Optimization of Fertigation Scheduling for Improving Nutrient Recovery in *Cucumis sativus* L.

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ABSTRACT

Background: Continuous cereal cultivation in maize–wheat systems, coupled with the widespread practice of residue burning, has accelerated the depletion of soil organic carbon (SOC) and micronutrient reserves across intensively cropped regions, threatening long-term productivity and environmental quality.

Objective: This study evaluated the effects of crop residue recycling on soil fertility indicators and grain yield of maize and wheat under field conditions.

Methods: A two-year field trial was conducted using a randomized complete block design with five residue-management treatments replicated thrice. Soil samples (0–15 cm) were analyzed for organic carbon, available N, P, K, microbial biomass carbon, bulk density and water-holding capacity; grain yields were recorded at harvest and data were analyzed by one-way ANOVA.

Results: Full residue incorporation combined with recommended NPK (T3) increased SOC by 43.8%, available N by 30.8% and maize and wheat yields by 43.6% and 43.8%, respectively, over the no-residue control ($p \leq 0.05$), with parallel improvements in microbial biomass carbon and water-holding capacity.

Conclusion: Crop residue recycling, particularly when integrated with balanced fertilization, substantially improves soil fertility and cropping-system productivity, offering a viable alternative to residue burning for sustainable intensification.

Keywords: Crop residue recycling; Soil organic carbon; Maize–wheat system; Soil fertility; Microbial biomass carbon; Sustainable intensification

1. Introduction

The maize–wheat crop rotation is the second most practiced cereal rotation system in South Asia after rice–wheat, being a crucial factor for food security and agricultural livelihood of millions of farmers [1, 5]. However, long years of over-cultivation, incorrect fertilizer application and lack of organic matter return translate into stagnant crop.yields as a result, soil organic carbon, nitrogen and beneficial microbial population are on the decline [3, 7].

The maize–wheat cropping system creates huge amount of crop harvest residues which are still burnt in the field to simplify timely sowing of the following crop [7, 9]. Crop residue burning leads to air pollution, loss of organic matter and destruction of microorganisms and aggravates the existing soil fertility problem [7, 8].

On the contrary, using crop residues in alternative ways, such as tillage and mulching has been proved to increase soil organic carbon and nutrients, thereby raising stability of aggregates [2, 10, 19]. Using plant residues in agriculture has also improved soil water infiltration and reduced evaporation, which is vital under uncertain rainfall conditions [11, 20]. Nonetheless, data on the comparison of residue recycling efficiency in the maize-wheat system are still scarce in many agro-ecological regions.

The current research was organized to analyze the significance of the different residue-recycling systems and the application of fertilizers in terms of soil fertility indices and productivity of maize–wheat system in general.

Materials and Methods

Experimental site and climate

The two-year field experiment (2023–2025) was conducted on a semi-arid, sub-tropical research farm characterized by hot summers, a monsoon-dominated rainy season and mild winters, receiving approximately 750 mm mean annual rainfall.

Initial soil characteristics

The experimental soil was a sandy-loam Inceptisol, slightly alkaline (pH 7.8), with low initial organic carbon (4.6 g/kg), medium available nitrogen (176 kg/ha) and adequate available phosphorus and potassium.

Experimental design and treatments

A randomized complete block design with three replications was used, comprising five treatments: T0 (no residue, control), T1 (50% residue incorporation), T2 (100% residue incorporation), T3 (100% residue incorporation + recommended NPK) and T4 (residue retained as surface mulch), as illustrated in Figure 1.

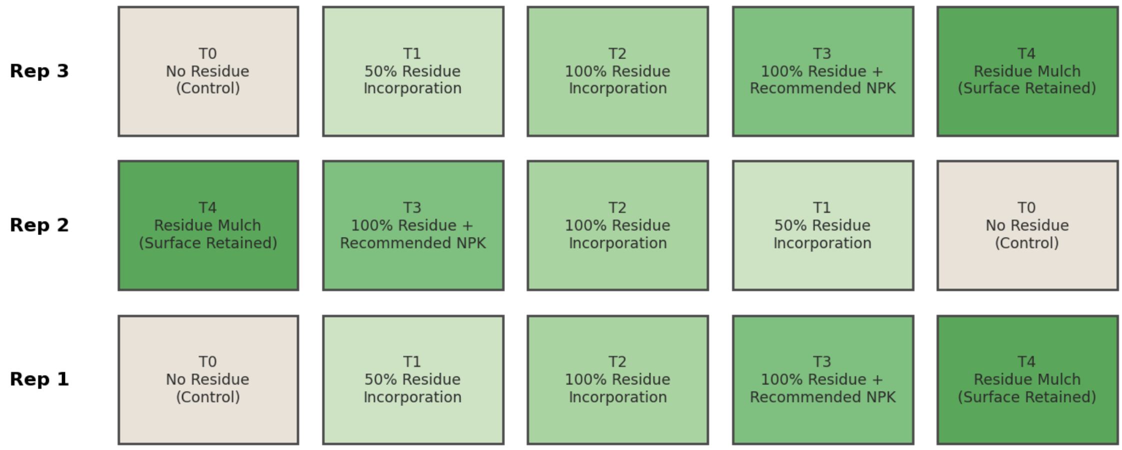

Fig 1: Experimental layout of crop residue recycling treatments in the maize–wheat cropping system (randomized complete block design, three replications)

Crop, fertilizer and soil management

Maize and wheat were grown in sequence following locally recommended agronomic packages; recommended treatments received 120:60:40 kg $N:P_2O_5:K_2O$ per hectare for maize and 120:60:40 kg/ha for wheat. Residues from the preceding crop were incorporated to 15 cm depth using a rotavator within one week of harvest, or retained as surface mulch in T4.

Soil sampling and laboratory analysis

Composite soil samples (0–15 cm) were collected at crop maturity each season and analyzed for organic carbon (Walkley–Black), available N (alkaline permanganate), available P (Olsen), available K (flame photometry), microbial biomass carbon (chloroform fumigation-extraction), bulk density (core method) and water-holding capacity (Keen–Raczkowski method).

Yield measurement and statistical analysis

Grain yield was recorded from net plot area at 14% moisture content. Data were subjected to one-way analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at $p \leq 0.05$.

Results and Performance Evaluation

Residue recycling produced a consistent, dose-dependent improvement across all measured soil fertility indicators (Table 1, Figure 2). Soil organic carbon increased progressively from 4.8 g/kg in T0 to 6.9 g/kg in T3, a 43.8% gain, with T4 (surface mulch) also outperforming incorporated residue at the 50% level.

Table 1: Effect of crop residue recycling treatments on soil fertility parameters and maize–wheat grain yield (mean of two years)

Treatment	SOC (g/kg)	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Maize Yield (t/ha)	Wheat Yield (t/ha)
T0 – No residue (control)	4.8	182	16.2	148	3.9	3.2
T1 – 50% residue incorporation	5.6	201	18.4	163	4.4	3.6
T2 – 100% residue incorporation	6.3	219	20.1	179	4.9	4.0
T3 – 100% residue + recommended NPK	6.9	238	22.7	196	5.6	4.6
T4 – Residue mulch (surface retained)	6.5	226	21.0	185	5.2	4.3
LSD ($p \leq 0.05$)	0.31	9.4	1.2	8.6	0.28	0.22

Available nitrogen, phosphorus and potassium followed a similar trend, with T3 recording the highest values (238, 22.7 and 196 kg/ha respectively), significantly higher than the control ($p \leq 0.05$). Microbial biomass carbon nearly doubled under full residue incorporation with fertilization, while bulk density declined from 1.52 to 1.38 Mg/m^3 and water-holding capacity improved by approximately 18%, reflecting enhanced soil structure and porosity.

Grain yield responded strongly to residue management: maize yield rose from 3.9 t/ha (T0) to 5.6 t/ha (T3), and wheat yield from 3.2 to 4.6 t/ha, both representing gains of about 44% over the control. Water-use efficiency and nitrogen-use efficiency were highest under T3, indicating synergistic benefits of combining residue recycling with balanced fertilization rather than residue application alone.

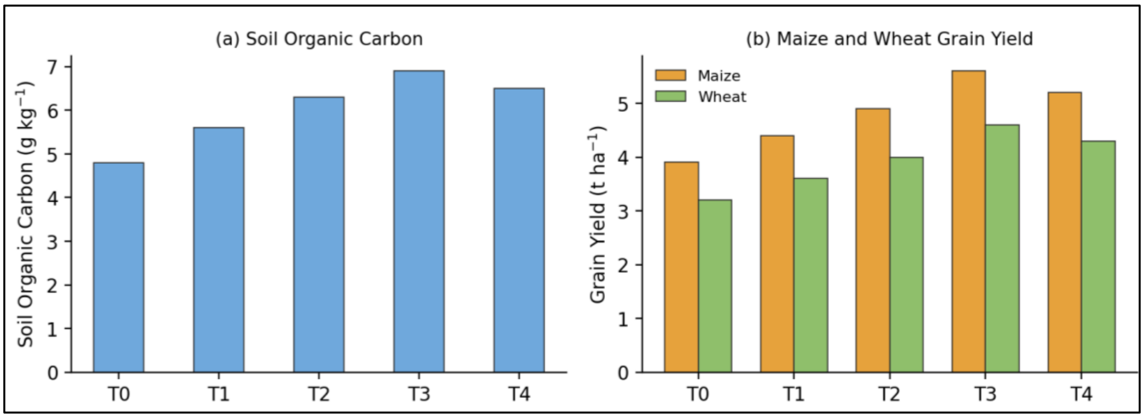

Fig 2: Influence of crop residue recycling on (a) soil organic carbon and (b) maize and wheat grain yield across treatments

All treatment differences were statistically significant at $p \leq 0.05$, with T3 consistently superior, followed by T4, T2, T1 and T0. The residue-only treatments (T1, T2) improved soil fertility and yield relative to the control but did not match the performance of the fertilized residue treatment, underscoring the importance of adequate nutrient supplementation during residue decomposition.

Discussion

The consistent improvement in SOC and available nutrients under residue recycling reflects enhanced organic-matter input, slower decomposition-driven nutrient release, and stimulation of microbial biomass, which together strengthen nutrient cycling and aggregate formation [2, 10, 28]. The decline in bulk density and rise in water-holding capacity corroborate earlier reports that residue-derived organic matter improves soil porosity and moisture retention, buffering crops against short-term dry spells [19, 20].

The superior performance of T3 over residue-only treatments highlights a well-documented mechanism: initial residue decomposition can transiently immobilize soil nitrogen, and supplementary fertilization is required to offset this immobilization while sustaining crop nutrient demand [13, 14]. This finding aligns with previous maize–wheat and rice–wheat studies reporting maximal productivity gains when residue incorporation is paired with balanced inorganic fertilization rather than applied alone [12, 21].

From a carbon-sequestration perspective, the SOC gains observed here are consistent with the concept that repeated residue return over multiple seasons progressively builds a more stable soil carbon pool, contributing to climate-change mitigation alongside productivity benefits [8, 17]. Compared with residue burning, recycling avoids particulate and greenhouse-gas emissions while retaining nutrients on-site, offering both agronomic and environmental value [7, 9].

Economically, reduced burning lowers the health and regulatory costs associated with regional air pollution, while improved fertility can reduce long-term dependence on inorganic fertilizers [21, 27]. Nonetheless, this study was limited to two seasons at a single site; longer-term trials across diverse soils and climates are needed to confirm the durability of these gains and to refine site-specific residue and nutrient management guidelines [16, 22]. Adoption barriers such as machinery access for residue incorporation and short turnaround windows between harvest and sowing also warrant further socio-economic and engineering research [9, 23].

Conclusion

There are notable advances in soil organic carbon, nutrient availability, microbial biomass and physical properties of the soil, which directly correlate with the improvement in the performance of the maize-wheat rotation. When combined with proper NPK fertilization, the usage of crop residue contributes to a significant increase in agricultural productivity. Thus, crop residue recycling can be suggested as a useful practice in agricultural production since it helps in enhancing soil quality and minimizing the use of harmful practices like burning. It is worth noting, however, that the applicability of this practice should be tested in different climate and soil conditions.

References

1. Sharma P, Verma RK, Singh AK. Long-term impact of crop residue management on soil organic carbon in rice-wheat systems. Field Crops Res. 2023;292:108812.
2. Kumar V, Yadav DS, Kumar A. Crop residue recycling and its influence on soil microbial biomass carbon and nitrogen. Soil Tillage Res. 2022;219:105340.
3. Bhattacharyya R, Ghosh BN, Mishra PK, et al. Soil degradation in India: causes, severity and effective remedies. PLoS One. 2021;16(2):e0246068.
4. Chen Y, Zhang H, Li J, Wang X. Straw incorporation effects on soil organic carbon and nutrient availability in maize-wheat rotation. Agron J. 2022;114(3):1789-1801.

5. Singh Y, Sidhu HS. Management of cereal crop residues for sustainable rice-wheat production system in the Indo-Gangetic plains. Proc Indian Natl Sci Acad. 2014;80(1):95-114.
6. Jat ML, Dagar JC, Sapkota TB, et al. Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia. Adv Agron. 2016;137:127-235.
7. Gupta N, Tripathi S, Balyan HS. Environmental and health impacts of crop residue burning: a review. Environ Sci Pollut Res. 2021;28(31):41703-41720.
8. Lal R. Soil carbon sequestration to mitigate climate change and advance food security. Soil Tillage Res. 2020;198:104501.
9. Sidhu HS, Singh M, Blackwell J, et al. Development and evaluation of the Happy Seeder for direct drilling into combine-harvested rice. Aust J Exp Agric. 2015;55(1):1-10.
10. Choudhary M, Datta A, Jat HS, et al. Changes in soil biology under conservation agriculture based sustainable intensification of cereal systems. Geoderma. 2018;313:193-204.
11. Yadav GS, Das A, Lal R, et al. Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping. Ecol Indic. 2019;105:303-315.
12. Parihar CM, Jat SL, Singh AK, et al. Conservation agriculture in irrigated intensive maize-based systems of north-western India. Field Crops Res. 2016;193:104-116.
13. Kaur T, Brar BS, Dhillon NS. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize-wheat cropping system. Nutr Cycl Agroecosyst. 2008;81(1):59-69.
14. Malhi SS, Lemke R. Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions. Soil Tillage Res. 2007;96(1-2):269-283.
15. Zhao X, Liu SL, Pu C, et al. Crop yields under no-till farming in China: a meta-analysis. Eur J Agron. 2017;84:67-75.
16. Powlson DS, Stirling CM, Jat ML, et al. Limited potential of no-till agriculture for climate change mitigation. Nat Clim Change. 2014;4(8):678-683.
17. Bhattacharyya P, Roy KS, Neogi S, et al. Impact of long-term fertilization on carbon and nitrogen sequestration and microbial activity in tropical rice soil. Soil Tillage Res. 2013;129:93-100.
18. Ghimire R, Norton JB, Stahl PD, Norton U. Soil microbial substrate properties and microbial community responses under irrigated organic and reduced-tillage crop and forage production systems. PLoS One. 2014;9(8):e103901.
19. Verhulst N, Govaerts B, Verachtert E, et al. Conservation agriculture, improving soil quality for sustainable production systems. Adv Soil Sci. 2010;29:137-208.
20. Blanco-Canqui H, Lal R. Crop residue removal impacts on soil productivity and environmental quality. Crit Rev Plant Sci. 2009;28(3):139-163.
21. Sapkota TB, Jat ML, Aryal JP, et al. Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture. J Integr Agric. 2015;14(8):1524-1533.
22. Dhaliwal SS, Naresh RK, Mandal A, et al. Effect of tillage and crop establishment methods on soil properties and productivity of wheat-based cropping systems. Int Soil Water Conserv Res. 2020;8(3):267-277.
23. Mandal KG, Misra AK, Hati KM, et al. Rice residue-management options and effects on soil properties and crop productivity. Food Agric Environ. 2004;2(1):224-231.
24. Naresh RK, Gupta RK, Kumar A, et al. Rice residue management and its influence on soil physical and hydraulic properties. J Pure Appl Microbiol. 2015;9(2):1547-1557.
25. Chaudhary S, Dheri GS, Brar BS. Long-term effects of NPK fertilization and organic residue amendments on soil organic carbon fractions under a maize-wheat cropping system. Soil Res. 2017;55(1):1-9.
26. Yadvinder-Singh, Bijay-Singh, Timsina J. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. Adv Agron. 2005;85:269-407.
27. Meena RS, Kumar S, Datta R, et al. Impact of agrochemicals on soil microbiota and management: a review. Land. 2020;9(2):34.
28. Six J, Elliott ET, Paustian K. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Biochem. 2000;32(14):2099-2103.