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Effect of soybean crop residue, tillage and nutrient management on post-harvest soil physico-chemical properties in *rabi* sorghum (*Sorghum bicolor* L.)

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Abstract

Aim: To study the effect of soybean crop residue, tillage and nutrient management on post-harvest soil physico-chemical properties in *rabi* sorghum (*Sorghum bicolor* L.)

Study Design: The study consisted of residue management and tillage practice as one factor which required a bigger plot size and second factor was nutrient management which is to be analyzed precisely. Thus, as one factor (residue management and tillage practices) needs a bigger plot size and the other (nutrient management) required a more precise results with small plot size, suitable design for the study was chosen as split-plot design.

Place and Duration of Study: Agricultural Research Station (ARS), Adilabad during consecutive *rabi* seasons (2024-25 and 2025-26).

Methodology: The study comprised three tillage and residue management practices viz., zero tillage with residue retention, conventional tillage and reduced tillage with residue incorporation in main plots, and three fertility levels (50%, 75% and 100% recommended dose of fertilizers) in sub plots. The treatments were replicated thrice. Soil samples collected after harvest were analyzed for pH, electrical conductivity (EC), organic carbon (OC) and available nitrogen (N), phosphorus (P) and potassium (K). The data were statistically analyzed using analysis of variance for split plot design.

Results: Soil pH and EC were not significantly influenced by tillage and fertility treatments, though slight reduction in pH and marginal increase in EC were observed under reduced tillage and higher fertility levels. Organic carbon content showed a non-significant but consistent increase under reduced tillage (0.37%) and 100% RDF (0.37%). Significantly higher available nitrogen (187.7 kg ha⁻¹) and phosphorus (49.5 kg ha⁻¹) were recorded under reduced tillage, while potassium showed non-significant variation. Among fertility levels, 100% RDF resulted in significantly higher available nitrogen (187.5 kg ha⁻¹), phosphorus (49.3 kg ha⁻¹) and potassium (279.1 kg ha⁻¹). Interaction effects were found to be non-significant for all parameters.

Conclusion: Reduced tillage with soybean residue incorporation along with application of 100% RDF improved soil organic carbon and nutrient availability, thereby sustaining soil fertility under *rabi* sorghum. This combination can be recommended for maintaining soil health and enhancing productivity in rainfed vertisols.

Keywords: Tillage, residue management, nutrient management, sorghum, RDF

1. Introduction

The rapidly increasing global population has created immense pressure on agriculture to produce more food from limited natural resources. By 2050, the world population is expected to cross 9 billion, which will substantially increase the demand for food, feed and nutritional security. However, sustaining higher crop productivity under changing climatic conditions, declining soil fertility and shrinking cultivable land has become a major challenge for modern agriculture. Global food demand is expected to increase considerably in the coming decades, necessitating sustainable approaches for improving agricultural productivity (Mottaleb *et al.*, 2023) [16]. Over the years, intensive farming practices aimed at maximizing production have heavily relied on repeated cultivation of the same crops, excessive tillage and indiscriminate use of chemical fertilizers. Although these practices initially improved crop yields, their continuous adoption has

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adversely affected soil health, reduced factor productivity and increased environmental degradation (Gathala *et al.*, 2020) ^[6].

Monocropping systems, particularly under rainfed conditions, often lead to depletion of soil nutrients and moisture from similar soil layers due to repeated cultivation of crops with comparable rooting patterns. Such systems also encourage the build-up of pests, diseases and weeds, ultimately resulting in declining productivity and poor sustainability of agricultural systems. In addition, intensive tillage disturbs soil structure, accelerates decomposition of soil organic matter and reduces microbial activity, thereby deteriorating important soil physical properties such as aggregation, porosity and water-holding capacity (Nunes *et al.*, 2020) ^[17]. These problems become more severe in dryland regions where soils are already low in organic carbon and moisture availability is uncertain.

Under these circumstances, crop diversification has emerged as an effective approach to improve the sustainability and resilience of farming systems. Inclusion of crops with contrasting growth habits, rooting patterns and nutrient requirements helps in better utilization of soil resources and improves overall system productivity. Diversified cropping systems also help in reducing pest and disease incidence, improving soil fertility and enhancing nutrient cycling. Legume-based cropping systems are particularly important because legumes enrich the soil through biological nitrogen fixation and leave beneficial residual effects for succeeding crops.

Among dryland cereals, sorghum (*Sorghum bicolor* L.) is considered one of the most suitable crops for moisture-stressed environments because of its drought tolerance, deep root system and ability to perform well under low-input conditions. Sorghum is regarded as a climate-resilient crop capable of growing under adverse environmental conditions and is widely cultivated in semi-arid regions (Hossain *et al.*, 2022) ^[9]. It plays an important role in food and fodder security, especially for small and marginal farmers. Its deep-rooted nature enables efficient extraction of moisture and nutrients from deeper soil layers, thereby improving resource-use efficiency under dryland conditions. In recent years, sorghum has gained renewed importance due to its nutritional superiority, gluten-free nature and suitability for climate-smart agriculture (Reddy, 2021) ^[20].

Soybean is an important legume crop widely cultivated in rainfed areas due to its high protein content and ability to fix atmospheric nitrogen. It is often referred to as the “miracle bean” because of its capacity to improve soil fertility through biological nitrogen fixation (Basant, 2021) ^[1]. However, improper management of soybean crop residues, particularly residue burning or removal from the field, leads to significant loss of nutrients and organic matter besides causing environmental pollution. Crop residue burning contributes to nutrient losses and release of greenhouse gases, thereby affecting both soil quality and environmental sustainability (Bhuvaneshwari *et al.*, 2019; Rawat *et al.*, 2025) ^[4, 19]. Recycling soybean residues through incorporation or retention in the soil can improve soil organic carbon, enhance microbial activity and increase nutrient availability for succeeding crops (Behera *et al.*, 2024) ^[2]. Since soybean residues possess a relatively narrow carbon-to-nitrogen ratio, they decompose faster and contribute to better nutrient mineralization and soil fertility improvement (Gezahegn *et al.*, 2016) ^[7].

Tillage and nutrient management practices also greatly influence soil properties and crop performance. Excessive tillage often results in soil compaction, breakdown of aggregates and rapid oxidation of soil organic matter, whereas conservation tillage practices help conserve soil moisture and maintain better soil

structure. Resource Conservation Technologies such as reduced tillage and residue retention have been recognized as sustainable approaches for improving soil health and conserving natural resources (Topa *et al.*, 2025) ^[23]. Likewise, integrated nutrient management involving crop residues along with balanced fertilizer application can improve nutrient-use efficiency and sustain soil productivity over the long term (Meena *et al.*, 2019) ^[13]. The combined effect of residue management, tillage and nutrient application has a strong influence on post-harvest soil physico-chemical properties, particularly in dryland cropping systems.

Although several studies have separately evaluated residue management, tillage and nutrient practices, limited information is available on their combined effect on post-harvest soil physico-chemical properties in *rabi* sorghum under vertisols conditions. Therefore, the present investigation was undertaken to study the effect of soybean crop residue, tillage and nutrient management practices on post-harvest soil physico-chemical properties in *rabi* sorghum grown under rainfed conditions.

2. Materials and Methods

A field experiment was carried out at plot no-23, Agricultural Research Station (ARS), Adilabad, during consecutive *rabi* seasons (2024-25 and 2025-26). The experimental site was geographically located at 19° 39' N latitude, 78° 32' E longitude and an altitude of 268.9 m above mean sea level (MSL). The experimental site lies in the Northern Telangana Agro-Climatic Zone and it is part of tenth agro-climatic zone of India *i.e.*, Southern plateau and hills and categorised as sub-humid with hot summer and cold winter. Experimental soil was clayey in texture, slightly alkaline in reaction with pH of 7.98 and EC of 0.18 dSm⁻¹. The soil was medium in organic carbon (0.45%) and available N (194 kg ha⁻¹), medium in available P₂O₅ (48.6 kg ha⁻¹) and available K₂O (285 kg ha⁻¹). The experiment was laid out in split plot design with three residue management and tillage practices imposed in main plots *viz.*, M₁- Zero tillage (*Kharif* soybean crop stubbles spreading (3 t ha⁻¹) and sprayed with PJTAU decomposer @ 2%), M₂- Conventional tillage (2 ploughings, 1 levelling and removing stubbles) and M₃- Reduced tillage (1 plough, 1 rotavator for residue incorporation @ 3 t ha⁻¹) and three nutrient levels in sub plots *viz.*, S₁: 50% RDF, S₂: 75% RDF and S₃: 100% RDF respectively. The seed was treated with carbendazim 50% WP @ 3 g kg⁻¹ seed. The variety selected was SVT-55 (Sorghum Varietal Trial - 55 also known as Tandur Jonna-55) suitable for *rabi* season. Sowing was done on 15th November, 2024 and 22nd November, 2025 after the harvest of *kharif* soybean by adopting a seed rate of 10 kg ha⁻¹. Half dose of nitrogen was applied as basal at the time of sowing. Nitrogen, phosphorus and potassium were supplied in the form of urea, diammonium phosphate and muriate of potash respectively. The crop was harvested at maturity and seed yield was recorded. Post-harvest, soil samples were collected, processed and analyzed for physico-chemical properties. Soil pH was measured in a 1:2.5 soil-water suspension using a pH meter and electrical conductivity was determined in the same suspension using an electrical conductivity (EC) meter. Organic carbon (OC) was determined by following Walkley and Black wet digestion method [Walkley and Black (1934)] ^[24]. Available soil nitrogen (N) was estimated by 2 M KCl extraction with continuous flow analyzer at 560 nm [Subbiah and Asija (1956)] ^[22]. Available phosphorus was extracted by 0.5 M Na HCO₃ as per the procedure of Olsens method [Olsen *et al.* (1954)] ^[18]. Available potassium in soil samples was determined by using neutral normal ammonium acetate method using ICP-OES

[Jackson (1973)]^[11]. Data was subjected to analysis of variance procedures as outlined for split plot design [Gomez and Gomez, 1984]^[8]. Statistically significance was tested by F-value at $p=0.05$ (5%) level of probability and critical difference was worked out where ever the effect was significant. Treatment differences that were non-significant were denoted as NS.

3. Results and Discussion

3.1. Soil pH, Electrical Conductivity (EC) (dS m^{-1}) and Organic Carbon (%) of post-harvest soil

The data pertaining to soil pH, electrical conductivity (EC) and organic carbon status of post-harvest soil as influenced by soybean crop residue, tillage and nutrient management practices in sorghum are presented in Table 1.

Among the residue and tillage management practices, soil pH of post-harvest soil was not significantly influenced during both the years of study. However, numerically higher soil pH was recorded under zero tillage (M_1), with values of 8.22 and 8.20 during 2024–25 and 2025–26, respectively, with a mean of 8.21. This was followed by conventional tillage (M_2) (8.20 and 8.19; mean 8.20) and reduced tillage (M_3) (8.19 and 8.18; mean 8.19). The slight reduction in pH under reduced tillage might be attributed to the production of organic acids during decomposition of soybean residues and increased microbial activity, although the effect was statistically non-significant.

Electrical conductivity of post-harvest soil also did not differ significantly due to tillage practices. The EC values ranged narrowly between 0.218 and 0.219 dS m^{-1} , with slightly higher values under conventional tillage (M_2) and reduced tillage (M_3) compared to zero tillage (M_1). The marginal increase in EC under these treatments might be due to release of soluble salts during residue decomposition and fertilizer application; however, the values remained within safe limits.

Organic carbon content of post-harvest soil showed a non-significant but consistent increasing trend under different tillage practices. Reduced tillage (M_3) recorded higher organic carbon content of 0.38 and 0.37% during 2024–25 and 2025–26, respectively, with a mean of 0.37%, followed by conventional tillage (M_2) (0.37 and 0.36%; mean 0.36%) and zero tillage (M_1) (0.35 and 0.34%; mean 0.35%).

The slight improvement in organic carbon under reduced tillage may be attributed to better incorporation and decomposition of crop residues, leading to enhanced carbon accumulation in soil. Similar findings were reported by Mithra *et al.* (2022)^[14], who observed higher organic carbon under reduced tillage compared to conventional tillage. Mondal *et al.* (2013)^[15] also reported higher total organic carbon under conservation tillage systems. Further, Mabasa *et al.* (2025)^[12] and Zulu *et al.* (2022)^[25] documented increased soil organic carbon under no-till or reduced tillage due to reduced soil disturbance and improved residue retention. Among the fertility levels, soil pH, EC and organic carbon of post-harvest soil were not significantly influenced during both years of experimentation. However, numerical variations were observed.

Soil pH was slightly higher under 50% RDF (S_1), recording 8.24 and 8.22 during 2024–25 and 2025–26, respectively, with a mean of 8.23, whereas lower values were observed under 75% RDF (S_2) (8.20 and 8.19; mean 8.19) and 100% RDF (S_3) (8.22 and 8.19; mean 8.20). The marginal decrease in pH at higher fertility levels might be due to acidifying effects of applied fertilizers.

Electrical conductivity increased slightly with increase in fertility levels. The highest EC was observed under 100% RDF (S_3) (0.219 and 0.222 dS m^{-1} ; mean 0.220 dS m^{-1}), followed by

50% RDF (S_1) (0.216 dS m^{-1}) and 75% RDF (S_2) (0.215 dS m^{-1}), though differences were non-significant.

Organic carbon content increased with increasing fertility levels, with the highest values under 100% RDF (S_3) (0.37 and 0.36%; mean 0.37%) followed by 75% RDF (S_2) (0.35 and 0.34%; mean 0.34%) and lowest under 50% RDF (S_1) (0.33 and 0.32%; mean 0.32%). The increase in organic carbon with higher fertility levels might be due to increased biomass production and subsequent addition of crop residues to the soil. These results are in agreement with Dixit *et al.* (2015)^[5], who reported higher organic carbon and improved soil properties with increased nutrient application. The slight increase in EC with higher RDF levels is also supported by findings of Indoria *et al.* (2025)^[10], who observed enhanced nutrient availability and ionic concentration with increased fertilizer inputs.

The interaction effects between residue management and fertility levels ($M \times S$ and $S \times M$) were found to be non-significant for soil pH, EC and organic carbon during both years of study, indicating that tillage and nutrient management practices exerted independent effects on these soil properties.

Compared to the initial soil values (pH: 8.31, EC: 0.190 dS m^{-1} and OC: 0.37%), post-harvest soil showed slight reduction in pH and marginal increase in EC, while organic carbon was maintained or slightly improved under reduced tillage and higher fertility levels.

3.2. Available nitrogen, phosphorus and potassium in post-harvest soil

The data pertaining to available nitrogen, phosphorus and potassium status of post-harvest soil as influenced by soybean crop residue, tillage and nutrient management practices in rabi sorghum are presented in Table 1.

Among the residue and tillage management practices, significantly higher available nitrogen content in post-harvest soil was recorded under reduced tillage (M_3) during both the years of study. The available nitrogen under reduced tillage was 177.8 and 197.7 kg ha^{-1} during 2024–25 and 2025–26, respectively, with a mean value of 187.7 kg ha^{-1} . This treatment was found to be statistically superior to zero tillage (M_1), which recorded the lowest available nitrogen content of 162.0 and 161.3 kg ha^{-1} during the respective years. Conventional tillage (M_2) remained intermediate between the two treatments.

The improvement in available nitrogen under reduced tillage might be attributed to better decomposition of soybean residues, enhanced microbial activity and gradual mineralization of nutrients under favorable soil conditions. Reduced soil disturbance in combination with residue retention possibly created a conducive environment for microbial proliferation and nitrogen transformation processes.

Similarly, available phosphorus in post-harvest soil was significantly influenced by residue and tillage practices. Reduced tillage (M_3) recorded significantly higher available phosphorus content of 49.3 and 49.7 kg ha^{-1} during 2024–25 and 2025–26, respectively, with a mean value of 49.5 kg ha^{-1} , which was on par with conventional tillage (M_2) and superior to zero tillage (M_1). Increased phosphorus availability under reduced tillage could be due to enhanced organic matter addition through residue retention, leading to the release of organic acids that improve solubilization of native soil phosphorus.

Available potassium content in post-harvest soil was numerically higher under reduced tillage (272.3 and 277.2 kg ha^{-1}) followed by conventional tillage. However, the differences among tillage treatments were found to be non-significant during both the years of study.

The present findings are in close agreement with the results of Mithra *et al.* (2022) ^[14], who reported higher post-harvest available N, P and K under reduced tillage compared to conventional tillage in castor-based systems. Similarly, long-term studies by Sharma *et al.* (2016) ^[21] at CRIDA indicated that conservation tillage practices improved soil organic carbon and available nitrogen and phosphorus. The enhanced nutrient availability under reduced tillage was also supported by Indoria *et al.* (2025) ^[10], who observed substantial increases in available N, P and K with residue retention due to improved nutrient cycling and microbial activity. Further, Bharambe *et al.* (2002) ^[3] reported that residue incorporation significantly increased soil organic carbon and available nutrients, which corroborates the present findings.

Among the fertility levels, application of 100% RDF (S_3) recorded significantly higher available nitrogen, phosphorus and potassium contents in post-harvest soil compared to lower fertility levels during both years. The highest available nitrogen under S_3 was 178.8 and 196.1 kg ha⁻¹ during 2024–25 and 2025–26, respectively, with a mean value of 187.5 kg ha⁻¹. Likewise, available phosphorus under S_3 was 49.0 and 49.6 kg ha⁻¹, while available potassium was 277.6 and 280.7 kg ha⁻¹ during the respective years.

The increase in available nutrient status with higher fertility level might be due to greater nutrient addition through fertilizers coupled with improved nutrient retention and reduced depletion from soil reserves. Higher fertilizer application might have also

enhanced crop biomass production, leading to greater residue return and subsequent nutrient recycling.

Lower values of available nitrogen, phosphorus and potassium were recorded with 50% RDF (S_1) during both years of experimentation.

These results are in conformity with the findings of Indoria *et al.* (2025) ^[10], who reported significant increases in available soil nutrients with higher nutrient inputs due to improved nutrient recycling and soil biological activity. The results also agree with Dixit *et al.* (2015) ^[5], who observed higher organic carbon and available nutrients with integrated and higher nutrient application, attributing it to improved nutrient retention and reduced losses. Increased nutrient availability with higher RDF levels may also be due to reduced nutrient mining and better maintenance of soil fertility status.

The interaction effects between residue management and fertility levels ($M \times S$ and $S \times M$) were found to be non-significant for available nitrogen, phosphorus and potassium content of post-harvest soil during both years, indicating independent influence of tillage and nutrient management practices on soil nutrient status.

Compared to the initial soil nutrient status (194.0 kg N, 48.6 kg P and 285.0 kg K ha⁻¹), variations in post-harvest available nutrient contents indicated that residue retention under reduced tillage along with balanced nutrient application helped in maintaining better soil fertility after harvest of *rabi* sorghum.

Table 1: Effect of soybean crop residue, tillage and nutrient management on Soil pH, EC (dS m⁻¹) and OC (%)

Treatments	pH			EC (dS m ⁻¹)			OC (%)		
	2024-2025	2025-2026	Mean	2024-2025	2025-2026	Mean	2024-2025	2025-2026	Mean
Main plot-Residue management & tillage(M)									
M1- Zero tillage	8.22	8.20	8.21	0.216	0.219	0.218	0.35	0.34	0.35
M2- Conventional tillage	8.20	8.19	8.20	0.217	0.220	0.219	0.37	0.36	0.36
M3- Reduced tillage	8.19	8.18	8.19	0.218	0.220	0.219	0.38	0.37	0.37
S.E.m±	0.07	0.05	0.03	0.001	0.001	0.002	0.01	0.01	0.01
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub plot-Fertility levels(S)									
S1-50% RDF	8.24	8.22	8.23	0.213	0.218	0.216	0.33	0.32	0.32
S2-75% RDF	8.20	8.19	8.19	0.214	0.216	0.215	0.35	0.34	0.34
S3-100% RDF	8.22	8.19	8.20	0.219	0.222	0.220	0.37	0.36	0.37
S.E.m±	0.10	0.08	0.06	0.003	0.003	0.003	0.02	0.02	0.02
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (M x S)									
S.E.m±	0.20	0.15	0.11	0.01	0.01	0.01	0.04	0.03	0.03
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (S x M)									
S.E.m±	0.20	0.16	0.11	0.01	0.01	0.01	0.04	0.03	0.04
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial	8.31			0.190			0.37		

Table 2: Effect of soybean crop residue, tillage and nutrient management on available N, P₂O₅ and K₂O of post-harvest soil

Treatments	Available N (kg ha ⁻¹)			Available P (kg ha ⁻¹)			Available K (kg ha ⁻¹)		
	2024-2025	2025-2026	Mean	2024-2025	2025-2026	Mean	2024-2025	2025-2026	Mean
Main plot-Residue management & tillage(M)									
M1- Zero tillage	162.0	161.3	169.2	44.9	45.0	44.9	259.8	257.3	258.6
M2- Conventional tillage	174.1	193.1	183.2	48.2	48.6	48.4	265.5	271.5	268.6
M3- Reduced tillage	177.8	197.7	187.3	49.3	49.7	49.5	272.3	277.2	274.7
S.E.m±	3.0	4.2	2.23	0.8	0.9	0.84	9.9	7.8	8.77
CD (p=0.05)	11.9	17.0	8.99	3.3	3.6	3.4	NS	NS	NS
Sub plot-Fertility levels(S)									
S1-50% RDF	165.8	174.9	173.0	46.4	46.6	46.5	257.9	260.1	259.0
S2-75% RDF	169.3	181.1	176.7	46.9	47.0	47.0	262.1	265.2	263.7
S3-100% RDF	178.8	196.1	190.0	49.0	49.6	49.3	277.6	280.7	279.1
S.E.m±	2.8	5.5	3.82	0.6	0.8	0.60	4.7	3.9	4.29
C.D. (P=0.05)	8.7	17.0	11.9	2.0	2.5	1.87	14.8	12.1	13.4

Interaction (M x S)									
S.Em±	5.1	7.29	3.86	1.4	1.56	1.45	17.1	13.53	15.2
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction (S x M)									
S.Em±	5.0	8.81	5.9	1.2	1.45	1.19	11.9	9.54	10.7
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Initial	194.0			48.6			285.0		

Conclusion

The present investigation clearly demonstrated that residue retention combined with reduced tillage and balanced nutrient management plays a crucial role in sustaining soil health and fertility under rabi sorghum. Although soil pH and electrical conductivity were not significantly influenced by tillage or fertility levels, a slight stabilizing trend under reduced tillage indicates improved soil buffering capacity. Organic carbon content showed a gradual improvement under reduced tillage and higher fertility levels, reflecting enhanced residue decomposition and organic matter buildup. Similarly, available nitrogen and phosphorus were significantly higher under reduced tillage and 100% RDF, while potassium remained statistically unaffected but showed a positive numerical trend. The non-significant interaction effects suggest that tillage and fertility practices independently contributed to soil property improvement. Overall, the findings highlight that adoption of reduced tillage along with adequate fertilizer application and residue management is an effective strategy for maintaining soil fertility, improving nutrient availability and ensuring long-term sustainability of sorghum-based cropping systems.

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