Effect of Tillage Practices and Microbial Consortia on Growth and Yield of Rainfed Sorghum (*Sorghum bicolor* L.)

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ABSTRACT

Background: Sorghum is a flexible cereal crop that can grow in a variety of climates. It is commonly used for food, fodder and bioenergy in tropical and semi-arid areas. A field experiment was conducted at the Agriculture Research Farm of Lovely Professional University during the 2024-2025 *Kharif* season to evaluate the combined effects of tillage practices and microbial consortia applications on the growth and yield of a rainfed sorghum.

Methods: The split-plot design included three tillage methods-zero tillage, minimum tillage and conventional tillage-as main plots, with four microbial consortia treatments as subplots: (i) seed treatment (30 g kg^{-1} seed), (ii) soil application (2.5 kg of consortia 50 kg^{-1} FYM), (iii) a combination of seed treatment (30 g kg^{-1} seed) and soil application (2.5 kg of consortia 50 kg^{-1} FYM) and (iv) no consortia (control).

Result: Growth parameters recorded included plant height (238.19 cm), plant dry weight (117.02 g) and plant population (15.56 plants m^{-2}). Yield attributes assessed were length of ear head (22.17 cm), number of grains per head (938.72), test weight (30.16 g), seed yield (3160.31 kg ha^{-1}), stover yield (6825.50 kg ha^{-1}) and harvest index (31.64%). The highest results for most parameters were observed with conventional tillage combined with seed treatment and soil application, indicating improved soil microbial activity, nutrient availability and overall crop performance under rainfed conditions. These results highlight the potential benefits of combining microbial consortia with appropriate tillage practices to increase productivity, sustain soil health and promote the long-term resilience of cereal-pulse cropping systems in semi-arid regions.

Key words: Microbial consortia, Seed treatment, Soil application, Soil health, Sorghum, Tillage.

INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is a hardy cereal that has been grown in semi-arid and arid agroecosystems worldwide. At present, sorghum is the fifth most important cereal in terms of global production, with 60 million tonnes produced annually, largely contributed by Africa, Asia and some parts of the Americas (FAO, 2022). In India, sorghum has traditionally been included in rainfed agriculture as a native, important food security and animal feed crop for smallholder farming systems (Reddy *et al*., 2023). Because of its remarkable drought and high-temperature tolerance and capacity for growth in marginal soils, sorghum is a vital crop in regions facing climate challenges and resource constraints. Additionally, aside from its resilience, sorghum is valued for its nutritional benefits as a source of energy, dietary fibre and micronutrients for rural populations in resource-limited settings (Tshering *et al*., 2023).

Tillage is very important for managing soil structure, residue management, nutrient availability and weed control. Conventional tillage usually involves full inversion of soil, which can enhance early root establishment but accelerates organic matter breakdown and increases the potential for soil erosion (Kumar *et al*., 2025) and (Foster *et al*., 2018). Reduced tillage or minimum tillage disturbs the soil to a lesser extent, which has the benefit of lowering the costs of cultivation and preserving soil structure (Kassar *et al*., 2020) and (Masaka *et al*., 2020). Alternatively, zero tillage leaves residues on the soil surface, conserving soil organic carbon, reducing evaporation loss and enhancing water infiltration rates (Jat *et al*., 2020). Microbial consortia application is another effective method of increasing sustainability in cereal-pulse rotations. Microbial consortia products are usually applied in soil or seed treatments (Kumar *et al*., 2021) and (Kaur *et al*., 2018). These consortia usually include synergistic strains of plant growth-stimulating rhizobacteria, nitrogen-fixing microorganisms, phosphate-solubilizing bacteria and supplemental beneficial microorganisms. Unlike single-strain inoculants, microbial consortia provide simultaneous multiple benefits with improved nutrient uptake, disease suppression from soil-borne pathogens, root growth stimulation and greater resistance to abiotic stresses (Ibarra-Villarreal *et al*., 2023).

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Application methods include coating seeds and drenching soil, resulting in rapid colonisation of the rhizosphere; they offer more consistent benefits under field conditions (Cano *et al*., 2025). In semi-arid cropping systems, where external inputs are limited by cost, these microbial technologies provide a low-cost, environmentally sustainable means to enhance productivity. To date, while the benefits of improved tillage and microbial consortia have been established in different cropping systems, no studies have evaluated the joint influence of these factors in sorghum within rainfed semi-arid cropping systems. This study aims to fill this gap by assessing the impacts of conventional tillage, minimum tillage and zero tillage in combination with microbial consortia as seed treatment and in-soil applied, on the performance of sorghum rotation under rainfed semi-arid conditions. This study is to provide site-specific recommen-dations to improve sustainable productivity and soil health for dryland systems, which may also be applicable to other regions with similar agro-ecological conditions. Under this research, it was tried to (i) Assess the influence of various tillage practices on the growth and yield attributes of sorghum and (ii) the combined effects of tillage practices and microbial consortia on sorghum performance, so that the production technology improved accordingly.

MATERIALS AND METHODS

The field experiment was carried out during the *Kharif* season of 2024-2025 at the research farm of Lovely Professional University, located in Phagwara, Punjab, India (31°14′43″N, 75°42′00″E; 252 m above mean sea level). The site for this study is located in the central plain zone of Punjab, in a subtropical climate with hot summers, cold winters and a distinct monsoon rainy season, with an average annual rainfall of some 711 mm. The soil in the test area was sandy loam in texture.

Design and layout

The field experiment was conducted using a split-plot design with three replications. The main plots consisted of three tillage practices: Zero tillage, Minimum tillage, Conventional tillage and under the sub-plots included four microbial consortia application methods: Seed treatment (30 g kg^{-1} seed), Soil application (2.5 kg consortia 50 kg^{-1} FYM), Seed treatment (30 g kg^{-1} seed) + Soil application (2.5 kg consortia 50 kg^{-1} FYM) and No consortia (Control).

Description of microbial consortia

A commercial lyophilized biofertilizer formulation (Katyayani NPK Microbial Consortia, Katyayani Organics Private Limited, India) was used in this experiment. The product consisted of a mixture of beneficial microorganisms responsible for nitrogen fixation, phosphate solubilization and potash mobilization, along with zinc- and silica-solubilizing bacterial strains. The active microbial components included Azotobacter/ Azospirillum (1×10^9 CFU g^{-1}), phosphate-solubilizing bacteria (1×10^9 CFU g^{-1}), potash-mobilizing bacteria (1×10^9 CFU g^{-1}) and silica-solubilizing bacteria (2×10^7 CFU g^{-1}), maintaining a total viable count of at least (1×10^9 CFU g^{-1}). The consortia was applied according to the experimental treatments, either as a seed treatment at 30 g kg^{-1} seed or through soil application at 2.5 kg mixed with 50 kg FYM ha^{-1}.

This arrangement led to a total of twelve treatment combinations (three tillage practices × four consortia methods). Sorghum variety CSV-41 was sown and each plot was sized at 5.0 m × 4.5 m, with a row spacing of 45 cm and a plant spacing of 15 cm to ensure an optimal crop stand. Sorghum (*Sorghum bicolor* L.) was grown completely rainfed with no irrigation. Weeds, pests and diseases were managed with recommended agronomic practices. Data on crop growth parameters, including plant height, plant population and dry weight, were recorded at 30, 60, 90 and 120 days after sowing (DAS). At harvest, observations were taken on yield attributes such as length of ear head, number of grains per head, test weight, seed yield, stover yield and harvest index. Measurements were obtained from five randomly selected plants in each plot to ensure accurate representation. Grain and stover yields were calculated on a per-hectare basis. After maturity, sorghum was harvested manually and the straw was chopped and put back into the same plots as per treatments. Soil samples were collected before sowing and after harvest to assess changes in soil properties and microbial activity using standard analytical procedures.

Statistical analysis

Data on crop growth, yield parameters were recorded sorghum crop. The data were analysed utilizing CVSTAT software and treatment means were compared through the Least Significant Difference (LSD) test at a 5% probability level. The coefficient of variation (CV) was calculated to evaluate the reliability and precision of the experiment.

RESULTS AND DISCUSSION

Growth parameters

Plant height (cm)

The plant height was significantly influenced by tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 1). The maximum plants height was recorded under conventional tillage (236.97 cm) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (238.19 cm), while the lowest plant height (201.00 cm) was observed in the control treatment. The significantly greater plant height under these treatments may be attributed to enhanced root development, improved nutrient availability and even increased microbial activity in the rhizosphere, which collectively promote cell elongation and prolonged vegetative growth. Conventional tillage improves soil aeration and loosens the soil structure, facilitating better root growth and nutrient uptake, which ultimately supports greater vegetative growth and plant

height. The significant interaction between tillage and microbial consortia in the present study (Table 2) may have enhanced root proliferation and nutrient uptake. Similar responses in plant height have been achieved by a combination of bio-inoculants applied with organic amendments in cereals. Similarly, synergistic responses of microbial consortia and integrated nutrient management systems have been recorded in cereals (Kavya *et al*., 2020).

Dry weight (g plant^{-1})

The dry weight was significantly influenced by tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 1). The maximum dry weight was recorded under conventional tillage (116.96 g plant^{-1}) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (117.02 g plant^{-1}), while the lowest dry weight (98.94 g plant^{-1}) was observed in the control treatment. This improvement in dry weight may be attributed to the treatment's likely provided better nutrient mineralization, rooting and photosynthetic rates which all led to better biomass accumulation compared to control plots. The present study is consistent with the results of (Kakde *et al*., 2020), which revealed that microbial inoculants used in combination with organic amendments enhanced dry matter accumulation in cereals via improved nutrient uptake. Furthermore, Conventional tillage also improves soil aeration and faster nutrient availability, which promotes higher biomass production, as well. The significant interaction between tillage and microbial consortia in the present study (Table 3) may have enhanced root activity and nutrient uptake, resulting in high dry matter production. Similarly, (Memon *et al*., 2013) and (Yadav *et al.,* 2025) showed that active responses in biomass production followed integrated nutrient management and biofertilizer application in both pulse and cereal crops.

Plant population (plants m^{-1})

The plant population was significantly influenced by tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 1). The maximum plant population was recorded under conventional tillage (15.00 plants m^{-2}) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (15.56 plants m^{-2}), while the lowest plant population (11.11 plants m^{-2}) was observed in the control treatment. The significant interaction between tillage and microbial consortia in the present study (Table 4) may have enhanced initial root development, stimulated rooting hormone production and improved nutrient availability, result in better crop establishment (Kakde *et al*., 2020). Furthermore, conventional tillage enhances soil structure

Table 1: Effect of tillage practices and microbial consortia on growth attributes of rainfed sorghum.

Treatment details	Plant height (cm)	Plant dry weight (g plant^{-1})	Plant population (plants m^{-2})
Tillage (Main plot) zero tillage	212.99	101.85	12.75
Minimum tillage	225.89	108.93	13.17
Conventional tillage	236.97	116.96	15.00
SE (m) ±	0.96	0.06	0.38
C.D. at 5%	3.77	0.23	1.48
Microbial consortia (Sub plot)	230.18	109.28	14.11
Seed treatment consortia (30 g kg^{-1} seed)			
Soil application of consortia (2.5 kg consortia 50 kg^{-1} FYM)	231.77	111.74	13.78
Seed treatment (30 g kg^{-1} seed) + soil application (2.5 kg consortia 50 kg^{-1} FYM)	238.19	117.02	15.56
No consortia (Control)	201.00	98.94	11.11
SE (m)±	0.69	0.25	0.43
C.D. at 5%	2.04	0.75	1.29
Interaction (A*B) F-test (0.05)	S	S	S

Table 2: Interaction effect on plant height (cm) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	221.63	224.11	225.59	180.62
M2	230.35	231.68	234.72	206.82
M3	238.56	239.52	254.25	215.55
SE(m)±	1.19			
C.D. at 5%	3.53			
Interaction (A*B) F-test (0.05)	S.			

and aeration, thereby creating a favourable environment for seedling emergence and root penetration, which further promotes a higher plant density (Yadav *et al*., 2009).

Yield parameters

Length of the ear head (cm)

The length of the ear heads was significantly affected by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 5). The maximum length of the ear heads was recorded under conventional tillage (21.89 cm) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (22.17 cm), while the lowest length of the ear heads (18.21 cm) was observed in the control treatment. The increase was likely attributed to a higher availability of nutrients, which potentially stimulated root activity and assimilate partitioning processes, both of which encouraged the spike elongation. The increased photosynthetic efficiency and consequently better translocation of nutrients to the elongating spikes were also likely factors in the improved yields (Kavya *et al*., 2020). The significant interaction between tillage and microbial consortia in the present study (Table 6) resulted in an important adjunct to improve soil microbial activity, aeration and therefore nutrient cycling, root growth and development of ear head elongation and grain yield.

Table 3: Interaction effect on plant dry weight (g $plant^{-1}$) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	101.44	102.86	105.59	97.52
M2	108.86	111.44	116.92	98.48
M3	117.55	120.92	128.56	100.81
SE (m) ±	0.43			
C.D. at 5%	1.29			
Interaction (A*B) F-test (0.05)	S			

Table 4: Interaction effect on plant population (plants m^{-2}) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	13.00	12.67	14.00	11.33
M2	13.67	12.67	14.33	12.00
M3	15.67	16.00	18.33	10.00
SE (m) ±	0.75			
C.D. at 5%	2.23			
Interaction (A*B) F-test (0.05)	S			

Table 5: Effect of tillage practices and microbial consortia on yield attributes of rainfed sorghum.

Treatment details	Length of the ear head (cm)	Number of grains per head	Test weight (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
Tillage (Main plot) zero tillage	19.71	804.37	27.28	2726.93	6405.06	29.70
Minimum tillage	20.81	867.99	28.74	2933.94	6612.31	30.64
Conventional tillage	21.89	926.77	30.00	3105.68	6824.81	31.22
SE (m) ±	0.09	1.85	0.11	4.24	5.18	0.03
C.D. at 5%	0.34	7.26	0.44	16.65	20.33	0.13
Microbial consortia (Sub plot)						
Seed treatment consortia (30 g kg^{-1} seed)	21.14	883.49	28.95	3050.39	6677.83	31.35
Soil application of consortia (2.5 kg consortia 50 kg^{-1} FYM)	21.71	911.92	29.26	3107.70	6780.33	31.42
Seed treatment (30 g kg^{-1} seed) + soil application (2.5 kg consortia 50 kg^{-1} FYM)	22.17	938.72	30.16	3160.31	6825.50	31.64
No consortia (Control)	18.21	731.37	26.32	2370.33	6172.58	27.67
SE (m) ±	0.09	3.32	0.10	9.77	12.50	0.10
C.D. at 5%	0.26	9.85	0.29	29.03	37.15	0.30
Interaction (A*B) F-test (0.05)	S	S	S	S	S	S

Number of grains per head

The number of grains per head was significantly affected by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 2). The maximum number of grains per head was recorded under conventional tillage (926.77) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (938.72), while the lowest number of grains per head (731.37) was observed in the control treatment. The increase in yield and number of grains of the combined treatment can be attributed to improved nutrient uptake related to microbial consortia. The significant interaction between tillage and microbial consortia in the present study (Table 7) may have improved microbial activity and the overall health of the rooting zone plant, which promotes more productive tillers and ultimately partitions more assimilates to grain development (Negi *et al.,* 2022). Conventional tillage is similar, as it encourages soil aeration and root proliferation, improving the availability of nutrients and water for reproductive growth.

Test weight (g)

The test weight was significantly affected by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 2). Test weight is an important measure of grain quality and reflects the density and quality of the grains. The maximum test weight was recorded under conventional tillage (30.00 g) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (30.16 g), while the lowest test weight (26.32 g) was observed in the control treatment. The significant interaction between tillage and microbial consortia in the present study (Table 8) may have improved soil tilth for allowing better root growth, nutrient uptake and support grain filling, which together contributed the grain test weight observed. The microbial consortia improves the amount of microbes in the soil to increase nutrient mineralization to improve nutrient availability for good growth of bold well well-filled grains. The soil tilth from conventional tillage practices increased soil aeration and loosening, which increased prolific roots and nutrient uptake and overall improved grain test weight. Whereas the control plot had reduced test weight due to poor physical conditions of the soil, low nutrients and resulting small, shrivelled or partially filled grains. The synergistic effects of microbial inoculation and conventional tillage are very important in developing quality grain products and yield improvement (Tshering *et al.,* 2023).

Table 6: Interaction effect on length of the ear head (cm) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	20.06	20.85	21.11	16.81
M2	21.28	21.55	21.87	18.55
M3	22.07	22.72	23.51	19.25
SE (m) ±	0.15			
C.D. at 5%	0.46			
Interaction (A*B) F-test (0.05)	S			

Table 7: Interaction effect on number of grains per head of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	806.87	845.07	863.77	701.77
M2	891.83	920.33	946.13	713.67
M3	951.77	970.37	1006.27	778.67
SE(m) ±	5.74			
C.D. at 5%	17.07			
Interaction (A*B) F-test (0.05)	S			

Table 8: Interaction effect on test weight (g) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	28.22	28.49	28.60	23.81
M2	29.04	29.13	29.37	27.44
M3	29.59	30.17	32.52	27.71
SE (m) ±	0.17			
C.D. at 5%	0.51			
Interaction (A*B) F-test (0.05)	S			

Seed yield (kg ha^{-1})

The seed yield was significantly influenced by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 2). The highest seed yield was recorded under conventional tillage (3105.68 kg ha^{-1}) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) combined with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (3160.31 kg ha^{-1}). The lowest seed yield (2370.33 kg ha^{-1}) was observed in the control treatment. These enhanced yields were directly linked to improved physical soil conditions and increased nutrient availability, supporting root development and grain filling. The superior yields from the integrated seed treatment and soil application are due to microbial activity that enhances nutrient mineralization and availability, supporting better root growth and grain filling. Microbial consortia contributed to nutrient mobilization through microbial exudates, which promote plant growth and improve soil biological health to boost nutrient uptake efficiency (Kavya *et al*. 2020). The significant interaction between tillage and microbial consortia in this study (Table 9) likely improved soil structure and aeration, which in turn enhanced root proliferation and nutrient uptake, ultimately increasing productivity. The lower yields in the control plot may have resulted from poor soil physical conditions and limited nutrients affecting crop development (Ibarra-Villarreal *et al*., 2023).

Stover yield (kg ha^{-1})

The stover yield was significantly affected by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 2). The maximum stover yield was recorded under conventional tillage (6824.81 kg ha^{-1}) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) in conjunction with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (6825.50 kg ha^{-1}), while the lowest stover yield (6172.58 kg ha^{-1}) was observed in the control treatment. The significant interaction between tillage and microbial consortia in the present study (Table 10) may be largely associated with the synergistic benefits of the microbial consortia, which increase soil microbial activity and nutrient cycling and root development, resulting in yield increases through increased biomass accumulation and productivity. In sorghum seed and soil inoculation of microbes increases fixation and available nutrients, while the benefits of tillage include improved aeration and root

Table 9: Interaction effect on seed yield (kg ha^{-1}) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	2858.72	2968.92	3037.37	2042.69
M2	3097.04	3103.99	3109.44	2425.29
M3	3195.41	3250.18	3334.12	2643.00
SE (m) ±	16.92			
C.D. at 5%	50.28			
Interaction (A*B) F-test (0.05)	S			

Table 10: Interaction effect on stover yield (kg ha^{-1}) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	6396.08	6562.39	6559.53	6102.22
M2	6677.55	6767.48	6886.55	6117.66
M3	6959.86	7011.12	7030.42	6297.87
SE (m) ±	21.66			
C.D. at 5%	64.34			
Interaction (A*B) F-test (0.05)	S			

Table 11: Interaction effect on harvest index (%) of sorghum.

Tillage (Main plot) \ Microbial consortia (Sub plot)	S1	S2	S3	S4
M1	30.90	31.15	31.65	25.08
M2	31.67	31.43	31.10	28.38
M3	31.48	31.67	32.16	29.56
SE (m) ±	0.18			
C.D. at 5%	0.52			
Interaction (A*B) F-test (0.05)	S			

proliferation, collectively contributing to increased stover yield. The stover yield increases support the results presented by Cano *et al.* (2025) and Kumar and Pareek, (2022).

Harvest index (%)

The harvest index was significantly affected by the tillage methods in the main plots and the microbial consortia treatments in the subplots (Table 2). The maximum harvest index was recorded under conventional tillage (31.22%) in the main plot and with the application of microbial consortia seed treatment (30 g kg^{-1} seed) combined with a soil application (2.5 kg enriched in 50 kg FYM) in the subplot, reaching (31.64%). In contrast, the lowest harvest index (27.67%) was observed in the control treatment. The increased harvest index seen in the integrated microbial consortia treatment can be attributed to improved nutrient uptake and more effective partitioning of assimilates to grain formation, supported by enhanced microbial activity and better soil health (Negi *et al*., 2022). The significant interaction between tillage and microbial consortia in this study (Table 11) may be due to microbial inoculants boosting root growth and increasing biological nitrogen fixation, thereby improving crop physiological efficiency and biomass partitioning. Conventional tillage improved soil conditions and root growth, allowing for more efficient water and nutrient absorption, which resulted in higher grain yield relative to total biomass (Khan *et al.,* 2022).

CONCLUSION

The present study shows that combining traditional tillage with microbial consortia treatments applied as seed and soil amendments can significantly boost the productivity and yield of rainfed sorghum. Traditional tillage improves soil physical properties, such as aeration and rooting, which enhances nutrient and water uptake. Using microbial consortia treatments alongside farmyard manure (FYM) increases microbial activity and populations in the soil, promotes nutrient cycling and supports biological nitrogen fixation. These effects lead to better plant growth, higher grain and stover yields and improved grain quality traits like test weight and grain count per head. Overall, this integrated approach markedly enhances crop establishment, biomass production and reproductive development under rainfed conditions. Therefore, combining effective tillage methods with microbial inoculation offers a sustainable and efficient strategy for increasing sorghum yield, improving soil health and optimizing resource use in rainfed agroeco systems. Future research should explore how these integrated practices influence soil microbial diversity and system resilience in the face of changing climate conditions.

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Conflict of interest

The authors declare no conflict of interest regarding the publication of this paper.

REFERENCES

Cano, R.D.J., Daniels, J.M., Carlin, M. and Huber, D. (2025). Enhancing soil health and corn productivity with a co-fermented microbial inoculant (CFMI-8). A field-based evaluation. *Microorganisms*. **13(7):** 1638.

FAO. (2022). FAOSTAT statistical database. Food and Agriculture Organization of the United Nations.

Foster, J.L., Bean, M.E., Morgan, C., Morgan, G., Mohtar, R., Landivar, J. and Young, M. (2018). Comparison of two tillage practices in a semi arid cotton-grain sorghum rotation. *Agronomy Journal*. **110(4):** 1572-1579.

Ibarra-Villarreal, A.L., Villarreal-Delgado, M.F., Parra-Cota, F.I., Yepez, E.A., Guzmán, C., Gutierrez-Coronado, M.A. and Santos-Villalobos, S.D.L. (2023). Effect of a native bacterial consortia on growth, yield and grain quality of durum wheat [*Triticum turgidum* (L.) subsp. durum] under different nitrogen rates in the Yaqui Valley, Mexico. *Plant Signaling and Behavior.* **18(1):** 2219837.

Jat, M.L., Chakraborty, D., Ladha, J.K., Rana, D.S., Gathala, M.K., McDonald, A. and Gerard, B. (2020). Conservation agriculture for sustainable intensification in South Asia. *Nature Sustainability*. **3(4):** 336-343.

Kakde, N.A., Manjunath, M., Hanwate, G.R. and Gourkhede, P.H. (2020). Influence of microbial consortia on the yield of kharif sorghum (*Sorghum bicolor* L.) and soil parameters under rainfed conditions. *Indian Journal of Dryland Agricultural Research and Development*. **35(2):** 54-56.

Kassar, F.H., Aridhee, J.K.A., Abood, A.M., Szymanek, M., Lysiak, G. and Dakhil, M.M. (2020). Effect of various tillage systems on sone of soil physical properties and wheat yield parameters. *International Journal Agricultural Statistical Science*. **16(1):** 1605-1610.

Kaur, A., Pandove, G. and Oberoi, H.K. (2018). Appraisal of microbial inoculant on growth, yield and quality attributes of forage sorghum. *Forage Research*. **44(3):** 179-184.

Kavya, Y., Trimurtulu, N. and Gopal, A.V. (2020). Effect of microbial consortia on soil enzymatic activities of sorghum [*Sorghum bicolor* (L.) Moench] rhizosphere under glass house conditions. *Pharmacognosy and Phytochemistry.* **9(2):** 1047-1050.

Khan, M.Y., Nadeem, S.M., Sohaib, M., Waqas, M.R., Alotaibi, F., Ali, L. and AlBarakah, F.N. (2022). Potential of plant growth promoting bacterial consortia for improving the growth and yield of wheat under saline conditions. *Frontiers in Microbiology*. **13:** 958-522.

Kumar, A., Maurya, B.R. and Raghuwanshi, R. (2021). The microbial consortia of indigenous rhizobacteria improving plant health, yield and nutrient content in wheat (*Triticum aestivum*). *Journal of Plant Nutrition*. **44(13):** 1942-1956.

Kumar, J., Singh, B., Yadav, D.B., Yadav, A., Yadav, P.K. and Tallapragada, S. (2025). Zero-tillage in mung bean-wheat cropping system: Impact on soil properties and crop productivity. *Legume Research-An International Journal*. **48(9):** 1497-1504. doi: 10.18805/LR-5154.

Kumar, R. and Pareek, B.L. (2022). Effect of organic manure, *Azospirillum* and inorganic fertilizer on growth and yield of wheat (*Triticum aestivum* L.). *The Pharma Innovation Journal.* **11(2):** 2179-2183.

Masaka, J., Dera, J. and Muringaniza, K. (2020). Dryland grain sorghum (*Sorghum bicolor*) yield and yield component responses to tillage and mulch practices under subtropical African conditions. *Agricultural Research*. **9(3):** 349-357.

Memon, S.Q., Mirjat, M.S., Mughal, A.Q. and Amjad, N. (2013). Effect of conventional and non-conventional tillage practices on maize production. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences*. **29(2):** 155-163.

Negi, R., Kaur, T., Devi, R., Kour, D. and Yadav, A.N. (2022). Assessment of nitrogen-fixing endophytic and mineral solubilizing rhizospheric bacteria as multifunctional microbial consortia for growth promotion of wheat and wild wheat relative Aegilops kotschyi. *Heliyon*. **8(12):** e12579. doi:10.1016/j.heliyon.2022.e12579.

Reddy, K.S., Rao, C.P., Luther, M.M. and Prasad, P.R.K. (2023). Evaluating the efficacy of inorganic fertilizers and biofertilizer consortia for enhanced crop yield and nutrient uptake in sorghum. *Emergent Life Sciences Research*. **9:** 332-339.

Tshering, K., Rengel, Z., Storer, P. and Solaiman, Z.M. (2023). Novel rock mineral fertiliser application with microbial consortia inoculant enhances growth, yield and grain protein content of wheat (*Triticum aestivum* L.) in sandy soil. *Archives of Agronomy and Soil Science*. **69(10):** 1734-1749.

Yadav, A., Kumar, R., Kabak, G., Menon, S., Saral, R., Mehta, S. and Dahiya, P. (2025). Impact of different rice straw management techniques and nitrogen levels on yield and nutrient uptake in wheat (*Triticum aestivum* L.). *Indian Journal of Agricultural Research.* **59(9):** 1430-1435. doi: 10.18805/IJARe.A-6383.

Yadav, A.K., Singh, P. and Sumeriya, H.K. (2009). Effect of tillage and integrated nutrient management on growth, yield attributes and yield of sorghum [*Sorghum bicolor* (L.) Moench]. *Haryana Journal of Agronomy*. **25(1/2):** 89-90.