Received Date: 29 August 2025
Accepted Date: 27 December 2025
DOI: https://doi.org/10.3126/jiaas.v39i1.88273

EFFECT OF CROP RESIDUE MANAGEMENT AND FERTILIZER RATES ON PADDY YIELD AND SOIL ORGANIC MATTER UNDER PADDY-WHEAT CROPPING SYSTEM IN WESTERN TERAI OF NEPAL

Rita Amgain[1*], Dinesh Khadka[1] and Narayan Khatri[2]
[1]National Soil Science Research Centre, NARC, Khumaltar Lalitpur, Nepal
[2]National Wheat Research Program, NARC, Bhairahawa, Rupandehi, Nepal
*Corresponding author: ritaamgainghimire@gmail.com
Rita Amgain: 0000-0002-8418-9765
Dinesh Khadka: 0000-0003-0909-8342
Narayan Khatri: 0009-0005-5984-8377

ABSTRACT

Crop residues are valuable natural resources in the paddy-wheat cropping system, and their proper management can enhance the physical, chemical, and biological properties of soil. Burning of crop residues is one of the major problems associated with paddy-wheat cropping system in western Terai of Nepal. In order to evaluate the different crop residue management practices and their effects on crop yield and soil organic matter under the paddy-wheat cropping system, a field experiment was conducted at the National Wheat Research Program, Bhairahawa, Rupandehi, Nepal between 2019 to 2021. The experiment was conducted in the split-plot design with three main-plot treatments of residue management (residue removal, residue incorporation, and residue burning) and three sub-plot fertilizer levels (control, recommended dose of NPK, and 125% of the recommended doses of NPK), replicated three times. The combined analysis of data over three years revealed that the residue management had significantly influenced the grain yield. The highest grain yield (3648 kg ha-^{1}) was recorded from the residue incorporation. Similarly, fertilizer levels significantly affected both the yield and yield components of paddy, with the highest mean grain yield (4173 kg ha-^{1}) obtained from the 125% NPK of the recommended dose. Although residue management and fertilizer levels did not significantly influence overall soil fertility status, residue management had a significant effect on soil organic matter content. The highest organic matter content (2.23%) was observed in the residue incorporation, while the lowest (1.85%) was recorded from the residue burning. The interaction between residue management and fertilizer level had no significant effect on grain yield or soil fertility status.

Key words: *Grain yield, fertilizer level, soil fertility status, yield components*

INTRODUCTION

Paddy is an economically important and staple food crop in Nepal which ranks first in terms of both areas of coverage and production. In the fiscal year 2022/23, Nepal produced about 5.48 million metric tons of paddy with an average productivity of 3.79 t ha^{-1}that was cultivated on 1.447 million hectares of land (MoALD, 2023). The paddy-wheat cropping system is the most widely practiced system in the Indo-Gangetic plains, accordingly in Nepal too. In Nepal, this system covers around 0.5 million hectares of land contributing 65.8% of the total cereal crop area and also accounts for 72.1% of total cereal production (Khanal et al., 2012). This system plays a key role in ensuring food security in the country and also helps to improve the livelihoods of the Nepali farmers (Tripathi, 2010).

Crop residues are a valuable natural resource in paddy-wheat cropping system. When properly managed, they form a protective layer on the soil surface, enhance soil quality, contribute to soil organic matter, and improve fertility. Nepal generates about 19.41 million metric tons of agricultural residues annually, with major contributions from paddy, corn, wheat, sugarcane, grain legumes, and millets (Pandey et al., 2023). Among these, paddy is the largest contributor, accounting for approximately 47.3% of the total crop residues.

The increasing use of combine harvesters in paddy farming in Nepal has led to significant amounts of paddy straw being left in the fields, as these machines typically cut the crop 15-20 cm above the ground. This creates a major challenge for timely residue management, particularly because of the short turnaround time between paddy harvest and wheat sowing. As a result, many farmers preferred for burning paddy straw. About 48.3% of farmers in rain-fed systems and 55% in irrigated systems burn paddy straw within one week of grain harvest in Rupandehi district (Pandey et al., 2023). Burning straw is the established strategy in the Terai region of Nepal due to labor shortages and the urgency of preparing fields for sowing of wheat. However, straw burning results in significant nutrient losses and environmental degradation. It destroys beneficial soil microorganisms, deteriorates soil structure, and contributes to air pollution. Burning paddy residues can lead to the loss of up to 80% of nitrogen, 25% of phosphorus, 21% of potassium (K_2O), and 4-60% of sulfur (Mandal et al., 2004) Similarly, (Gupta et al., 2002) reported that 10 t ha^{-1} of crop residue can remove up to 730 kg of NPK from the soil. Failure to recycle these residues leads to the depletion of essential nutrients and may result in a negative nutrient balance and multi-nutrient deficiencies in subsequent crops.

Effective residue management combined with appropriate fertilizer application significantly enhances paddy yield and soil health. Retention or incorporation of crop residues improves soil organic matter, enhances nutrient cycling, and increases microbial activity, which together contribute to higher productivity. Studies have shown that incorporating paddy straw into the soil, rather than burning or removing it, can improve nitrogen use efficiency and grain yield when combined with balanced fertilizer application. The integrated residue management and site-specific nutrient application led to a good increase in paddy yield compared to conventional practices. It improves grain yield and maintains soil fertility over the long term. These findings suggest that residue retention along with optimal fertilizer use creates a synergistic effect that supports sustainable intensification of paddy production systems (Yadav et al., 2005). Therefore, identifying and adopting appropriate residue management practices is essential to mitigate the adverse effects of residue burning. This study aims to assess the effectiveness of different residue management strategies combined with varying levels of nutrient application on soil organic matter dynamics and paddy grain yield within the paddy-wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted at National Wheat Research Program (NWRP), Bhairahawa, Nepal over three consecutive years: 2019, 2020 and 2021. Experiment was laid out in split-plot design with three replications. The main plot comprised of three crop residue management practices, representing post-harvest residue left by combine harvester: residue burning (R1), residue incorporation in the soil (R2), and removal of residue (R3). The sub plot allotments included three fertilizer application levels: control-no fertilizer (F1), recommended dose of fertilizer (100:30:30 N P_2O_5 K_2O, F2) and 125% of recommended dose of fertilizer (F3). Paddy variety Bahuguni-1 was used with crop geometry of 20 cm × 20 cm. The plot size of 4×3 m^2 was used as an experimental unit. Fertilizer sources urea, di- ammonium phosphate (DAP) and muriate of potash were used for supplying nitrogen, phosphorus and potassium fertilizers. Half of nitrogen along with full dose of phosphorus and potassium was applied as the basal dose during final land preparation and the remaining half of the nitrogen was top dressed in two equal splits, at active tillering stage and at panicle initiation stage.

At harvest, five plants were randomly selected from each plot and the plant height and panicle length were measured. Data on number of tillers m^{-2} was recorded. Observations on the filled grains $panicle^{-1}$, 1000-grain weight and grain yield were recorded at the harvest. Average number of filled grain $panicle^{-1}$ was counted from five panicles for each treatment. The 1000-grain weights were recorded from randomly taken five samples from each treatment. Grain yield was recorded from an area of 8 m^{-2} and yield was adjusted to 14% moisture content, following the method described by (Yoshida, 1981).

Soil samples were collected randomly from a depth of 0-20 cm in a Z –pattern at the beginning of the experiment and a composite soil sample was prepared. The sample was air dried, ground, passed through sieve of 2 mm size and analyzed for soil pH, soil organic matter and major macronutrients in the laboratory of National Soil Science Research Center, Khumaltar, Lalitpur by using the standard laboratory protocols (Table 1). Likewise, the soil samples were taken after crop harvest for post experiment soil analysis from the depth of 0-10 and 10-20 cm.

Table 1: Soil chemical properties of the study site before experiment

Soil parameters	Value	Category	Methods of determination
Soil pH	8.11	Moderately alkaline	Potentiometric 1:2 (Jackson, 1973)
Soil organic matter (%)	2.09	Medium	Walkley and Black (Walkley & Black, 1934)
Soil total Nitrogen (%)	0.10	Medium	Kjeldahl distillation (Bremner & Mulvaney, 1982)
Available phosphorus (mg kg^{-1})	11	Low	Modified Olsen's (Olsen et al., 1954)
Available potassium (mg kg^{-1})	41	Low	Ammonium acetate (Jackson, 1967)

The collected data were compiled and tabulated in Microsoft Excel Professional Plus 2013. The data analysis was performed using Analysis of Variance ((ANOVA) in GenStat (15^{th} Edition) statistical package. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% level of significance (Gomez & Gomez, 1984).

RESULTS AND DISCUSSION

Grain yield and yield components

The pooled analysis of the three-year data revealed that residue management practices did not have a statistically significant effect ($p>0.05$) on plant height, tiller density (number of tillers m^{-2}) and panicle length in paddy (Table 2). Across treatments, mean plant height ranged from 94.12 to 94.60 cm, tiller density from 254.1 to 260.4 tillers m^{-2}, and panicle length from 23.50 to 23.81 cm. However, the number of filled grains $panicle^{-1}$ was significantly influenced ($p<0.05$) by the residue management practices. The highest grain yield (3648 kg ha^{-1}) was recorded for the R2, whereas the lowest yield (3353 kg ha^{-1}) was observed under the R1 treatment. Nonetheless, residue management did not significantly affect ($p>0.05$) the 1000-grain weight.

The results suggest that there was a positive role of residue incorporation for the paddy yield components under paddy-wheat cropping system which may be more substantial in long run. The result of highest grain yield obtained from residue incorporation was in line with the findings of Singh et al., 2019 and Kumar et al., 2003. This might be due to residues as the crop residues are an important source of organic matter and plant nutrients. Properly incorporated crop residues help to speed up decomposition process and can provide nutrients to the soil, increase nutrient availability and uptake by plant, improve soil health and lead to better crop yield in long run. According to Gupta et al., 2023, 20.8% increment on grain yield of paddy was recorded from residue incorporated plot as compared to residue removal plot. Kumari et al., 2019 also reported that 2.65% average of grain yield was increased with incorporation of crop residue as compared to without crop residue.

In contrast, the fertilizer levels had a statistically significant ($p<0.001$) effects on plant height, panicle length and grain yield (Table 2). Application of 125% of the recommended fertilizer dose (F3) significantly increased plant height, panicle length, and grain yield ($p<0.001$) compared to F2 and F1. The F3 treatment produced the tallest plants (101.03 cm), the longest panicles (24.61 cm), and the highest grain yield (4173 kg ha^{-1}). Furthermore, both the F3 and F2 treatments significantly increased the number of tillers, the number of filled grains per panicle, and 1000-grain weight compared to the control ($p<0.01$). However, these two fertilizer treatments did not differ significantly ($p>0.05$) from each other for these traits.

The results of the highest plant height, longer panicle length and higher number of tiller m^{-2}, highest number of filled grain $panicle^{-1}$, highest grain yield and more thousand grain weight from plot treated with 125% of recommended dose of fertilizer is in agreement with the results of Gupta et al., 2023 and Khatri et al., 2020. Highest grain yield could have contributed by more number of tillers, higher number of filled grain $panicle^{-1}$ and higher thousand seed weight. This might be due to the increment in the availability of more nutrients with the increased fertilizer level. Increasing the fertilizer level particularly nitrogen is a crucial nutrient which promotes vegetative and reproductive growth. Increase in fertilizer level especially elemental N plays an active role in increasing cellular growth through cell division and cell enlargement and increases crop productivity by enhancing photosynthetic surfaces, dry matter accumulation and sink growth. Grain yield depends on the production of photosynthates and their distribution among various plant parts (Gupta et al., 2023).

Table 2: Effect of crop residue management and fertilizer levels on paddy yield

Treatments	Plant height (cm)	No. of tiller m^{-2}	Panicle length (cm)	Number of filled grains $panicle^{-1}$	Grain yield (kg ha^{-1})	1000-grain wt (g)
Residue management options						
R1- Residue burning	94.60	254.1	23.79	85.6	3353^{b}	23.60
R2- Residue incorporation in the soil	97.44	260.4	23.81	87.3	3648^{a}	23.63
R3- Residue removal	94.12	260.0	23.50	80.8	3545^{ab}	23.45
F-test	ns	Ns	ns	*	*	Ns
SEM	1.01	7.91	0.15	2.62	62.9	0.14
LSD (0.05%)	3.99	31.05	0.60	10.28	246.9	0.58
Fertilizer level						
F1- Control	96.16^{c}	214.6^{b}	22.01^{c}	77.7^{b}	2477c	23.00^{b}
F2- Recommended dose	97.28^{b}	273.8^{a}	24.48^{b}	86^{a}	3896^{b}	23.80^{a}
F3- 125% of recommended dose	101.03^{a}	286.1^{a}	24.61^{a}	90^{a}	4173^{a}	23.90^{a}
F-test	***	***	***	**	***	***
SEM	0.54	6.41	0.12	2.21	84.9	0.11
LSD (0.05%)	1.68	19.74	0.38	6.80	261.7	0.36

*Columns represented with same superscripts are not significantly different among each other at 5% level of significance. *= significant at 5%level of significance, **= Significance at 1 % level of significance, ***= significance at 0.1% level of significance, ns=non-significant, SEM= standard error of mean, LSD= Least significant difference,*

Interaction effect

The interaction effect between residue management and fertilizer level on paddy grain yield was statistically non-significant (p>0.05) (Table 3). Nevertheless, the grain yield was ranged from 2414 kg ha^{-1} (control treatment-no fertilizer) combined with R3 to 4250 kg ha^{-1} (R3 residue management combined with F3 fertilizer level).

The result of non-significant interactions between different levels of crop residue management practices and fertilizer applications was supported by the results of (Mandal et al., 2004). They reported that the crop yields were lower during the first one to three years of residue incorporation because of immobilization of soil N in presence of crop residue with wide C/N ratio, but in later year's residue incorporation enhance crop yield compared to either burning or removal of residues. But this could be the limitations of our three-year duration study. However, this study concluded that the combined use of paddy and wheat straw and inorganic fertilizer can increase the yield of paddy and wheat in paddy wheat cropping system in long run (Mahapatra et al., 1991).

Table 3: Interaction effect of crop residue management and fertilizer level on paddy yield

Residue management options	Fertilizer level Grain yield (kg ha^{-1})		
	Control	Recommended dose (100:30:30) NPK kg ha^{-1}	125% of recommended dose
Residue burning	2493	3535	4031
Residue incorporation	2525	4181	4237
Residue removal	2414	3973	4250
F test	Ns		
SEM	135.6		
LSD (0.05)	406.7		
CV%	13.8		

SEM= standard error of mean, LSD= Least significant difference, ns=non-significant, CV= coefficient of variation

Soil organic matter status

Soil organic matter status after completion of three years experiment is presented in table 4. The soil organic matter in upper surface (0-10cm soil depth) was affected significantly with residue management options. Highest soil organic matter (2.23%) was found for R2 and lowest (1.85%) for R1 (p<0.01). Soil organic matter in R2 was increased by 6.7% in comparison to initial soil organic matter.

Table 4: Soil organic matter under different residue management options and fertilizer application levels after 3 years

Treatments	OM %(0-10cm)	OM%(10-20cm)
Residue management options		
R1- Residue burning	1.85	1.72
R2- Residue incorporation	2.23	1.87
R3- Residue removal	1.90	1.73
LSD (0.05%)	0.17**	0.32^{ns}
SEM	0.04	0.08
Fertilizer level		
F1- Control	1.94	1.70
F2- Recommended dose	2.03	1.75
F3- 125% of recommended dose	2.02	1.87
LSD (0.05%)	0.16^{ns}	0.07**
SEM	0.05	0.02

*Columns represented with same superscript are not significantly different among each other at 5% level of significance. *= significant at 5%level of significance, **= Significance at 1 % level of significance, ns= non-significant, SEM= standard error of mean, LSD= Least significant difference*

Crop residues serve as a vital source of organic matter that can be returned into the soil, promoting nutrient recycling and enhancing the soil physical, chemical and biological properties (Kumar and Goh 2000). Crop residues contain plant nutrients like nitrogen, phosphorus and potassium which are returned back to the soil as the residues decompose resulting higher nutrient content in residue incorporated soil. Soil organic matter and major macronutrient were observed higher in residue incorporated plot (Gupta et al., 2023). The result of this experiment was in agreement with their findings. Crop residue incorporation might help to reduce nutrient loss and improved the organic matter through carbon transformation processes. In a study, Singh et al., 2019 reported that the organic carbon is increased by 52.63%, available N increased by 15.17%, available P increased by 77.78% and available K increased by 40.43% under incorporation of crop residue in comparison to residue burning practices.

CONCLUSION

The finding of the study revealed that incorporating paddy-wheat residue and application of 125% of recommended dose of fertilizer had improve the paddy grain yield. Additionally, improvement in soil organic matter was observed in residue incorporation. Therefore, residue incorporation is recommended as the most effective and sustainable practice for improving soil health and enhancing crop productivity in the paddy-wheat cropping system. Therefore, integrating crop residue incorporation with the application of 125% of recommended dose of fertilizer emerges as a promising strategy for optimizing productivity and soil health in the intensive paddy-wheat systems of western Terai of Nepal.

ACKNOWLEDGEMENTS

The authors are grateful to the Nepal Agricultural Research Council for providing the fund for this study. We are very much thankful to staffs of National Wheat Research Program Bhairahawa for their hard work during entire period of experiment. Similarly, support of the National Soil Science Research, Khumaltar, Lalitpur for providing technical support and necessary facilities for carrying out the field and laboratory work is highly acknowledged.

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