and root systems. However, the average of two years of data showed that the grain yield of rice with Zn uptake in grain and straw was positively correlated.

Zn concentration and uptake in wheat: The results (Table 2) shows the effect of different CEM and IRM on zinc (Zn) concentration and Zn uptake in wheat for two consecutive years (2019–20 and 2020–21). The analysis provides insights into the influence of these agricultural practices on Zn accumulation in wheat grain and straw. The Zn concentration in succeeding wheat crops was significantly influenced by the effect of different CEM of rice in grain and straw in both the years. Zn concentration

Table 2 Effect of crop establishment methods and *in situ* rice residue management options on zinc (Zn) concentration and Zn uptake in wheat

Treatment	Zn concentration in grain (mg/kg)		Zn concentration in straw (mg/kg)		Zn uptake by grain (g/ha)		Zn uptake by straw (g/ha)		Total Zn uptake (g/ha)	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Crop establishment methods (CEM)										
M_1	36.30	37.24	26.88	27.65	168.7	175.3	213.5	221.5	382.16	396.86
M_2	36.05	36.99	26.65	27.42	163.1	169.8	206.4	214.0	369.55	383.78
SEm±	0.00	0.00	0.00	0.00	0.13	0.13	0.16	0.17	0.28	0.30
LSD (*P*= 0.05)	0.01	0.01	0.01	0.01	0.77	0.77	0.99	1.06	1.75	1.82
In situ *rice residue management options (IRM)*										
S_1	34.15	35.10	25.26	26.02	147.9	153.9	187.5	193.9	335.37	347.85
S_2	35.65	36.59	26.30	27.07	159.7	166.3	201.9	209.3	361.59	375.55
S_3	35.25	36.19	25.90	26.67	156.2	162.7	196.7	203.5	352.81	366.21
S_4	37.19	38.13	27.85	28.61	177.0	184.1	226.2	235.3	403.18	419.41
S_5	36.70	37.65	27.20	27.96	170.4	177.3	215.6	224.1	386.07	401.39
S_6	36.19	37.14	26.60	27.37	165.0	171.7	207.8	215.5	372.80	387.27
S_7	38.08	39.03	28.24	29.01	185.0	191.9	234.2	242.6	419.18	434.55
SEm±	0.01	0.01	0.01	0.01	0.3	0.3	0.37	0.39	0.66	0.69
LSD (*P*= 0.05)	0.04	0.04	0.03	0.03	0.85	0.87	1.10	1.16	1.95	2.03
Interaction (CEM × IRM)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Treatment details are given under Materials and Methods. Straw incorporated/mulched@6 t/ha; Recommended dose of Pusa decomposer @25 litres/ha (liquid formulation); I, Interaction.

in grain (36.30 and 37.24 mg/kg) and straw (26.88 and 27.65 mg/kg) of aerobic rice-wheat (AR-W) were higher than conventional transplanted rice-wheat (CTR-W) in both the years. The higher zinc concentrations in the grain and straw of AR-W compared to CTR-W could be due to a combination of various factors such as zinc fertilization, water management, rice cultivars and agronomic practices (Choudhary *et al*. 2022). Further research is needed to fully understand the mechanisms behind these differences in zinc content. However, when considering Zn uptake, the total Zn uptake by wheat (grain + straw) was consistently higher in AR-W compared to CTR-W for both the years. This difference was statistically significant (P<0.05). In 2019–20, AR-W resulted in a Zn uptake of 382.16 g/ha compared to 369.55 g/ha in CTR-W. Similarly, in 2020–21, AR-W led to a Zn uptake of 396.86 g/ha compared to 383.78 g/ha in CTR-W. These findings suggest that among CEM, AR-W positively affected Zn uptake by wheat compared to CTR-W. Significant results were found with respect to Zn concentration in grain and straw of rice in both the years among *in situ* rice residue management options.

Paddy straw incorporation (PSI) + Pusa decomposer (PD) + urea @10 kg/ha treated plots recorded higher Zn concentration (38.08 and 39.03 in grain, 28.24 and 29.01 mg/kg in straw) compared to other treatments and control. PSI + urea @20 kg/ha showed a maximum Zn concentration in grain and straw than PSI and paddy straw mulching (PSM) treatments in both the years of the experiment. However, PSI results were at par with PSM. The lowest Zn content in grain and straw was recorded in clean cultivation (removal of paddy straw). PSI + PD was at par with PSM + PD with respect to Zn content in grain and straw. The interaction between the CEM and IRM options was non-significant in zinc content of grain and straw. Zn uptake in grain and straw of AR-W (168.7 and 175.3 g/ha in grain; 213.5 and 221.5 g/ha in straw) was significantly higher than CTR-W in both the years. Comparatively higher Zn uptake in grain and straw was observed in 2020–21 compared to 2019–20. In the plots with IRM practices, PSI + PD + Urea @10 kg/ha treated plots recorded significantly higher Zn uptake (185.0 and 191.9 in grain; 234.2 and 242.6 g/ha in straw) compared to other treatments and control, which was followed by PSI + PD. PSM with PD significantly showed higher Zn uptake in grain and straw than PSM without PD. It could be due to the accelerated decomposition of crop residues and enhanced nutrient availability in the soil assisted by PD (Tuiwong *et al*. 2021). This conforms that the use of PD can improve the nutrient cycling and availability in the soil, which ultimately benefiting crop growth and productivity. Zn uptake in grain and straw was higher in PSI + urea @20 kg/ha compared to PSI. Among the options, PSI + PD + urea @10 kg/ha consistently resulted in the highest total Zn uptake by wheat in both the years. In 2019–20, PSI + PD + urea @10 kg/ha had a Zn uptake of 434.55 g/ha, while in 2020–21, it had a Zn uptake of 419.18 g/ha. This was significantly higher than the other IRM options. These results indicate that the combination of PSI, the use of Pusa decomposer, and urea application at 10 kg/ha had a pronounced positive effect on Zn uptake by wheat. This suggests that the impact of CEM and IRM on Zn accumulation in wheat was independent of each other, and their effects were additive and complex. Hence, more in-depth studies on the agronomic practices such as crop residue mulching and nutrient management can be conducted as it influences the zinc content in rice grains and straw. The average of two years of data showed that the grain yield of wheat with Zn uptake in grain and straw was positively correlated. The higher value of Zn concentration and uptake was recorded with PSI + CI (compost inoculants) + Urea in grain and straw during both the years of studies compared to bare soil. It might be attributed to the availability of micronutrients in the soil, and their absorption may have been enhanced by the microbe-mediated decomposition of crop residue with compost inoculant and concomitant release of organic acids (Meena 2015).

Principal component analysis (PCA) between nutrient uptake and yield parameters: The data were classified into multiple principal components. The top two principal components (PC_1 61.2% and PC_2 37.5%) were taken for biplot analysis. Biplot analysis revealed that the main plot treatment M_2 (Conventional transplanted rice (CTR)-wheat) and subplot S_6 (Paddy straw incorporation + urea @20 kg/ha) are in same quadrat. Biplot reveals that the parameters such as Zn concentration, uptake, yield of rice grain and straw are towards positive dispersions (Fig. 1).

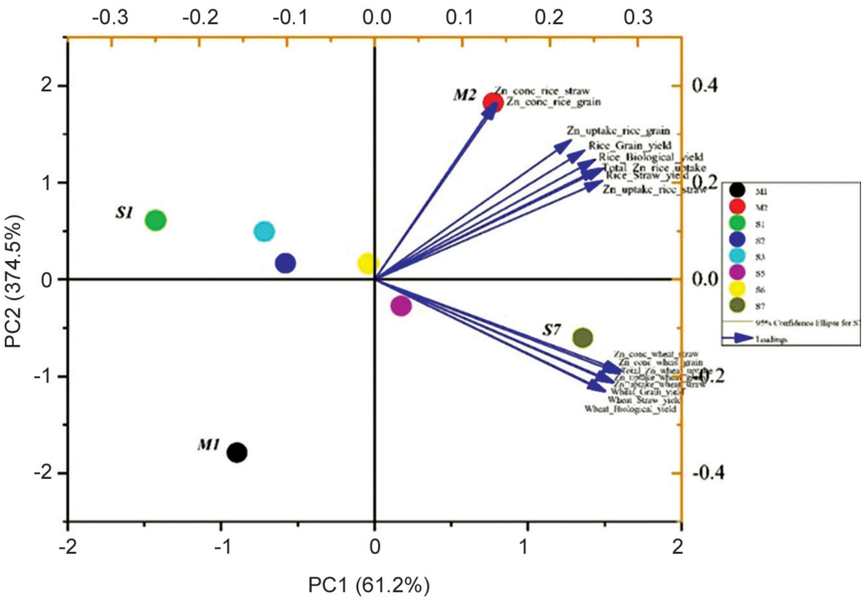

Fig. 1 Principal component analysis between nutrient uptake and yield parameters.

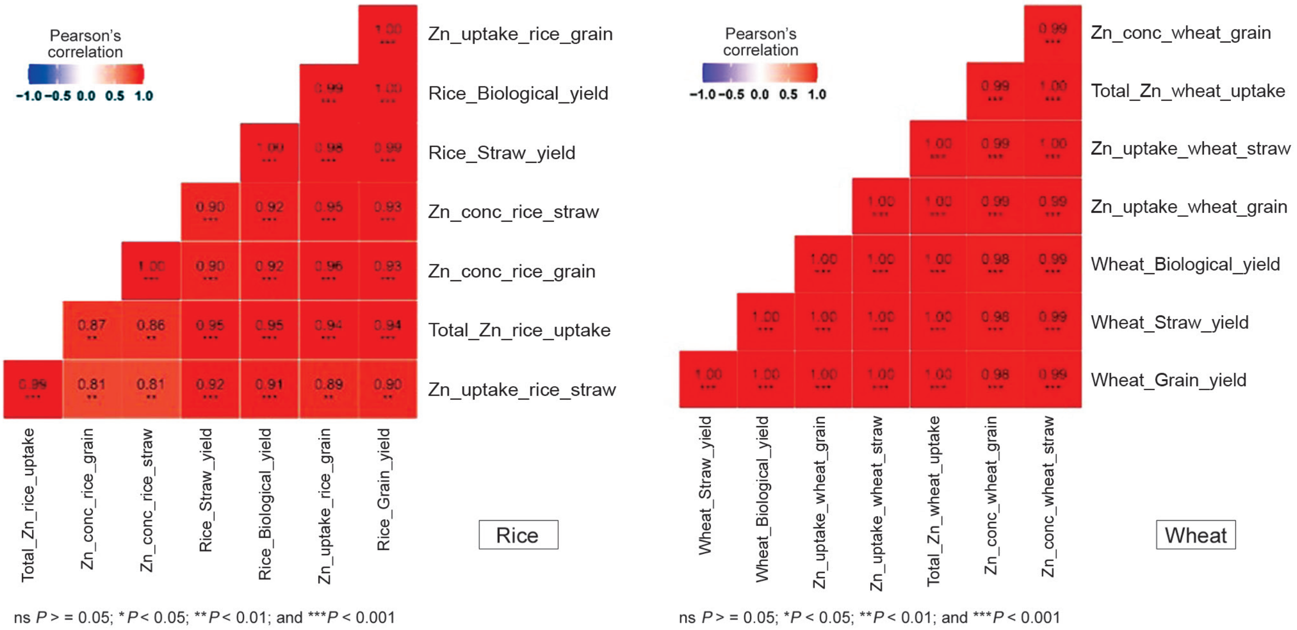

Fig. 2 Correlation analysis between nutrient uptake and yield parameters of rice and wheat.

Correlation analysis between nutrient uptake and yield parameters: Pearson correlation analysis demonstrates a positive relationship among Zn concentration, uptake, and the yield of both rice grain and straw (Fig. 2). Additionally, this positive correlation was also observed in wheat (Fig. 2). These findings suggest that Zn nutrient levels have a beneficial impact on the grain and straw yield of both rice and wheat. Our results align with those of a prior study conducted by Saini and Kaur (2021).

The current study may conclude that rice performance was superior under conventional transplanted conditions than aerobic rice regarding zinc concentration and uptake in grain and straw. This method has shown promise in raising zinc concentration and absorption in wheat and rice crops, improving crop output and nutritional quality. In the case of *in situ* rice residue management options, paddy straw incorporation + Pusa decomposer + urea @10 kg/ha-wheat was found effective *in situ* rice management options with higher zinc concentration and uptake in grain as well as straw compared to control. Hence, combining paddy straw incorporation + Pusa decomposer + urea could be a better option for higher Zn concentration and uptake in the rice-wheat cropping system. Investigating the economic viability and scalability of using these techniques in the long-term effects on soil health and overall crop productivity in real agricultural contexts may provide insightful information to farmers and policymakers. Adopting these sustainable farming methods may improve zinc concentration and absorption in crops, which might help to alleviate micronutrient deficiency in food production.

REFERENCES

Almagro M, Ruiz-Navarro A, Diaz-Pereira E, Albaladejo J and Martinez-Mena M. 2021. Plant residue chemical quality modulates the soil microbial response related to decomposition and soil organic carbon and nitrogen stabilization in a rainfed mediterranean agroecosystem. *Soil Biology and Biochemistry* **156**: 108198.

Cardoen D, Joshi P, Diels L, Sarma P M and Pant D. 2015. Agriculture biomass in India, part-1: Estimation and characterization. *Resource Conservation and Recycling* **102**: 39–48.

Choudhary A K, Sood P, Rahi and Tyagi V. 2022. Rice productivity, Zn biofortification, and nutrient-use efficiency as influenced by Zn fertilization under conventional transplanted rice and the system of rice intensification. *Frontiers in Environmental Science* **10**: 869194.

Dhaliwal S S, Sharma V, Shukla A K, Verma V, Kaur M, Shivay Y S and Hossain A. 2022. Biofortification-A frontier novel approach to enrich micronutrients in field crops to encounter the nutritional security. *Molecules* **27**(4): 1340.

Dinesh G K, Sharma D K, Jat S L, Bandyopadhyay K K, Srinivasa Rao C, Venkatramanan V, Kadam P V, Sinduja M, Sathya V, Sethupathi N and Bhatia A. 2023. Effect of conservation agriculture practices on carbon pools in a sandy loam soil of Indo-Gangetic plains. *Communications in Soil Science and Plant Analysis* **54**(20): 2845–862.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*, pp. 76–83. A Willey Inter Science Publication, New York, USA.

Goswami S B, Mondal R and Mandi S K. 2020. Crop residue management options in rice-rice system: A review. *Archives of Agronomy and Soil Science* **66**(9): 1218–234.

Manu S M, Singh Y V, Shivay Y S, Shukla L, Sharma V K, Saha N D, Shekhawat K, Bandopadhyay K K and Gouda H S. 2023. Nitrogen budgeting under the influence of *in situ* rice residue management options in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. *The Indian Journal of Agricultural Sciences* **93**(2): 151–56.

Meena R K. 2015. 'Effect of residue and nitrogen management on productivity and soil health in aerobic Basmati rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system'. PhD Thesis, ICAR-Indian Agricultural Research Institute, New Delhi.

Paul L C, Suman A A and Sultan N. 2013. Methodological analysis of principal component analysis (PCA) method. *International Journal of Computational Engineering and Management* **16**(2): 32–38.

Prasad R, Shivay Y S, Kumar D and Sharma S N. 2006. *Learning by Doing Exercises in Soil Fertility: A Practical Manual for Soil Fertility*, pp. 68. Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

Prasad R and Shivay Y S. 2018. Relative grain zinc loading ability of cereals (rice, wheat, maize) and a grain legume (chickpea). *The Indian Journal of Agricultural Sciences* **88**(2): 307–13.

Ravindra K, Singh T and Mor S. 2019. Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. *Journal of Cleaner Production* **208**: 261–73.

R Core Team. 2013. R: A language and environment for statistical computing.

Saini S and Kaur M. 2021. Nitrogen and rice straw incorporation impact Zn fractions and wheat yield in rice-wheat system. *The Indian Journal of Agricultural Sciences* **91**(4): 619–23.

Sandhu P S, Walia S S, Gill R S and Dheri G S. 2020. Thirty-one years study of integrated nutrient management on physico-chemical properties of soil under rice-wheat cropping system. *Communications in Soil Science and Plant Analysis* **51**(12): 1641–657.

Saurabh K, Rao K K, Mishra J S, Kumar R, Poonia S P, Samal S K, Roy H S, Dubey A K, Choubey A K, Mondal S and Bhatt B P. 2021. Influence of tillage-based crop establishment and residue management practices on soil quality indices and yield sustainability in rice-wheat cropping system of eastern Indo-Gangetic Plains. *Soil and Tillage Research* **206**: 104841.

Yadvinder S, Bijay S and Timsina J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy* **85**: 269–407.

Suganya A, Saravanan A and Manivannan N. 2020. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. *Communication in Soil Science and Plant Analysis* **51**(15): 2001–021.

Tuiwong P, Lordkaew S and Prom-u-thai C. 2021. Improving grain zinc concentration in wetland and upland rice varieties grown under waterlogged and well-drained soils by applying zinc fertilizer. *Agronomy* **11**(3): 554.

Yadvinder S, Bijay S and Timsina J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy* **85**: 269–407.