



Finger Millet Residue Management: Impacts on Soil Health and System Productivity in Succeeding Crops – A Review

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Received:- 04 January 2026/ Revised:- 16 January 2026/ Accepted:- 22 January 2026/ Published: 31-01-2026

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Abstract— Rainfed and upland agriculture in India faces mounting challenges due to continuous cereal monoculture, leading to soil degradation and vulnerability to climate variability. Finger millet (*Eleusine coracana* L. Gaertn.), a climate-resilient and nutrient-rich small millet, offers a sustainable alternative for diversification. This review synthesizes evidence on the role of finger millet residue management in enhancing the productivity, nutrient uptake, soil properties, and economics of succeeding crops. With significant residue biomass (approximately 5 tonnes ha⁻¹) often underutilized, in-situ incorporation or mulching of these residues consistently improves dry matter accumulation, growth, and yield of subsequent legumes and cereals. These practices enhance nutrient cycling, increasing nitrogen, phosphorus, and potassium uptake by 10-30% in crops like greengram, groundnut, and maize. Long-term residue retention boosts soil organic carbon by 15-30%, reduces bulk density, and improves overall soil fertility compared to removal or burning. Economically, residue-based systems, particularly when integrated with legumes, yield higher gross and net returns with favorable benefit-cost ratios, despite marginally higher initial costs. Finger millet residue management is thus a viable strategy for ecological intensification. Adopting finger millet–legume systems with efficient residue recycling can significantly contribute to soil health, climate resilience, and livelihood security in India's rainfed regions.

Keywords— Crop residue recycling; ecological intensification; *Eleusine coracana*; nutrient cycling; rainfed agriculture; soil organic carbon; sustainable cropping systems.

I. INTRODUCTION

Agriculture in India's rainfed and upland regions underpins rural livelihoods and national food security. However, reliance on intensive cereal-based systems, particularly continuous rice cultivation, has led to declining productivity, accelerated soil degradation, and heightened climate vulnerability (Woźniak, 2019). These issues are acute in fragile uplands, where water scarcity, poor soil health, and socio-economic constraints limit sustainable intensification. Consequently, identifying resilient, resource-efficient cropping alternatives is imperative.

Finger millet (*Eleusine coracana* L. Gaertn.) emerges as a promising solution. A hardy, climate-smart small millet traditionally grown in southern and central India, it is valued for its exceptional nutritional profile, being rich in calcium, iron, dietary fiber, and the essential amino acid methionine—often deficient in staple cereals (Devi et al., 2011). Agronomically, it thrives in marginal environments with minimal inputs, exhibits drought tolerance, and adapts to short growing seasons (Kumar et al., 2024). Beyond grain, its straw is a valuable resource, high in organic matter (89-92%) and containing significant crude protein (3-5%), calcium (344 mg 100g⁻¹), and potassium (408 mg 100g⁻¹) (Malleshi et al., 2021).

In India, finger millet is the leading small millet, cultivated on approximately 1.2 million hectares with a production of 1.56 million tonnes (Department of Agriculture & Farmers Welfare, 2023). With an estimated straw yield of 5 tonnes ha⁻¹, annual residue production approaches 6 million tonnes nationally. However, a considerable proportion is either discarded or burned, representing a significant loss of organic nutrients and contributing to environmental degradation. Efficient utilization of this residue through in-situ incorporation or mulching offers a direct pathway to enhance soil fertility, improve nutrient cycling, and bolster farm-system resilience.

Continuous cereal monoculture depletes soil organic carbon (SOC) and microbial diversity (Woźniak, 2019). Diversification with finger millet, particularly in rotation with legumes (e.g., greengram, groundnut, horsegram), facilitates ecological intensification by enabling biological nitrogen fixation, improving soil structure, and suppressing pests. Within such diversified systems, the management of finger millet residues becomes a critical lever for sustainability. This review synthesizes available evidence on the impact of finger millet residue management on the performance of succeeding crops, focusing on crop growth, nutrient uptake, soil properties, and system economics, to guide sustainable practices in rainfed agro-ecosystems.

II. METHODOLOGY FOR LITERATURE SYNTHESIS

This review was conducted by systematically searching peer-reviewed literature from 2000 to 2024. Primary databases included Scopus, Web of Science, Google Scholar, and the journals of the Indian Society of Agronomy. Key search terms were: "finger millet residue," "Eleusine coracana straw," "small millet residue management," "crop residue incorporation," "residue mulching," "rainfed cropping systems," and "soil organic carbon." Studies were selected based on relevance to finger millet systems or analogous residue management principles in comparable rainfed cereal-legume systems. Data on crop yield, nutrient uptake, soil parameters, and economics were extracted, compared, and synthesized thematically. Given the limited number of studies exclusively on finger millet residue, evidence from well-managed experiments with residues of similar quality (e.g., rice, wheat, other millets) is also discussed to elucidate underlying mechanisms, with clear distinctions made.

III. IMPACT ON GROWTH AND YIELD OF SUCCEEDING CROPS

Retaining crop residues on the soil surface as mulch or incorporating them into the soil significantly improves the growth environment for subsequent crops. Residue mulch conserves soil moisture, moderates temperature, and suppresses weeds, while incorporation adds organic matter and facilitates nutrient release upon decomposition.

Research consistently shows positive yield responses. Meena et al. (2008) reported that conventional tillage with residue retention produced significantly higher dry matter accumulation in greengram (467.0 g m⁻² at 60 DAS) compared to residue removal (367.6 g m⁻²). Similarly, in a rice-groundnut system, incorporation of field bean residues increased groundnut dry matter production by 23-25% over the control (Kumari et al., 2010). These benefits extend to cereals. For instance, wheat residue mulching at 5 t ha⁻¹ increased maize plant height by 5% and dry matter per plant by 8% (Ajamirali and Halagalimath, 2017). Almaz et al. (2017) observed that incorporating soybean residue with balanced fertilization more than doubled maize plant height compared to a no-residue, no-fertilizer control.

The mechanism is multifaceted: residues improve soil physical properties (discussed later), which enhances root growth and water infiltration. Furthermore, as residues decompose, they release nutrients, particularly potassium, which is abundant in finger millet straw. The gradual nutrient release synchronizes better with crop demand compared to chemical fertilizers alone, leading to more sustained growth.

TABLE 1
SUMMARY OF RESIDUE MANAGEMENT EFFECTS ON CROP PERFORMANCE IN SELECTED STUDIES

Residue Type	Management Practice	Succeeding Crop	Key Impact	% Increase over Control	Reference
General Crop Residue	Incorporation + GM*	Wheat	Dry matter (120 DAS)	~155%	Dhar et al. (2014)
Wheat Straw	Mulching (5 t ha ⁻¹)	Maize	Plant height, Dry matter/plant	~5%, ~8%	Ajamirali & Halagalimath (2017)
Field Bean Residue	Incorporation	Groundnut	Dry matter at harvest	~25%	Kumari et al. (2010)
Soybean Residue	Incorporation + PK	Maize	Plant height	~116%	Almaz et al. (2017)

IV. ENHANCEMENT OF NUTRIENT UPTAKE

Effective residue management enhances the nutrient cycling efficiency within cropping systems. Crop residues act as a slow-release nutrient source and foster a more active microbial community responsible for mineralization.

Studies report substantial increases in macro-nutrient uptake. In a maize-wheat sequence, retaining maize residues increased nitrogen uptake in wheat grain and straw by 31% and 64%, respectively (Bakht et al., 2009). Integrating legumes in the rotation amplifies this benefit through biological nitrogen fixation. Bana and Shivay (2012) found that a preceding summer cowpea forage crop increased total N, P, and K uptake in basmati rice by up to 20% compared to fallow. Kouelo et al. (2013) reported that incorporating *Mucuna* residues increased grain N uptake in maize by over 350%.

The quality of residue is crucial. Finger millet straw, with a favorable carbon-to-nitrogen (C:N) ratio and high potassium content, is expected to decompose relatively quickly, minimizing nitrogen immobilization and rapidly supplying potassium—a key nutrient for legume seed development and stress tolerance. This makes it particularly suitable for legume-based systems prevalent in rainfed areas.

V. IMPROVEMENT OF SOIL PHYSICO-CHEMICAL PROPERTIES

The long-term benefits of residue recycling are most evident in soil health parameters. Continuous residue addition is a primary strategy for rebuilding SOC in degraded soils.

- **Soil Organic Carbon (SOC):** SOC is the cornerstone of soil health. Singh and Yadav (2006) reported that long-term residue incorporation increased SOC by 17.7% compared to residue removal. Similarly, Singh et al. (2009) found straw retention increased SOC by 29.6%, whereas burning only increased it by 11.6%. Higher SOC enhances cation exchange capacity, water retention, and provides energy for soil microbes.
- **Soil Physical Properties:** Residue management reduces soil compaction. Gangwar et al. (2006) recorded the lowest bulk density (1.58 Mg m⁻³) with residue incorporation, compared to 1.61 Mg m⁻³ with removal. Lower bulk density improves porosity, aeration, and root penetration.
- **Soil Chemical Fertility:** Residue decomposition releases nutrients and can moderate soil pH. Kumar et al. (2008) observed that long-term residue application with fertilizers significantly increased available N, P, and K by 24%, 49%, and 39%, respectively, over fertilizer application alone. While some studies note a slight increase in pH with residue addition (Das et al., 2001; Kachroo & Dixit, 2005), this is often beneficial in acidic upland soils.

TABLE 2
 IMPACT OF RESIDUE MANAGEMENT ON KEY SOIL PROPERTIES

Soil Property	Residue Management Practice	Reported Effect	Reference
Organic Carbon	Surface retention/Incorporation	Increase of 15-30% over removal/burning	Singh et al. (2009); Singh & Yadav (2006)
Bulk Density	Incorporation	Reduction of 1.8-2.0% compared to removal	Gangwar et al. (2006)
Available N, P, K	Long-term incorporation + fertilizers	Significant increase over fertilizers alone	Kumar et al. (2008)
pH	Residue incorporation	Slight increase/amelioration in acidic soils	Das et al. (2001)

VI. ECONOMIC VIABILITY

The adoption of any practice hinges on its economic feasibility. While residue incorporation may involve higher initial costs related to tillage or decomposition aids (e.g., microbial consortia), it typically results in superior returns.

Research indicates positive economic outcomes. In a legume-rice-groundnut sequence, incorporating field bean residues with FYM resulted in net returns of approximately Rs. 21,000 ha⁻¹ and a favorable B:C ratio (Kumari et al., 2010). Pooniya and Shivay (2012) found that incorporating *Sesbania* green manure residues in rice provided net returns over Rs. 60,000 ha⁻¹ with a B:C ratio above 2.0. Rajkumara et al. (2014) reported that applying crop residues under no-tillage enhanced net returns in a maize-chickpea system by about 9%.

The economic advantage stems from reduced need for purchased fertilizers (due to improved nutrient cycling), higher and more stable yields, and often, lower irrigation requirements due to better soil moisture conservation. Integrating a legume in the system provides an additional cash crop or fodder, further improving income diversity and risk resilience for smallholder farmers.

VII. SYNTHESIS, CHALLENGES, AND FUTURE PERSPECTIVES

Synthesis: The collective evidence strongly supports finger millet residue retention (via mulching or incorporation) as a keystone practice for sustainable rainfed farming. It creates a positive feedback loop: improved soil structure and moisture → better crop growth and yield → higher residue return → enhanced SOC and nutrient cycling → sustained system productivity and resilience.

Addressing Challenges:

Practical adoption faces hurdles:

1. **Resource Competition:** Residues are valuable fodder. Integrated farming systems that allocate a portion for soil health while meeting livestock needs are essential.
2. **Short-term Immobilization:** Incorporating high C:N residues can temporarily tie up soil N. This can be mitigated by co-applying a small dose of starter N fertilizer or using pre-decomposed residues.
3. **Operational Constraints:** Smallholders may lack access to appropriate machinery for incorporation or mulch management. Promoting community-based residue managers or low-cost choppers can help.
4. **Pest and Disease Risk:** Residue retention must be managed alongside integrated pest and disease management strategies to avoid harboring pathogens.

Future Research Needs:

- **Finger Millet-Specific Studies:** Quantified data on decomposition rates, nutrient release patterns (N, P, K, Ca), and soil carbon sequestration potential of finger millet residue under different agro-climates.
- **System Optimization:** Research on ideal rates, timing (immediate vs. decomposed), and methods (mulch vs. incorporation) of finger millet residue management within diversified cropping sequences (e.g., finger millet-legume-vegetable).
- **Trade-off Analysis:** Comprehensive studies evaluating the trade-offs between residue use for soil amendment, fodder, and alternative uses (e.g., bioenergy), considering both biophysical and socio-economic factors.
- **Climate Interaction:** Assessing how residue management affects system resilience under extreme weather events (drought, intense rainfall) and its impact on greenhouse gas fluxes (N₂O, CH₄).

VIII. CONCLUSION

Finger millet is more than a climate-resilient nutricereal; its substantial residue biomass represents a critical on-farm resource for ecological sustainability. This review affirms that in-situ management of finger millet residues through mulching or incorporation significantly enhances the productivity and nutrient uptake of succeeding crops, improves key soil health indicators like SOC and bulk density, and proves economically viable. Moving away from residue burning or removal towards systematic recycling is a low-cost, high-impact strategy. Promoting diversified finger millet–legume systems coupled with scientific residue management can be a cornerstone for achieving sustainable intensification, restoring degraded uplands, and securing livelihoods in India's rainfed regions. Policy support, extension services, and context-specific research are needed to translate this potential into widespread farm-level practice

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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