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SOIL HEALTH AND WATER RETENTION RESPONSE TO MOISTURE CONSERVATION TECHNIQUES IN BER (*ZIZIPHUS MAURITIANA*)-BASED AGRI-HORTICULTURE SYSTEMS

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ABSTRACT

This study investigates the impact of various moisture conservation practices on soil physico-chemical properties in a Ber (*Ziziphus mauritiana*)-based agri-horticultural system under semi-arid conditions, conducted during the rabi season of 2024–2025 at Banda University of Agriculture and Technology, Uttar Pradesh, India. Seven treatments, including organic mulches (Shisham leaves, Karanj leaves, Neem leaves, Paddy straw), synthetic mulches (White polythene), and hand weeding, were assessed for their effect on soil pH, electrical conductivity (EC), water holding capacity (WHC), organic carbon content, and macronutrient availability (N, P, K). The results showed that Karanj leaves (T₃) achieved the highest soil pH of 8.10 at 0–15 cm depth and 8.30 at 15–30 cm depth. The highest EC value (0.33 dS m⁻¹) was recorded for Karanj leaves (T₃) and White polythene (T₆) at 0–15 cm depth. For WHC, Karanj leaves (T₃) again performed best, showing 50.00% at 0–15 cm depth, while Paddy straw (T₅) had the highest WHC (49.30%) at the same depth. The highest organic carbon content (0.36%) was found in Paddy straw (T₅) at 0–15 cm depth, with Shisham leaves (T₂) following closely at 0.34%. For available macronutrients, Shisham leaves (T₂) exhibited the highest nitrogen (238.36 kg ha⁻¹) and phosphorus (25.66 kg ha⁻¹) at 0–15 cm depth, while Paddy straw (T₅) recorded the highest potassium (291.64 kg ha⁻¹) at the same depth. At 15–30 cm depth, Shisham leaves (T₂) continued to show the highest nitrogen (190.73 kg ha⁻¹) and potassium (287.25 kg ha⁻¹), while Neem leaves (T₄) had the highest phosphorus (23.34 kg ha⁻¹). These findings highlight the effectiveness of organic mulches, particularly Karanj leaves (T₃) and Paddy straw (T₅), in improving soil pH, nutrient availability, and water retention, thereby enhancing soil health and productivity in Ber-based agroforestry systems under semi-arid conditions. The results suggest that integrating such moisture conservation practices can be a sustainable solution for improving soil fertility and moisture retention in dryland farming systems.

Keywords: Soil health, Water retention, Moisture conservation, Ber (*Ziziphus mauritiana*).

Introduction

Drylands, which encompass nearly 40% of the Earth's terrestrial surface, are characterized by low and erratic precipitation that falls significantly short of atmospheric water demand (Whitford, 2002; Odorico *et al.*, 2019). Despite their sparse vegetation, these

regions contribute to approximately 40% of global net primary productivity (NPP) and play a crucial role in regulating the global carbon cycle (Poulter *et al.*, 2014; Lal, 2019). The ecosystems and agricultural systems within drylands are highly sensitive to climate variability due to their dependence on limited and unpredictable rainfall. In India, rainfed agriculture

dominates vast portions of the southern plateau, central, and eastern regions. These regions experience severe moisture stress caused by erratic rainfall, prolonged dry spells, and increasing climatic variability (Rao *et al.*, 2015). The average per capita landholding has drastically declined from 2.4 ha in 1970–71 to 0.29 ha in 2010–11, intensifying the challenges of food production and livelihood security (Mall *et al.*, 2011). Although research programs such as the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) have advanced water and soil management technologies, their adoption remains suboptimal (Reddy, 2019). Consequently, improving productivity in rainfed areas demands innovative moisture conservation and soil management approaches. Moisture conservation practices play a pivotal role in stabilizing yields and enhancing sustainability in rainfed ecosystems. Techniques such as mulching, contour bunding, conservation tillage, and water harvesting reduce surface evaporation, increase infiltration, and maintain favorable soil moisture regimes (Vanitha *et al.*, 2022). These methods also enhance soil structure, reduce erosion, and improve nutrient availability, leading to better crop growth and resilience to climatic stress. Studies have reported yield improvements of 15–40% in cereals such as sorghum and pearl millet, and 20–30% in pulses such as pigeon pea and chickpea under moisture conservation practices (Kuyah *et al.*, 2022). With climate change intensifying drought frequency and variability in rainfall, integrating moisture conservation into production systems is essential for long-term sustainability and food security (Singh *et al.*, 2015).

Agri-horticultural systems represent a sustainable farming approach that integrates annual crops with perennial fruit trees to optimize resource use, enhance land productivity, and improve resilience in resource-poor regions (Colmenares *et al.*, 2020). By diversifying cropping patterns, these systems mitigate risks associated with monoculture, improve microclimate conditions, and enhance soil fertility through increased organic matter input and better nutrient cycling. This integration provides not only ecological benefits but also additional income opportunities through fruit production, thereby strengthening rural livelihoods.

Ber (*Ziziphus mauritiana* Lamk.) is a hardy, drought-tolerant fruit tree well-suited for arid and semi-arid environments due to its deep root system, which allows it to utilize sub-surface moisture and reduce competition with shallow-rooted crops such as lentil (*Lens culinaris* Medik.) (Jain *et al.*, 2024). Ber begins fruiting within 2–3 years and provides economic returns even during years of crop failure

(Omanya and Pasternak, 2005). Its canopy moderates the microclimate by lowering soil temperature, reducing evapotranspiration, and protecting intercrops from desiccating winds (Biswas *et al.*, 2023). Moreover, its litter fall contributes organic matter that enhances soil aggregation, nutrient availability, and microbial activity (Hobbie, 2015). Beyond soil health, Ber plantations support biodiversity and ecological balance, offering habitat and promoting beneficial species such as pollinators and predators (Kassam *et al.*, 2023). Among moisture conservation strategies, mulching has emerged as an effective method for improving soil-water relations and maintaining soil temperature. Derived from the German word *molsch* meaning “easy to decay,” mulching involves covering the soil surface with organic or inorganic materials to minimize evaporation, suppress weeds, and enhance water infiltration (Demo and Bogale, 2024). Organic mulches such as crop residues, straw, and compost enrich the soil as they decompose, while inorganic mulches like polyethylene film are effective in regulating soil temperature and conserving moisture (El-Beltagi *et al.*, 2022). Studies indicate that mulching reduces soil temperature fluctuations, enhances infiltration, and improves crop yield stability, particularly under dryland conditions (Du and Effah, 2022).

The integration of Ber with short-duration pulse crops such as lentil offers a promising agri-horticultural model for semi-arid regions. Lentil is an important *rabi* pulse crop valued for its high protein content and soil-enriching nitrogen-fixation properties (Feleke *et al.*, 2021). However, it is highly sensitive to moisture stress, especially during flowering and pod-filling stages. Ber-based systems, when combined with suitable moisture conservation practices like mulching or contour bunding, can improve the soil’s moisture regime, reduce thermal stress, and enhance lentil performance. This system not only improves land productivity but also contributes to ecological stability and economic diversification (Bhattacharyya *et al.*, 2023). Although Ber-based agri-horticultural systems have demonstrated potential for improving dryland productivity, systematic research evaluating their influence on soil physico-chemical properties under different moisture conservation practices remains limited. Understanding these interactions is crucial for optimizing soil health, water use efficiency, and overall system sustainability.

Material and Methods

The field experiment was conducted at the Forestry Instructional Farm (CEDA Project) of Banda University of Agriculture and Technology (BUAT),

Banda, Uttar Pradesh, India in 2024-2025, situated in Agro-Climatic Zone VIII the Central Plateau and Hill Region of India. The site is located at 25°31'26.110" N latitude and 80°20'37.220" E longitude, at an altitude of 143 m above mean sea level. The climate is hot and semi-arid, with a mean annual temperature (MAT) of 38.57°C and mean annual precipitation (MAP) of 805.95 mm. The soil of the experimental field is clay loam to sandy clay loam in texture, slightly alkaline in reaction (pH 8.62), with an electrical conductivity of 0.25 dS m⁻¹, organic carbon content of 0.33%, and available nitrogen, phosphorus, and potassium levels of 218.98, 20.39, and 281.07 kg ha⁻¹, respectively. The soils are derived from alluvial parent material. The region experiences long, hot summers and short, mild winters, with nearly 80% of annual rainfall received from the southwest monsoon (June–September). During the experimental period (November 2024–March 2025), only three light rainfall events were recorded, totaling about 9.4 mm, and temperatures ranged from 8.5°C minimum in early January to 36.5°C maximum in March.

The experiment was laid out in a Randomized Block Design (RBD) with three replications during the *rabi* season of 2024–25. The experimental system comprised *Ber* (*Ziziphus mauritiana*) as the perennial fruit tree and *Lentil* (*Lens culinaris* Medik.) var. IPL 316 as the intercrop. The plot size was 5.0 m × 5.0 m with a net plot size of 4.5 m × 4.5 m. The spacing was maintained at 6 m × 6 m for ber and 30 cm × 10 cm for lentil. The recommended fertilizer dose of 20:40:20 N:P:K kg ha⁻¹ was applied uniformly to all plots. Seven moisture conservation treatments were imposed under the ber-based agri-horticultural system: T₁ – No mulch

(control), T₂ – Shisham (*Dalbergia sissoo*) leaves, T₃ – Karanj (*Pongamia pinnata*) leaves, T₄–Neem (*Azadirachta indica*) leaves, T₅–Paddy (*Oryza sativa*) straw, T₆–White polythene mulch, and T₇ – Hand weeding. These treatments were designed to study their influence on soil physico-chemical properties and moisture retention. Before sowing and after harvest, composite soil samples were collected from each plot at depths of 0–15 cm, and 15–30 cm using a soil auger. Samples were air-dried, ground, and sieved through a 2 mm mesh before analysis. Bulk density was determined using the core sampler method (Piper, 1966), while particle density was measured using the pycnometer method. Porosity was calculated from the bulk and particle density values. Soil pH and electrical conductivity were measured in a 1:2.5 soil–water suspension using a pH meter and conductivity meter, respectively (Jackson, 1973). Water holding capacity was determined by the Keen–Raczkowski box method (Piper, 1966). Organic carbon content was estimated using the Walkley and Black (1934) wet oxidation method. Available nitrogen was analyzed using the alkaline KMnO₄ distillation method (Subbiah and Asija, 1956), available phosphorus by Olsen’s method (colorimetric determination at 660 nm), and available potassium by flame photometry (Hanway and Heidal, 1952). All analyses were carried out following standard laboratory protocols. The initial soil characteristics of the experimental site before sowing are presented in Table 1 which served as the baseline for evaluating the effects of various moisture conservation treatments on soil physico-chemical properties under the ber-based agri-horticultural system.

Table 1 : Soil characteristics before sowing of lentil crop under Ber-based agri-horticultural system

S. No.	Parameter	0–15 cm	15–30 cm
1	Bulk density (g cm ⁻³)	1.33	1.34
2	Particle density (g cm ⁻³)	2.67	2.66
3	Porosity (%)	50.19	49.62
4	Soil pH	8.20	8.30
5	EC (dS m ⁻¹)	0.31	0.32
6	Water holding capacity (%)	48	46
7	Organic carbon (%)	0.26	0.19
8	Available N (kg ha ⁻¹)	230	225
9	Available P (kg ha ⁻¹)	23.30	20.60
10	Available K (kg ha ⁻¹)	275	273.20

Result and Discussion

The soil properties under different moisture conservation practices in the ber-based agri-horticultural system showed considerable variation.

The influence of treatments on soil reaction (pH), electrical conductivity (EC), water holding capacity (WHC), organic carbon, and available macronutrients (N, P, K) are presented in the following sub-sections.

Soil pH

The pH of the soil varied significantly among treatments (Table 2). The highest pH was recorded in T₃ (Karanj Leaves), registering 8.10 at 0–15 cm and 8.30 at 15–30 cm depth, followed by T₄ (Neem Leaves) and T₅ (Paddy Straw), both with pH values ranging between 8.20 and 8.30. The lowest pH (7.80) was noted in T₁ (No Mulch-Control) at 0–15 cm. The increase in soil pH under organic mulches may be due to the release of basic cations (Ca²⁺, Mg²⁺, K⁺) during decomposition and improved microbial activity. Similar observations were made by Ahmad *et al.* (2014) and Kiprotich (2020), who reported enhanced soil pH stability under organic mulching.

Electrical Conductivity (dS m⁻¹)

The EC of the soil also showed notable variation across treatments. The maximum EC (0.33 dS m⁻¹) was recorded in T₃ (Karanj Leaves) and T₆ (White Polythene) at 0–15 cm depth, followed by T₁ (No Mulch-Control) (0.32 dS m⁻¹). The lowest EC (0.31 dS m⁻¹) occurred under T₂ (Shisham Leaves), T₄ (Neem Leaves), and T₅ (Paddy Straw). These variations may be attributed to the influence of mulching materials on soil moisture and salt movement. Aragüés *et al.* (2014) reported that mulching modifies EC by altering soil leaching and ion concentration near the root zone.

Water Holding Capacity (%)

Water holding capacity (WHC) improved significantly with the application of organic mulches. The highest WHC (50.00%) was observed under T₃ (Karanj Leaves) at 0–15 cm, followed by T₅ (Paddy Straw) (49.30%) and T₂ (Shisham Leaves) (49.00%). The lowest WHC was recorded in T₁ (No Mulch-Control) (48.70%). Increased WHC under mulches is attributed to enhanced organic matter content, better aggregation, and reduced evaporation losses. Similar results were reported by Nath *et al.* (2023), and Cechmanková *et al.* (2019), who found that mulching significantly improved soil moisture retention and structure.

Organic Carbon (%)

Organic carbon content increased significantly under organic mulch treatments (Table 2). At 0–15 cm depth, the highest organic carbon (0.36%) was observed in T₅ (Paddy Straw), followed by T₂ (Shisham Leaves) (0.34%). The lowest organic carbon (0.27%) was recorded in T₁ (No Mulch-Control). At

15–30 cm depth, T₅ again recorded the highest (0.27%) followed by T₂ (0.26%). The lowest organic carbon (0.21%) was found in T₁ and T₇ (Hand Weeding). Organic mulches improved soil carbon due to the continuous addition of decomposed residues and enhanced microbial activity. Similar results were reported by Liu *et al.* (2019) and Yang *et al.* (2020), who found higher soil organic carbon under residue-based mulches.

Available Macronutrients – Nitrogen, Phosphorus, and Potassium (kg ha⁻¹)

Available nitrogen, phosphorus, and potassium were all positively influenced by moisture conservation treatments (Table 4.13). At 0–15 cm, T₂ (Shisham Leaves) recorded the highest nitrogen (238.36 kg ha⁻¹), phosphorus (25.66 kg ha⁻¹), and second-highest potassium (290.84 kg ha⁻¹), while T₅ (Paddy Straw) had the highest potassium (291.64 kg ha⁻¹) and high nitrogen (209.14 kg ha⁻¹). The lowest nitrogen and potassium were found in T₁ (No Mulch-Control), while the lowest phosphorus was in T₃ (Karanj Leaves). At 15–30 cm, T₂ maintained the highest nitrogen (190.73 kg ha⁻¹) and potassium (287.25 kg ha⁻¹), while T₄ (Neem Leaves) showed the highest phosphorus (23.34 kg ha⁻¹).

Organic mulches significantly increased the availability of NPK due to improved decomposition, enhanced microbial mineralization, and better moisture conservation. Sahu (2023) and Mathivanan *et al.* (2024) reported that organic mulches improve soil fertility through enhanced humification and nutrient cycling, while Lasmini *et al.* (2022) observed similar increases in NPK under straw and leaf mulch.

Conclusions

The study concluded that organic mulches, particularly Shisham leaves (T₂) and Paddy straw (T₅), significantly improved the physico-chemical properties of the soil under the ber-based agri-horticultural system. These treatments enhanced soil organic carbon, nutrient availability (NPK), and water retention, while maintaining moderate soil pH and EC levels. The results suggest that integrating organic mulching with Ber-based agroforestry systems can be an effective strategy for improving soil health and moisture conservation in semi-arid regions.

Table 2: Effect of Moisture Conservation Practices on pH, EC, and WHC of Soil under Ber-Based Agri-Horticultural System

Symbols	Treatments	pH (0–15 cm)	pH (15–30 cm)	EC (dS m ⁻¹) (0–15 cm)	EC (dS m ⁻¹) (15–30 cm)	WHC (%) (0–15 cm)	WHC (%) (15–30 cm)	Organic Carbon (%) (0–15 cm)	Organic Carbon (%) (15–30 cm)	Available N (kg ha ⁻¹) (0–15 cm)	Available N (kg ha ⁻¹) (15–30 cm)	Available P (kg ha ⁻¹) (0–15 cm)	Available P (kg ha ⁻¹) (15–30 cm)	Available K (kg ha ⁻¹) (0–15 cm)	Available K (kg ha ⁻¹) (15–30 cm)
T ₁	No Mulch (Control)	7.80	8.10	0.32	0.31	48.70	47.80	0.27	0.21	179.84	171.44	22.94	22.70	264.31	263.84
T ₂	Shisham (<i>Dalbergia sissoo</i>) Leaves	7.90	8.00	0.31	0.31	49.00	49.00	0.34	0.26	238.36	190.73	25.66	23.04	290.84	287.25
T ₃	Karanj (<i>Pongamia pinnata</i>) Leaves	8.10	8.30	0.33	0.31	50.00	48.30	0.32	0.24	184.05	178.97	23.31	21.32	283.46	282.66
T ₄	Neem (<i>Azadirachta indica</i>) Leaves	8.30	8.20	0.31	0.31	48.30	49.30	0.33	0.24	182.04	171.78	25.12	23.34	272.25	275.97
T ₅	Paddy (<i>Oryza sativa</i>) Straw	8.20	8.20	0.32	0.32	49.30	48.70	0.36	0.27	209.14	187.79	23.94	22.38	291.64	281.92
T ₆	White Polythene	8.20	8.10	0.33	0.33	48.70	49.00	0.26	0.19	184.09	180.35	25.55	22.36	275.15	278.12
T ₇	Hand Weeding	7.90	8.20	0.31	0.32	48.30	48.30	0.28	0.21	192.36	183.36	24.86	21.74	277.03	278.96
SEm ±		0.1	0.1	0.01	0.01	0.7	0.6	0.01	0.01	9.9	6.9	1.0	0.8	9.0	9.9
CD (5%)		0.2	0.2	0.02	0.02	2.1	1.9	0.01	0.01	29.7	20.7	3.0	2.5	27.1	29.7
CV (%)		1.2	1.6	4.45	4.23	2.5	2.3	2.25	3.10	8.9	6.7	7.1	6.5	5.6	6.2

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