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RICE RESIDUE MANAGEMENT FOR SUSTAINABLE RICE-FALLOW SUNFLOWER PRODUCTION: VALIDATION OF OPTIONS THROUGH FRONT-LINE DEMONSTRATIONS

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ABSTRACT

Open-field burning of rice residues is a common practice in rice-growing regions of Telangana, resulting in nutrient losses, deterioration of soil health and environmental pollution. Front Line Demonstrations (FLDs) were conducted during *rabi* 2024–25 in farmers' fields of Siddipet district, Telangana, to validate suitable rice residue management options for improving productivity and profitability of rice-fallow sunflower. The demonstrations were laid out in a randomized block design with seven replications (farmers' fields) and comprised three treatments: T_1: residue burning followed by recommended fertilizer dose (farmers' practice), T_2 : zero tillage with residue retention, and Tƒ : residue incorporation with C:N:P adjustment (30:1:0.3) along with the recommended fertilizer dose. Conservation-based residue management significantly improved sunflower productivity over residue burning. Residue incorporation recorded the highest seed yield (1,656 kg ha^{-1}), followed by zero tillage with residue retention (1,611 kg ha^{-1}), compared with residue burning (1,498 kg ha^{-1}), representing yield increases of 10.55% and 7.54%, respectively. Zero tillage with residue retention proved to be the most profitable treatment, recording the highest net returns (Rs 77,904 ha^{-1}) and benefit-cost ratio (2.06),while residue incorporation recorded net returns of Rs 75,916 ha^{-1} with a benefit-cost ratio of 1.70. The extension gap was 114 kg ha^{-1} under zero tillage and 158 kg ha^{-1} under residue incorporation, indicates considerable scope for enhancing sunflower productivity through wider adoption of improved residue management practices. The study demonstrates that conservation-based residue management, particularly zero tillage with residue retention, is a technically feasible, economically viable, and environmentally sustainable alternative to residue burning for rice-fallow sunflower cultivation in Telangana.

Key Words: Crop residue management, front line demonstrations, rice fallows, sunflower, zero tillage, residue incorporation

Rice (*Oryza sativa* L.) is one of the major cereal crops cultivated in India and generates enormous quantities of crop residues after harvest. In many rice-growing regions, particularly under mechanized harvesting systems, rice straw is frequently disposed off by open-field burning to facilitate timely sowing of the succeeding crop. This practice causes substantial losses of valuable plant nutrients, reduces soil organic carbon, deteriorates soil biological activity, and contributes to greenhouse gas emissions and air pollution. Consequently, sustainable crop residue management has become an important component of conservation agriculture and climate-resilient crop production (Bhuvaneshwari *et al.,* 2019; Gupta *et al.*, 2015).

Conservation agriculture emphasizes minimum soil disturbance, residue retention and crop diversification to improve soil health and sustain crop productivity. Retaining or incorporating crop residues enhances soil moisture conservation, improves aggregation, increases microbial activity and promotes nutrient recycling, thereby improving crop growth and yield (Hobbs *et al.*, 2008; Lal, 2015; Fu *et al.,* 2021). Residue retention also reduces evaporation losses and improves water-use efficiency, which is particularly beneficial for rainfed and rice-fallow cropping systems where the succeeding crop largely depends on residual soil moisture (Zhao *et al.,* 2019; Cárceles Rodríguez *et al.,* 2022).

Sunflower (*Helianthus annuus* L.) is an important oilseed crop cultivated extensively in the rice-fallow ecosystems of Telangana. Productivity of sunflower under these conditions is largely influenced by soil moisture availability, soil physical condition and nutrient dynamics immediately after rice harvest. Adoption of suitable residue management practices can therefore improve resource-use efficiency while reducing the environmental impacts associated with residue burning.

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Earlier studies conducted in Telangana demonstrated that residue incorporation and residue retention significantly improved sunflower productivity and profitability compared with residue burning (Prasad *et al.*, 2024). Subsequent investigations also reported enhanced soil microbial activity and enzyme dynamics (Prasad *et al.,* 2025a), improved soil moisture conservation with reduced bulk density (Prasad *et al.,* 2025b), and greater aggregate stability and soil organic matter accumulation under residue-retained systems (Prasad *et al.,* 2025c). More recently, Sridevi *et al.* **(2026)** reported that conservation-based residue management improved productivity, profitability and soil fertility in a maize–sunflower cropping system under semi-arid conditions.

Although the benefits of conservation-based residue management have been demonstrated under experimental conditions, validation under farmers' field conditions is essential before large-scale dissemination. Front Line Demonstrations provide an effective platform for assessing the technical feasibility, economic viability and adoptability of improved technologies under real farming situations. Therefore, the present study was undertaken to evaluate the performance of rice residue management options in rice-fallow sunflower through Front Line Demonstrations conducted in Siddipet district of Telangana and to identify a suitable residue management practice for enhancing productivity and profitability under farmers' field conditions.

MATERIAL AND METHODS

Description of the Study Area

The Front-Line Demonstrations (FLDs) were conducted during the rabi season of 2024–25in farmers' fields located inSiddipet district of Telangana, India, the demonstrations were implemented jointly by the Agricultural Research Station (ARS), Tornala, and the Telanagana Rythu Vignana Kendra (TRVK), Tornala.

The study was conducted in seven representative villages covering different mandals of Siddipet district, namely Ramancha (ChinnaKoduru), Choutukunta Tanda (Akkannapet), Ghanapur (Thoguta), Chittapur (Akberpet–Bhoompally) and Mantoor (Raipole). The selected villages represent major rice-growing areas where sunflower is commonly cultivated as a rice fallow crop after the harvest of kharif rice. The geographical coordinates of all demonstration fields were recorded using Global Positioning System (GPS) to facilitate documentation and future monitoring (Table 1).

The climate of the study area is semi-arid tropical with hot summers and moderate winters. Rice is cultivated during the southwest monsoon season (*kharif*), whereas sunflower is grown during the post-rainy (*rabi*) season utilizing residual soil moisture supplemented by limited irrigations wherever available. Farmers in the region generally adopt residue burning to facilitate rapid field preparation before sowing sunflower.

Selection of Farmers

Seven progressive farmers were selected in consultation with the Department of Agriculture based on their willingness to participate in the demonstrations, availability of suitable land under rice–sunflower cropping system, and their readiness to follow the recommended management practices throughout the cropping season. Each farmer's field served as one replication in the experiment. Prior to initiation of the demonstrations, participating farmers received technical guidance regarding residue management, nutrient management and sunflower production practices.

Experimental Design and Treatments

The demonstrations were conducted following a **Randomized Block Design (RBD)** with **seven replications**, where each farmer's field represented one replication. The study evaluated three residue management options after harvest of the preceding rice crop.

T_1 – Farmers' Practice (Residue Burning):

Rice residues were burned *in situ* approxi 1mately two weeks after rice harvesting. Thereafter, sunflower was sown following the existing farmers' practice with application of the recommended dose of fertilizers (75:90:30 kg N:P, O… :K, O ha^{-1}).

T_2 – Zero Tillage with Residue Retention

Rice residues were retained on the soil surface, and sunflower was directly sown under zero tillage without disturbing the soil. The recommended dose of fertilizers was applied following the recommended schedule.

Tƒ – Residue Incorporation with Nutrient Adjustment

Rice residues were incorporated using a shredder and rotavator into the soil after adjusting the

Table1. Yield of Sunflower under different residue management options in rice fallows under FLDs in farmers' fields

S.No	Name of the Farmer	Village, Mandal & GPS	Variety /Hybrid	Quantity of rice residue (t/ha)	Seed of Sunflower (Kg/ha)			Additional Yield (%) over residue burning	
					Residue burnt	Zero till Sunflower	Residue incorporated	Zero till Sunflower	Residue incorporated
1	G.Swamy	Ramancha (V), ChinnaKoduru (M) 18.161888, 78.834434	NDSH 1012	5.50	1334	1483	1544	11.11	15.74
2	Bhukhya Mahesh	ChoutukuntaTanda (V), Akkannapet (M) 18.020921, 79.155387	NDSH 1012	5.00	939	1038	1013	10.53	7.89
3	Bhukhya Raju	Choutukunta Tanda (V), Akkannapet (M) 18.015914, 79.150554	NDSH 1012	4.50	1038	1161	1186	11.90	14.29
4	Bhukhya Mahesh	Choutukunta Tanda (V), Akkannapet(M) 18.018946, 79.154915	NDSH 1012	4.50	1236	1310	1396	6.00	13.00
5	Akkam Swamy	Ghanapur (V), Thoguta (M) 18.052178, 78.748343	Tilhan Tech SunH -1	5.50	1829	1952	2039	6.76	11.49
6	Mongari Ramesh	Chittapur (V), Akberpet, Bhoompally	Advanta	6.00	1932	2031	2009	5.12	3.96
7	Rajinikar Reddy	Mantoor (V), Raipole (M) 17.5733, 78.4028	Ajith	5.50	2174	2305	2397	6.02	10.23
Average				5.21	1497	1611	1656	7.61	10.94

C:N:P ratio to 30:1:0.3 by applying the portion of the recommended dose of nitrogen and phosphorus necessary for adjustment through urea and single superphosphate (SSP) at the time of residue incorporation. The remaining recommended nitrogen was applied in two subsequent splits, while phosphorus and potassium were applied as per recommendation.

Crop Management

Rice was cultivated during the kharif season following the recommended agronomic practices of the region. After harvesting the rice crop, the respective residue management treatments were imposed before sowing sunflower. Recommended sunflower hybrids suitable for the locality, including NDSH-1012, Tilhan Tech SunH-1, Advanta and Ajith, were used depending on farmers' preference and local availability. Recommended package of practices regarding seed rate, fertilizer application, irrigation, weed management and plant protection measures were uniformly followed across all treatments except for the residue management interventions.

Data Collection

Observations were recorded from all demonstration fields on the following parameters: Quantity of rice residue generated after harvesting (t ha^{-1}), Seed yield of sunflower (kg ha^{-1}) ,Percentage increase in yield over farmers' practice, Cost of cultivation (Rs ha^{-1}), Gross returns (Rs ha^{-1}), Net returns (Rs ha^{-1}) and Benefit-cost ratio (B:C)

Economic analysis was carried out using the prevailing market price of sunflower seed (Rs 72.80 kg^{-1}) during the study period. Gross returns were computed based on seed yield and market price, while net returns were obtained by deducting the total cost of cultivation from the gross returns. The benefit-cost ratio was calculated as the ratio of gross returns to the total cost of cultivation.

Assessment of Extension Parameters

The effectiveness of the demonstrated technologies was evaluated using extension parameters commonly employed in Front Line Demonstration studies.

Percentage yield increase over farmers' practice (%)

$$\text{Yield increase (\%)} = \left(\frac{Yield\ in\ Demonstration - Yield\ in\ Farmers\ Practice}{Yield\ in\ Farmers\ Practice}\right)\ x\ 100$$

Extension gap (kg ha^{-1})

Extension Gap = Demonstration Yield Farmers' Practice Yield

Using the average yield data obtained during the demonstrations, the extension gap was estimated separately for zero tillage and residue incorporation treatments. Technology gap and technology index were not computed because the potential yield of the demonstrated technologies under research conditions was not available.

The relative production and economic efficiencies of residue management practices over residue burning were worked out using the following formulae.

Relative Productive Use Efficiency (%)

$$= \frac{\text{Productivity of Residue Management Practice} - \text{Productivity in Residue Burning}}{\text{Productivity in Residue Burning}} \text{ X 100}$$

Relative Economic Efficiency (%)

$$= \frac{\text{Net Returns in Residue Management Practice} - \text{Net Returns in Residue Burning}}{\text{Net Returns in Residue Burning}} \text{ X 100}$$

Statistical Analysis

The demonstrations were laid out in a Randomized Block Design with seven farmer fields serving as replications. Treatment-wise mean values of yield and economic parameters were computed. Percentage yield increase, extension gap, gross returns, net returns and benefit-cost ratio were calculated using standard procedures. If the original field observations for individual plots are available, analysis of variance (ANOVA) can be performed following the procedure described by Gomez and Gomez (1984) to test treatment differences at the 5% level of significance.

RESULTS AND DISCUSSION

Effect of Rice Residue Management on Sunflower Productivity

The Front-Line Demonstrations conducted across seven farmers' fields in Siddipet district demonstrated the superiority of conservation-based residue management over the conventional practice of residue burning for sunflower cultivation in rice fallows. Mean sunflower seed yield ranged from 1,498 kg ha^{-1} under residue burning (farmers' practice) to 1,611 kg ha^{-1} under zero tillage with residue retention and 1,656 kg ha^{-1} under residue incorporation. Consequently, zero tillage and residue incorporation increased seed yield by 7.61% and 10.51%, respectively, over residue burning, indicating the adaptability of these technologies under farmers' field conditions (Table 1).

The higher yield under residue incorporation may be attributed to improved nutrient recycling through gradual decomposition of rice straw, enhanced microbial activity and increased nutrient availability during crop growth. Adjustment of the C:N:P ratio at the time of residue incorporation minimized nutrient immobilization and promoted better crop establishment. In contrast, residue retention under zero tillage conserved soil moisture, reduced evaporation losses and maintained favourable soil physical conditions, resulting in improved crop growth despite minimal soil disturbance.

The present findings corroborate the research station results of Prasad *et al.* (2024), who reported significantly higher sunflower yield and profitability under residue incorporation compared with residue burning and residue removal. Similarly, Prasad *et al.* (2025b) observed higher soil moisture and lower bulk density under residue-retained treatments, while Prasad *et al.* (2025c) reported improvements in aggregate stability and soil organic matter following residue incorporation. Enhanced soil microbial activity and enzyme dynamics under residue incorporation and residue retention, as reported by Prasad *et al.* (2025a), further explain the higher productivity observed under conservation residue management.

The results also agree with the findings of Sridevi *et al.* (2026), who reported that residue mulch under zero tillage produced the highest sunflower yield and system productivity, while residue incorporation improved post-harvest soil fertility through increased availability of nitrogen, phosphorus and potassium. These studies collectively confirm that residue recycling improves soil quality and crop productivity under semi-arid conditions.

The present observations are consistent with earlier reports indicating that residue incorporation enhances soil aggregation, nutrient mineralization and water-holding capacity (Fu *et al.,* 2021), while residue retention improves soil moisture availability and crop productivity (Zhao *et al.,* 2019). Likewise, Cárceles Rodríguez *et al.* (2022) and Sarkar *et al.* (2020) concluded that conservation agriculture enhances soil health, nutrient-use efficiency and long-term sustainability of intensive cropping systems.

Although residue incorporation recorded the highest seed yield, the difference between residue incorporation and zero tillage was relatively small (45 kg ha^{-1}), suggesting that both technologies are effective alternatives to residue burning. Residue incorporation may be preferred where appropriate machinery is available, whereas zero tillage offers a simpler and more economical option with comparable productivity. The consistent yield advantage observed across all demonstration locations highlights the technical feasibility and wide adaptability of conservation-based residue management practices for sunflower cultivation in the rice fallows of Telangana.

Economics and Profitability

Conservation-based residue management practices markedly improved the economic returns from sunflower cultivation compared with the conventional practice of residue burning. Although residue incorporation recorded the highest seed yield (1,656 kg ha $^{-1}$), zero tillage with residue retention proved to be

Table 2. Economics of Sunflower under different residue management options in rice fallows under FLDs in farmers' fields

S.No	Name of the Farmer	Village, Mandal & GPS	Cost of Cultivation (Rs/ha)			Gross Returns (Rs/ha)			Net Returns (Rs/ha)			B:C ratio		
			Residue burnt	Zero till Sunflower	Residue incorporated	Residue burnt	Zero till Sunflower	Residue incorporated	Residue burnt	Zero till Sunflower	Residue incorporated	Residue burnt	Zero till Sunflower	Residue incorporated
1	G.Swamy	Ramancha (V), ChinnaKoduru (M) 18.161888, 78.834434	43984	37065	44478	97140	107933	112431	53156	70868	67953	1.21	1.91	1.53
2	Bhukhya Mahesh	ChoutukuntaTanda (V), Akkannapet (M) 18.020921, 79.155387	24216	21004	24710	68358	75553	73754	44142	54550	49044	1.82	2.60	1.98
3	Bhukhya Raju	Choutukunta Tanda (V), Akkannapet (M) 18.015914, 79.150554	38548	33359	39536	75553	84548	86347	37006	51189	46811	0.96	1.53	1.18
4	Bhukhya Mahesh	Choutukunta Tanda (V), Akkannapet(M) 18.018946, 79.154915	44725	40772	45714	89944	95341	101637	45219	54570	55924	1.01	1.34	1.22
5	Akkam Swamy	Ghanapur(V),Thoguta (M) 18.052178, 78.748343	51891	46949	53127	133118	133118	148408	81227	86169	95282	1.57	1.84	1.79
6	Mongari Ramesh	Chittapur (V), Akberpet,	51891	44478	53440	140674	147870	146249	88782	103392	92808	1.71	2.32	1.74
7	Rajinikar Reddy	Mantoor (V), Raipole (M) 17.5733, 78.4028	50161	43243	50903	158302	167835	174492	108141	124593	123590	2.16	2.88	2.43
Average			43631	38124	44558	108968	116028	120474	65382	77904	75916	**1.49**	**2.06**	**1.70**

Table 3. Mean Productivity and economics of sunflower under different residue management options

Treatment	Mean Seed yield (kg ha^{-1})	Relative Production Efficiency (%)	Mean Cost of cultivation (Rs ha^{-1})	Mean Gross returns (Rs ha^{-1})	Mean Net returns (Rs ha^{-1})	B:C ratio	Relative Economic Efficiency (%)
Residue burning (Farmers' practice)	1,498	–	43,631	108,968	65,382	1.49	
Zero tillage + residue retention	1,611	7.54	38,124	116,028	77,904	2.06	19.15
Residue incorporation with nutrient adjustments	1,656	10.55	44,558	120,474	75,916	1.70	16.11
SEm±	13.03		376.6	1,273.62	1397.03		
CD(p=0.05)	40.58		1173.31	3967.87	4352.36		

the most profitable treatment (Table 2) by recording the highest net returns (Rs 77,904 ha^{-1}) and benefit–cost ratio (2.06), followed by residue incorporation (Rs 75,916 ha^{-1}; B:C ratio 1.70). The conventional practice of residue burning resulted in the lowest net returns (Rs 65,382 ha^{-1}) and benefit–cost ratio (1.49).

The superior profitability of zero tillage was primarily due to lower cultivation costs achieved by eliminating tillage operations and reducing labour and fuel requirements, while maintaining a yield comparable to residue incorporation. Although residue incorporation involved additional expenditure for residue shredding, incorporation and nutrient supplementation, the higher seed yield partially compensated for these costs. These results indicate that both conservation-based practices are economically superior to residue burning, with zero tillage providing the greatest financial advantage under farmers' field conditions, as evidenced by higher relative production and efficiencies (Table 3).

The present findings are in close agreement with Sridevi *et al.* (2026), who reported that residue mulch under zero tillage produced the highest system productivity, net returns and benefit–cost ratio in a maize–sunflower cropping system due to lower production costs and efficient utilization of crop residues. Likewise, Prasad *et al.* (2024) observed significantly higher profitability under residue incorporation compared with residue burning, emphasizing that residue recycling not only improves crop productivity but also enhances farm income through efficient nutrient utilization.

Several studies have similarly demonstrated the economic benefits of conservation agriculture. Hobbs *et al.* (2008) and Gathala *et al.* (2015) reported that reduced tillage and residue retention substantially decrease production costs while maintaining or increasing crop yields, resulting in improved profitability. These findings reinforce the suitability of conservation residue management as an economically viable option for sustainable sunflower cultivation in rice-fallow ecosystems.

Extension Gap and Technology Validation

The extension gap, which represents the difference in productivity between the demonstrated technology and farmers' practice, was 114 kg ha^{-1} under zero tillage and 158 kg ha^{-1} under residue incorporation. The higher extension gap observed under residue incorporation indicates substantial scope for increasing sunflower productivity through adoption of improved residue management practices.

The observed extension gap reflects the continued adoption of residue burning by many farmers despite its adverse effects on soil health and crop productivity. Burning of rice residues results in considerable losses of plant nutrients and soil organic carbon, while conservation-based residue management enhances nutrient recycling, moisture conservation and biological activity. The yield advantage achieved in the present demonstrations therefore highlights the importance of effective extension programmes for promoting residue recycling technologies among farming communities.

The consistency of yield improvement across all demonstration locations validates the technical feasibility and adaptability of the demonstrated technologies under real farming situations. The close agreement between the present FLD results and earlier experimental findings of Prasad *et al.* (2024) and Sridevi *et al.* (2026) further confirms that the benefits of conservation residue management observed under research station conditions can be successfully translated to farmers' fields.

CONCLUSION

The Front-Line Demonstrations confirmed that conservation-based rice residue management is a viable alternative to residue burning in rice-fallow sunflower. Residue incorporation recorded the highest seed yield (1,656 kg ha^{-1}), while zero tillage with residue retention proved to be the most profitable, with the highest net returns (Rs 77,904 ha^{-1}) and benefit–cost ratio (2.06). Wider adoption of these practices can enhance productivity, profitability and sustainability while reducing the environmental impacts of residue burning.

These findings provide strong scientific evidence for promoting zero tillage and residue incorporation through extension programmes and government-supported conservation agriculture initiatives. The choice of technology may depend on the availability of machinery, labour, and farmers' investment capacity. Where residue incorporation equipment is available, maximum productivity can be achieved, whereas zero tillage offers a practical and cost-effective alternative for large-scale adoption.

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