Soil Nutrient Dynamics under Selected Tree Species in the Jorbeer Conservation Reserve, Bikaner, Rajasthan, India

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Abstract: The study assessed soil physicochemical properties and nutrient availability of selected desert tree species in the Jorbeer Conservation Reserve of the Western Thar Desert, Bikaner. Four tree species, *Acacia tortilis*, *Prosopis cineraria*, *Acacia senegal*, and *Salvadora oleoides*, were investigated across grassland and dumping habitats, four seasons, and two soil depths (0–15 and 15–30 cm). Soil pH, electrical conductivity (EC), organic carbon (OC), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) were analyzed using standard laboratory methods. The findings indicated that the soils were moderately alkaline and non-saline, with low organic carbon but comparatively high phosphorus and potassium, particularly beneath *P. cineraria*. Zn and Fe were adequate to abundant, while Cu and Mn were comparatively low. Tree-covered soils showed greater nutrient accumulation than control sites, and habitat, tree species, soil depth, and season significantly influenced all soil parameters.

Keywords: Jorbeer Conservation Reserve; Western Thar Desert; Soil nutrients; Soil organic carbon; Seasonal variation; Desert ecosystem.

1. Introduction: -

Soil and vegetation are closely interconnected components of terrestrial ecosystems and together play an important role in maintaining ecological balance, nutrient cycling, soil fertility, and ecosystem productivity (Freschet et al., 2018; Yadav et al., 2022). The characteristics of soil are strongly influenced by the type and density of vegetation growing over it, while soil properties determine the availability of water and nutrients required for plant growth (Kooch et al., 2024). This relationship becomes particularly important in arid and semi-arid ecosystems, where limited rainfall, high temperatures, low organic matter, and poor nutrient availability can restrict vegetation growth and influence overall ecosystem functioning (Chen et al., 2025). In such environments, the presence of native and well-adapted tree species can contribute to the improvement and maintenance of soil quality through litter deposition, decomposition of plant residues, root turnover, and enhancement of microbial activity. These processes can contribute to the accumulation and recycling of organic matter and nutrients in the soil surrounding vegetation (Semenov et al., 2019).

The availability of essential soil nutrients is an important indicator of soil fertility and ecosystem health. Nutrients such as organic carbon (Joyea and Yadav, 2025; Pareek et al., 2024), phosphorus, potassium, zinc, iron, copper, and manganese support plant growth and various biological processes, while their availability is influenced by vegetation type, soil characteristics, depth, moisture, and seasonal conditions (Rajpoot et al., 2024). In arid ecosystems, nutrient distribution is also affected by litter deposition, root activity, and decomposition of organic matter beneath vegetation, resulting in differences between tree-covered and open soil areas. These interactions are particularly relevant in the Jorbeer Conservation Reserve where vegetation develops under harsh arid conditions. Different tree species may influence surrounding soil properties through variations in canopy structure, litter production, root distribution, and nutrient cycling. Consequently, the associated soils may differ in their physicochemical characteristics and nutrient availability. Therefore, the present study focuses on assessing soil physicochemical properties and nutrient concentrations associated with selected tree species in the Jorbeer Conservation Reserve, Bikaner, Rajasthan, to understand their role in maintaining soil fertility and ecosystem functioning.

2. Materials and Methods: -

2.1.Collection of Soil Samples:

A detailed survey of the Jorbeer Conservation Reserve, located in the Western Thar Desert (Fig.-1) , was conducted prior to sample collection to identify representative sampling sites and select the target tree species for investigation. Based on the survey, four ecologically important desert tree species, namely *Acacia tortilis, Prosopis cineraria, Acacia senegal*, and *Salvadora oleoides*, were selected for evaluating their influence on soil properties and nutrient dynamics. Sampling was carried out from two distinct habitat types, namely grassland areas and dumping sites, to assess the effect of land-use conditions on soil characteristics. In addition, one control site devoid of tree influence was included for comparative analysis. For each selected tree species, five representative sampling locations were established within each study area. Soil samples were collected seasonally during spring, summer, rainy, and winter seasons to capture temporal variations in soil quality. To evaluate vertical distribution patterns of soil nutrients and organic matter, samples were collected from two soil depths: 0–15 cm and 15–30 cm, using standard sampling procedures with appropriate replication. After removing surface litter and debris, soil samples from the designated depths were collected, properly labelled, transported to the laboratory, and stored under suitable conditions until analysis.

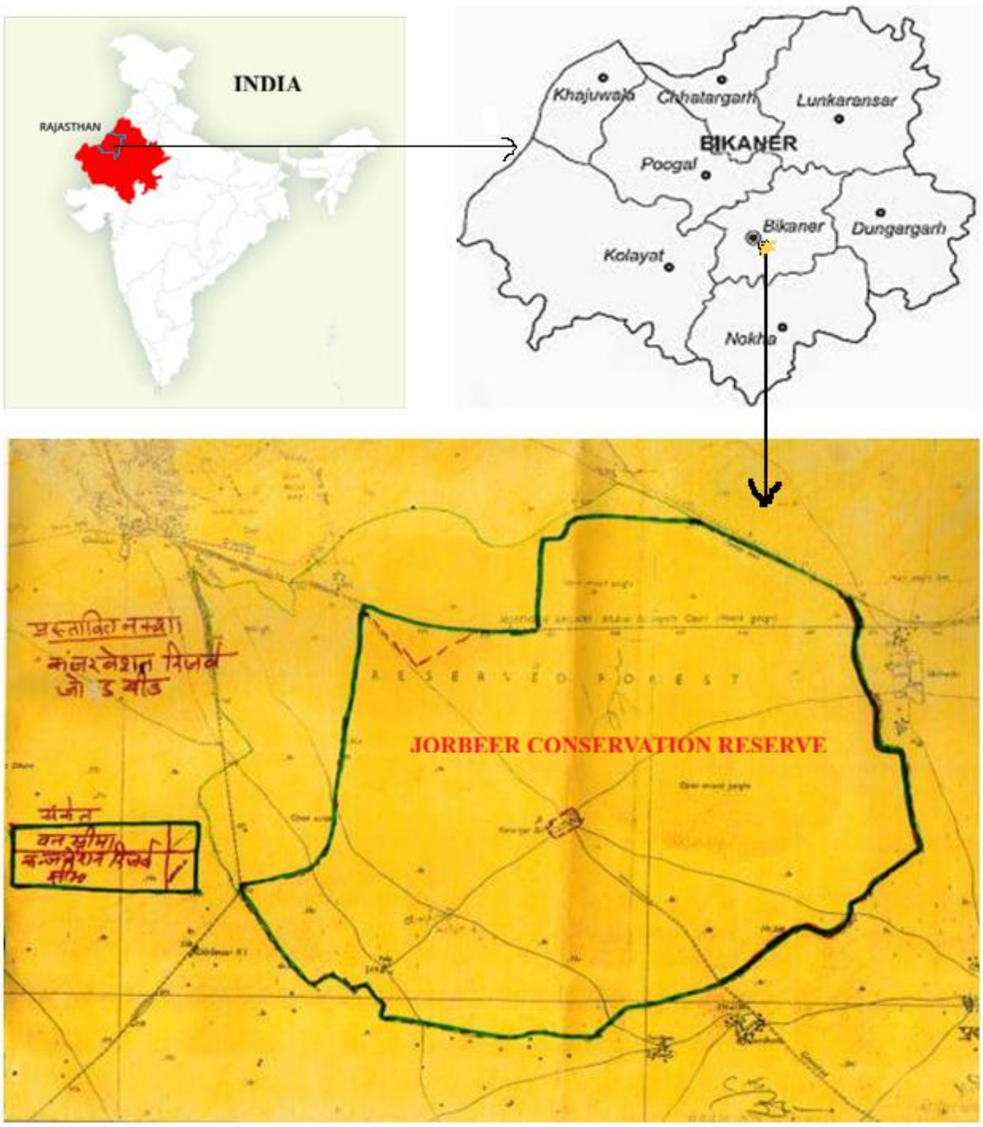


Fig.- 1 Map of Study Area (Not on Scale)

The collected soil samples were subsequently processed for the estimation of soil organic carbon (SOC) and comprehensive assessment of soil fertility under the selected tree species and the control area. Physicochemical analyses included the determination of soil pH, electrical conductivity (EC), organic carbon (OC), total phosphorus (P), available potash (K), and essential micronutrients such as zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn). In addition, total nitrogen and other major soil nutrients were evaluated to understand nutrient cycling and ecosystem productivity beneath different tree canopies.

2.2.Analysis of Soil Samples:

The collected soil samples were air-dried, homogenized, and sieved prior to laboratory analysis to ensure uniformity and accuracy of the results. The physicochemical properties of the soil were determined using standard analytical procedures. Soil pH was measured using a glass pH electrode (FiveEasyPlus™ FE28, Mettler Toledo, Switzerland). The soil organic carbon (SOC) content was estimated by the Walkley and Black potassium dichromate titration method, while total nitrogen was determined using the micro-Kjeldahl method following the procedure described by Lu (2000). Total phosphorus (TP) was analyzed using the Olsen method. In addition, the collected soil samples were analyzed for electrical conductivity (EC), organic carbon (OC), available phosphorus (P), potash (K), and the micronutrients zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn) using standard laboratory protocols. The analytical results were used to compare the soil nutrient status under different tree species, between grassland and dumping site conditions, across soil depths, and among different seasons. Statistical analysis, tabulation, and graphical representation of the data were performed using IBM SPSS Statistics ver. 26 and Microsoft Excel. To facilitate the interpretation of the analytical results, the observed soil physicochemical properties were compared with the reference values recommended by the Indian Standards and other commonly accepted standard guidelines for soil quality assessment. These reference values provide a useful basis for evaluating the nutrient status, salinity, and overall soil health of the study area.

Table 1: Reference Values for Selected Soil Physicochemical Parameters

Soil Parameter	Standard Value
pH	6.5–8.5
Electrical Conductivity (EC)	0.07–6.0 dS/m
Organic Carbon (OC)	0.5–7.5 %
Available Phosphorus (P)	< 2.5 mg/kg
Available Potash (K)	< 60 mg/kg
Zinc (Zn)	0.3–1.4 mg/kg
Iron (Fe)	2.9–6.7 mg/kg
Copper (Cu)	0.3–1.5 mg/kg
Manganese (Mn)	3.8–6.9 mg/kg

3. Results and Discussion: -

The seasonal variation in soil pH indicated alkaline conditions throughout the study period under all four plant species and control sites (Fig.-2). Soil pH was consistently higher in the dumping area than in the corresponding grassland ecosystem, reflecting the influence of dumping activities on soil alkalinity. In all plant species, the subsurface soil (15–30 cm) exhibited slightly higher pH than the surface soil (0–15 cm). Across seasons, the highest pH values were generally observed during summer, while comparatively lower values occurred during the rainy season. Among the studied species, *Salvadora oleoides* recorded the highest pH values, followed by *Acacia senegal*, *Acacia tortilis* and *Prosopis cineraria*. The control sites followed a similar seasonal trend, with the dumping area control exhibiting the highest pH values overall. These observations indicate that soil depth, season and site conditions collectively influenced soil pH, while all soils remained within the alkaline range.

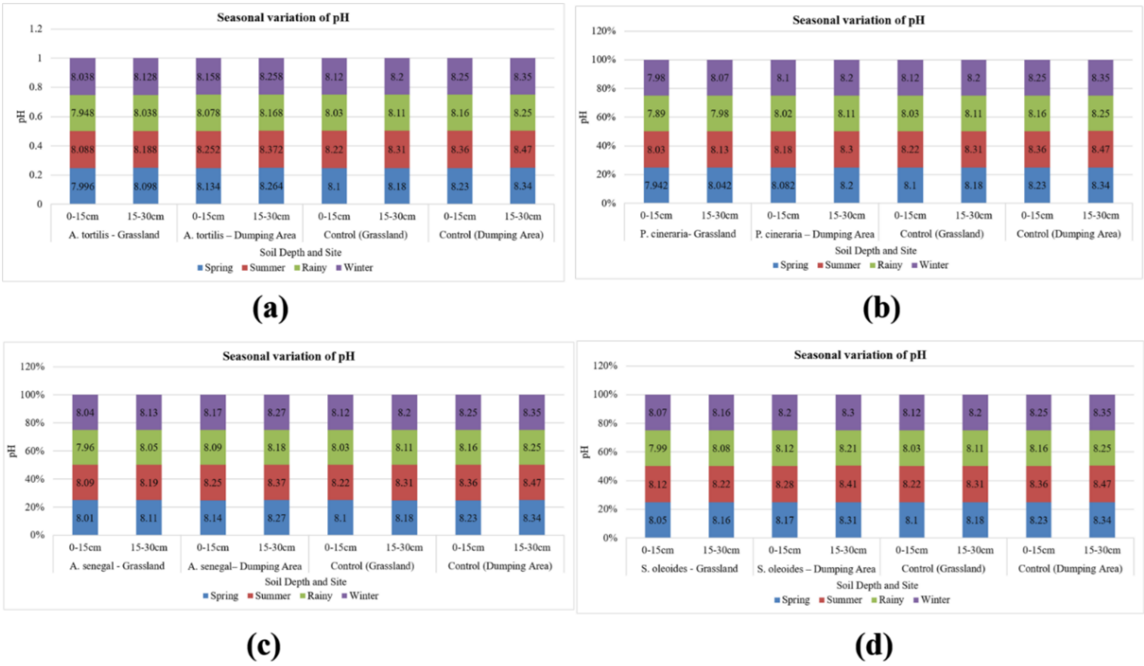


Fig. 2: Seasonal variation of soil pH across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

Electrical conductivity (EC) varied with plant species, ecosystem type, soil depth, and season (Fig.-3). Across all species, EC values were consistently higher in the dumping area than in the grassland, indicating greater accumulation of soluble salts in the dumping ecosystem. Subsurface soil (15–30 cm) exhibited higher EC than the surface soil (0–15 cm), suggesting downward movement and accumulation of soluble ions. Seasonally, EC reached its maximum during summer and minimum during the rainy season for all species and control sites, reflecting increased salt concentration under dry conditions and dilution during rainfall. Among the studied species, *Salvadora oleoides* recorded the highest EC values, followed by *Acacia senegal*, *Acacia tortilis*, and *Prosopis cineraria*. The dumping area control also showed higher EC than the grassland control throughout the study, further demonstrating the influence of dumping activities on soil salinity.

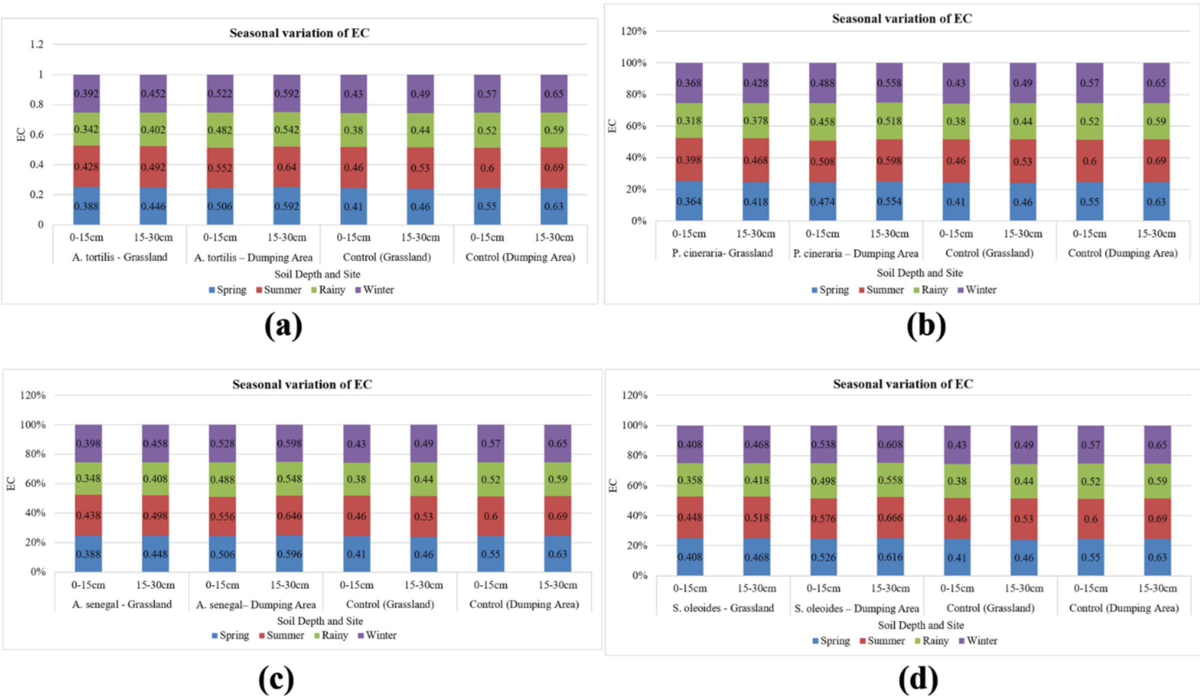


Fig. 3: Seasonal variation of soil electrical conductivity (EC) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

The organic carbon (OC) content varied considerably with plant species, ecosystem type, soil depth and season (Fig.-4). In general, the dumping area exhibited higher OC values than the corresponding grassland under all four plant species, indicating greater organic matter accumulation in the disturbed ecosystem. Among the studied species, *Prosopis cineraria* recorded the highest OC values in both ecosystems, followed by *Acacia tortilis*, *Acacia senegal* and *Salvadora oleoides*. Seasonal variation showed that OC was generally highest during winter and summer and comparatively lower during the rainy season in the surface soil, whereas the subsurface soil (15–30 cm) exhibited relatively higher OC during summer under all species. The vegetated sites consistently recorded higher OC values than the corresponding control sites, highlighting the positive influence of tree vegetation on soil organic matter accumulation. Overall, both vegetation type and ecosystem condition played significant roles in determining the seasonal and depth-wise distribution of soil organic carbon.

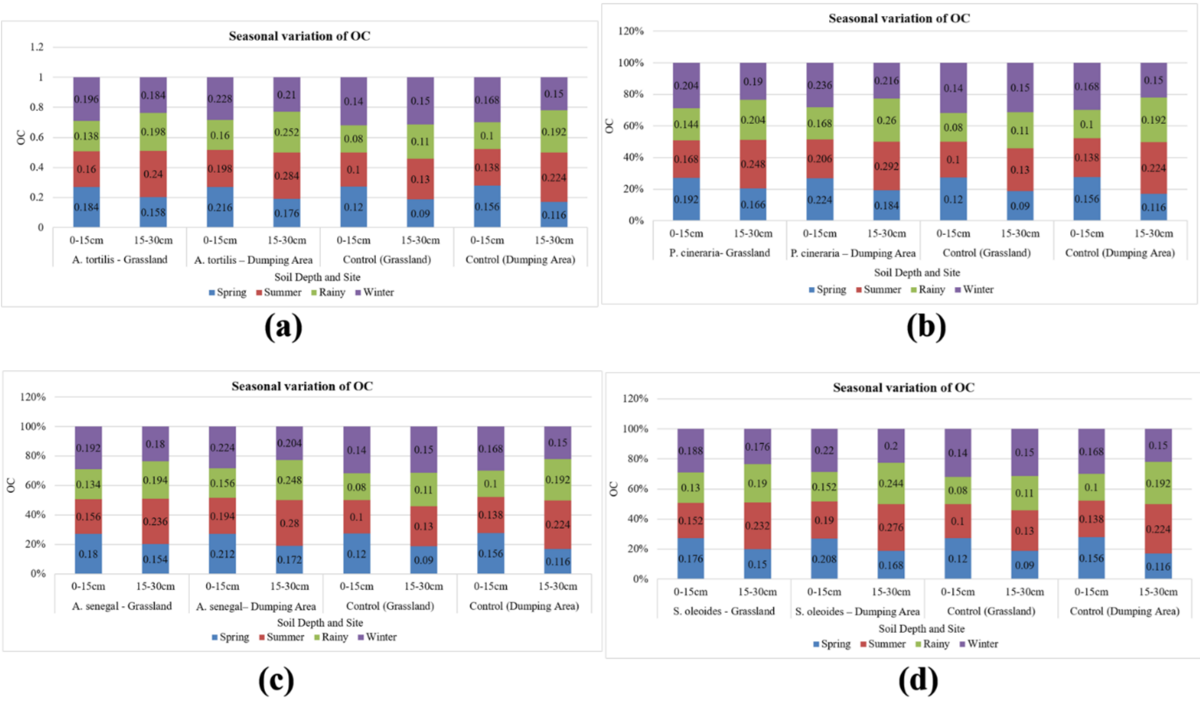


Fig. 4: Seasonal variation of soil organic carbon (OC) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

Available phosphorus varied considerably with plant species, ecosystem type, soil depth and season (Fig.-5). Across all species, phosphorus concentrations were consistently higher in the dumping area than in the grassland at both soil depths, indicating enrichment of available phosphorus in the dumping ecosystem. Surface soils (0–15 cm) contained higher phosphorus than subsurface soils (15–30 cm), reflecting greater nutrient accumulation in the upper soil layer due to litter deposition and organic matter decomposition. Among the studied species, *Prosopis cineraria* recorded the highest available phosphorus throughout the seasons in both ecosystems, whereas *Salvadora oleoides* exhibited comparatively lower values. Seasonal variation showed maximum phosphorus concentrations during the rainy season and minimum values during summer for all species and control sites, suggesting enhanced nutrient availability under increased soil moisture conditions. The control sites followed a similar seasonal trend but generally recorded lower phosphorus concentrations than the vegetated sites, highlighting the positive influence of tree vegetation on soil phosphorus availability.

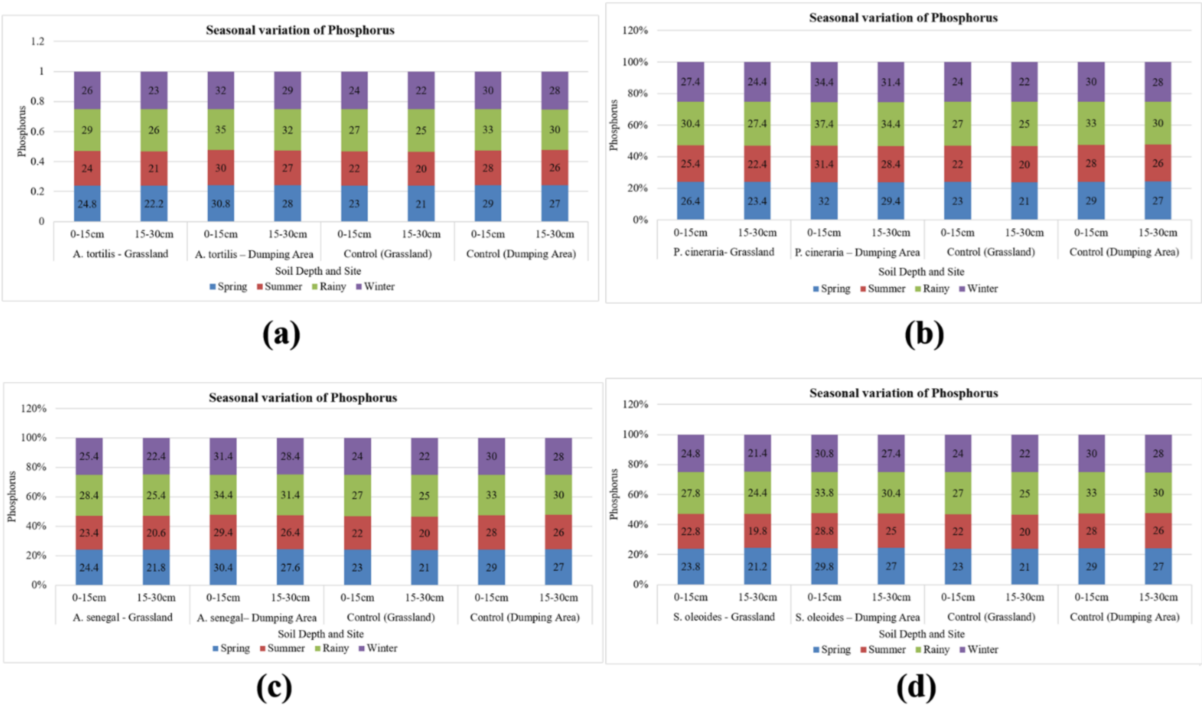
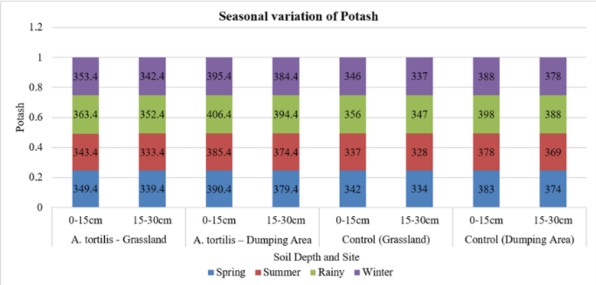


Fig. 5: Seasonal variation of available phosphorus (P) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

The available potassium content varied with plant species, ecosystem type, soil depth, and season (Fig.-6). In all cases, potassium concentrations were consistently higher in the dumping area than in the corresponding grassland sites. Surface soils (0–15 cm) contained greater potassium than subsurface soils (15–30 cm), indicating nutrient enrichment in the upper soil layer. Among the studied species, *Prosopis cineraria* recorded the highest available potassium throughout the seasons, followed by *Acacia tortilis*, *Acacia senegal*, and *Salvadora oleoides*. Seasonal variation showed that potassium content was highest during the rainy season, followed by winter, spring, and summer across all species and control sites. The dumping area control also exhibited higher potassium concentrations than the grassland control, suggesting that dumping activities contributed to increased potassium accumulation in the soil. Overall, vegetation combined with seasonal conditions and dumping activities played an important role in influencing the distribution of available potassium in the study area.



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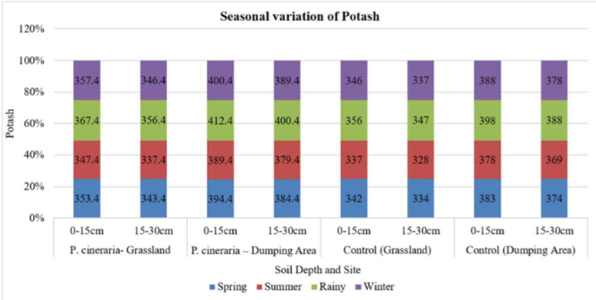

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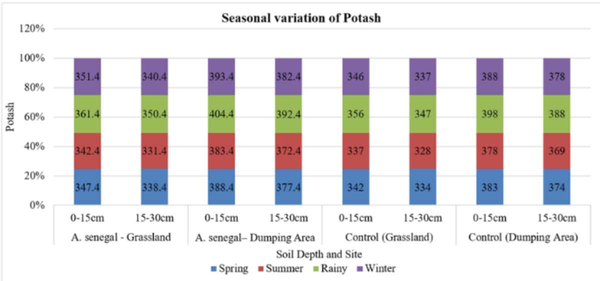

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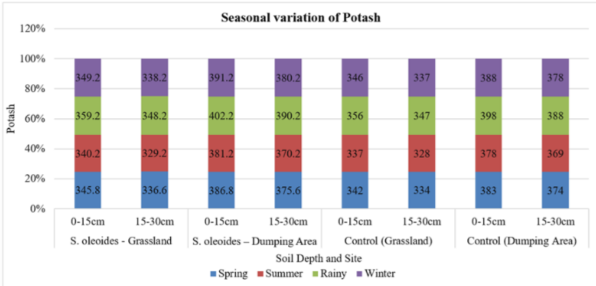


(d)

Fig. 6: Seasonal variation of available potassium (K) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

The zinc (Zn) concentration varied with plant species, ecosystem type, soil depth and season (Fig.-7). Across all species, Zn concentrations were consistently higher in the dumping area than in the grassland, indicating greater micronutrient accumulation in soils affected by dumping activities. Surface soils (0–15 cm) generally contained higher Zn concentrations than subsurface soils (15–30 cm), reflecting greater nutrient enrichment in the upper soil layer. Seasonal variation showed that Zn concentration was highest during the rainy season, followed by winter, spring and summer in both ecosystems. Among the studied species, *Prosopis cineraria* recorded the highest Zn concentration throughout the study, followed by *Acacia tortilis*, *Acacia senegal* and *Salvadora oleoides*. The control sites also exhibited higher Zn concentrations in the dumping area than in the grassland, although values remained lower than those recorded under the vegetated sites, suggesting that vegetation contributed to enhanced zinc availability in the soil.

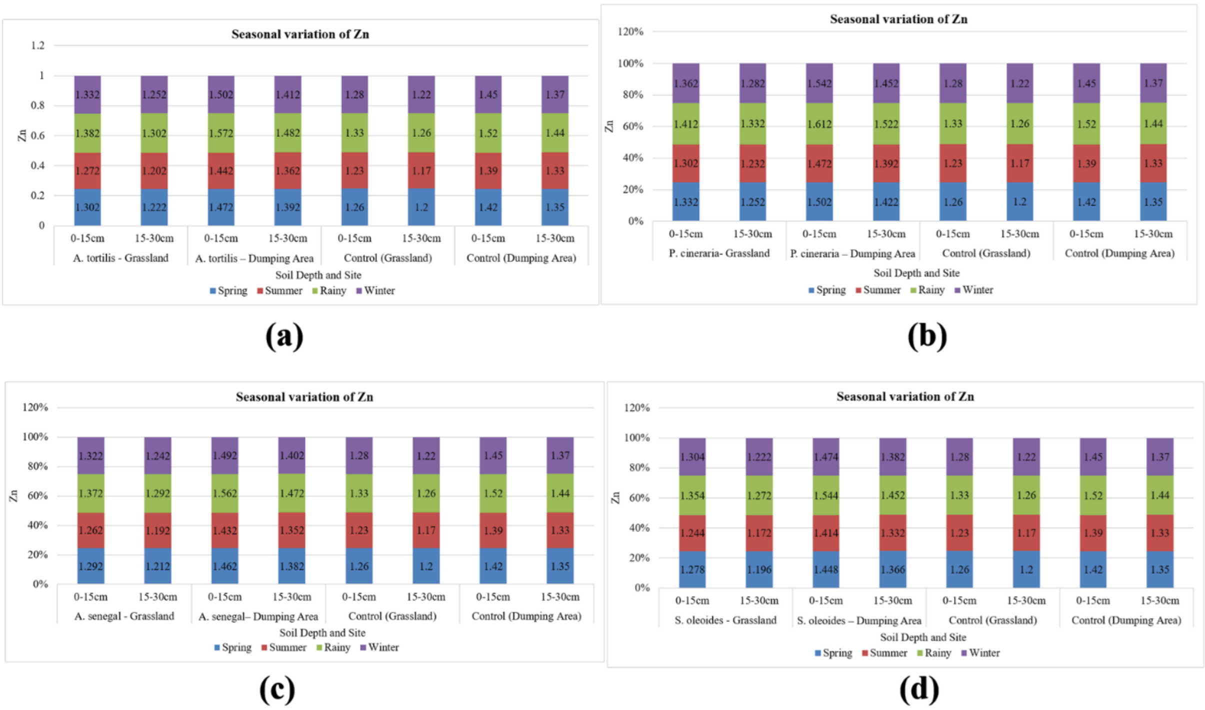
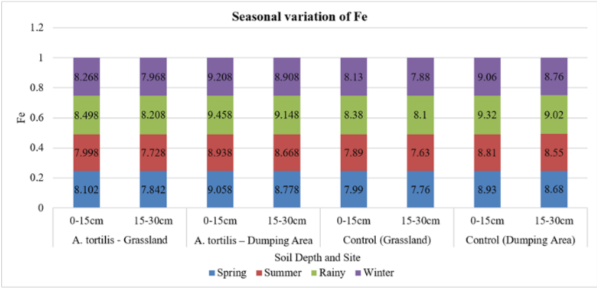


Fig. 7: Seasonal variation of available zinc (Zn) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

The available iron (Fe) content exhibited clear variations among plant species, ecosystems, soil depths, and seasons (Fig.-8). In all cases, the dumping area recorded higher Fe concentrations than the corresponding grassland sites, indicating greater iron availability under dumping conditions. Surface soils (0–15 cm) consistently contained higher Fe than subsurface soils (15–30 cm), reflecting greater accumulation of nutrients in the upper soil layer. Among the four plant species, *Prosopis cineraria* recorded the highest Fe concentrations throughout the year, followed by *Acacia tortilis*, *Acacia senegal*, and *Salvadora oleoides*. Seasonal variation showed that Fe concentrations were highest during the rainy season, followed by winter, spring, and were lowest during summer across all species and sites. Both grassland and dumping controls followed a similar seasonal trend but generally exhibited lower Fe concentrations than the soils under the respective plant species. These findings suggest that vegetation, particularly *Prosopis cineraria*, enhances iron availability in soil, while dumping activities further contribute to increased Fe content.



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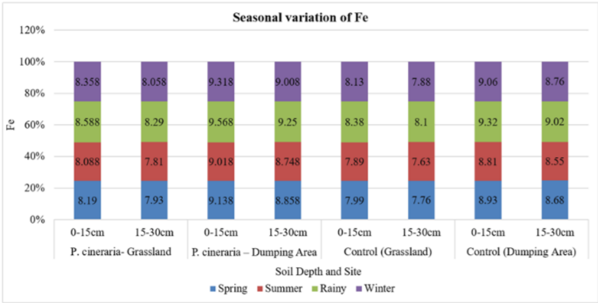

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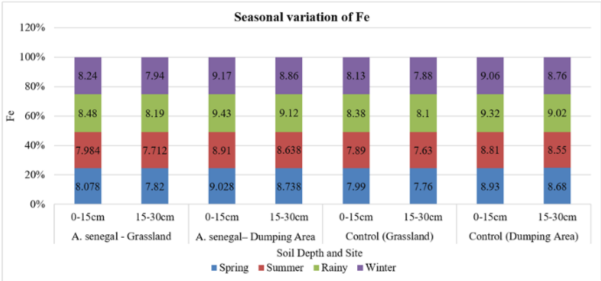

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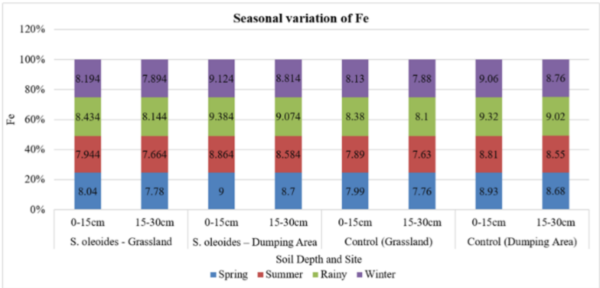
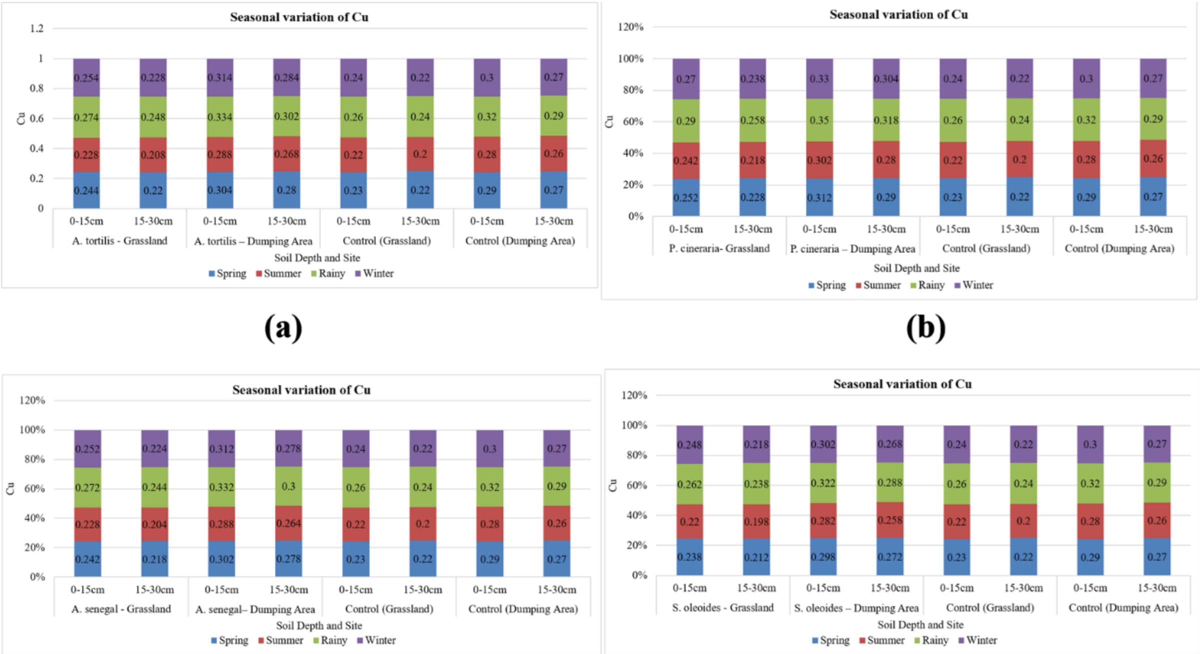


(d)

Fig. 8: Seasonal variation of available iron (Fe) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

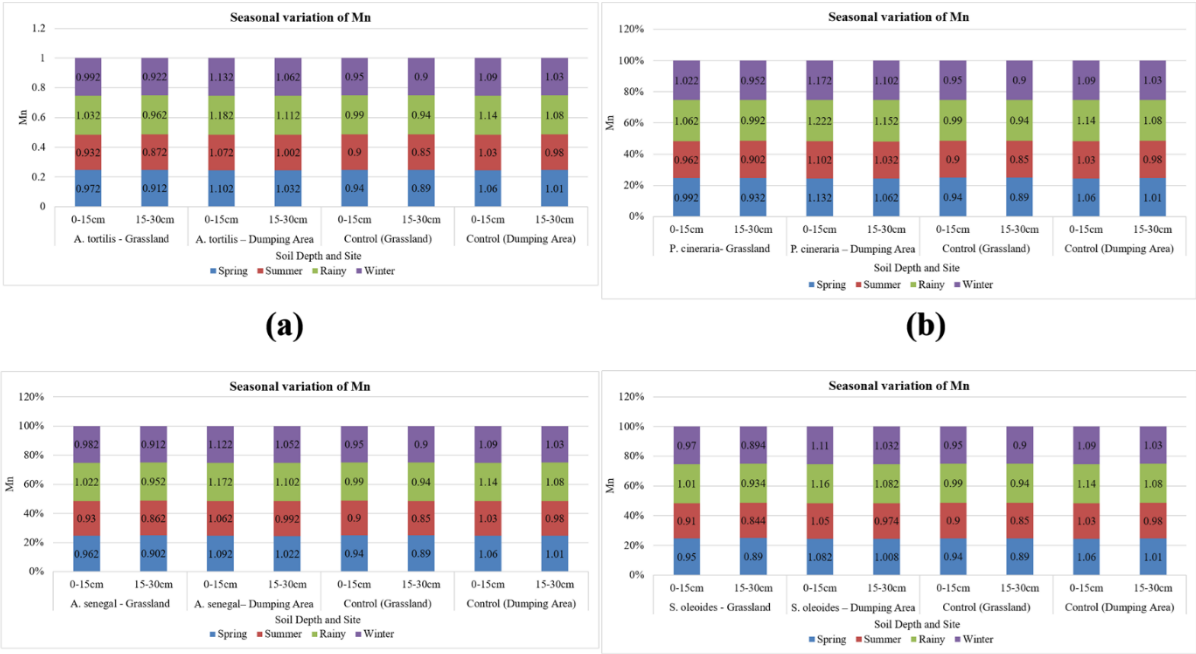
Copper (Cu) concentration exhibited clear variations with ecosystem type, soil depth, season, and plant species (Fig.-9). In all species, Cu concentrations were consistently higher in the dumping area than in the grassland, indicating the influence of dumping activities on soil micronutrient enrichment. Surface soil (0–15 cm) contained higher Cu concentrations than the subsurface layer (15–30 cm), suggesting greater accumulation of copper in the upper soil due to litter deposition and organic matter decomposition. Among the studied species, *Prosopis cineraria* recorded the highest Cu concentrations in both ecosystems throughout the study period, followed by *Acacia tortilis*, *Acacia senegal*, and *Salvadora oleoides*. Seasonal variation showed that Cu concentrations were generally highest during the rainy season, followed by winter, spring, and summer. The control sites also exhibited higher Cu concentrations in the dumping area than in the grassland, although values remained lower than those observed under the vegetated sites. Overall, the results indicate that vegetation, particularly *P. cineraria*, together with dumping activities, enhanced the accumulation of available copper in the soil.



(a) **(b)** **(c)** **(d)**

Fig. 9: Seasonal variation of available copper (Cu) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

The manganese (Mn) concentration varied with plant species, ecosystem type, soil depth, and season (Fig.-10). In general, the dumping area exhibited consistently higher Mn concentrations than the grassland ecosystem for all plant species and seasons. Surface soil (0–15 cm) contained greater Mn than the subsurface layer (15–30 cm), indicating nutrient enrichment in the upper soil horizon. Among the studied species, *Prosopis cineraria* recorded the highest Mn concentrations throughout the study, followed by *Acacia tortilis*, *Acacia senegal*, and *Salvadora oleoides*. Seasonal variation showed the highest Mn concentration during the rainy season, followed by winter, spring, and summer. The control sites also followed a similar seasonal and depth-wise pattern but exhibited comparatively lower Mn concentrations than the soils under the respective plant species, demonstrating the positive influence of vegetation on manganese availability. Overall, the results suggest that both vegetation and dumping activities enhanced manganese accumulation in the soil, with the maximum enrichment occurring in the surface layer during the rainy season.



(d)

Fig. 10: Seasonal variation of available manganese (Mn) across different soil depths for (a) *Acacia tortilis*; (b) *Prosopis cineraria*; (c) *Acacia senegal*; (d) *Salvadora oleoides*

A four-way ANOVA was conducted to assess the effects of habitat, tree species, soil depth, season, and their interactions on the selected soil physicochemical properties. The results showed that habitat, tree species, soil depth, and season significantly influenced all the studied parameters ($p < 0.001$). Soil pH was significantly affected by habitat, season, depth, and species, with significant habitat × season, habitat × depth, and season × depth interactions; the model explained 98.0% of the variation ($R^2 = 0.980$). EC showed significant main effects and several interactions, particularly involving habitat, species, depth, and season, explaining 98.9% of the variation ($R^2 = 0.989$). SOC was significantly influenced by all four factors, with significant habitat × depth, habitat × season, depth × season, and habitat × depth × season interactions, and the model accounted for 99.9% of the variation ($R^2 = 0.999$). Available phosphorus and potassium were also significantly affected by all four factors, with R^2 values of 0.984 and 0.998, respectively, while their significant interactions indicated variations according to habitat, species, depth, and season.

Similarly, zinc, iron, copper, and manganese concentrations were significantly influenced by habitat, tree species, soil depth, and season ($p < 0.001$). Zinc showed significant habitat × depth, habitat × season, and depth × season interactions, with the model explaining 99.5% of its variation ($R^2 = 0.995$). Iron exhibited several significant two-way and three-way interactions and showed the highest explanatory power, with $R^2 = 0.999$. Copper was significantly affected by habitat × species, species × season, and depth × season interactions, with $R^2 = 0.987$. Manganese showed significant interactions among habitat, species, depth, and season, with the model explaining 99.3% of the variation ($R^2 = 0.993$). Overall, the ANOVA results demonstrate that soil properties in the Jorbeer Conservation Reserve are strongly regulated by habitat, vegetation type, soil depth, and seasonal conditions, with the fitted models explaining a very high proportion of the observed variability across all parameters.

The physicochemical assessment of soils from the Jorbeer Conservation Reserve showed that soil pH ranged from 7.89–8.47, indicating moderately alkaline conditions, while EC (0.318–0.666 dS m^{-1}) indicated non-saline soils. Organic carbon remained low (0.08–0.292%), although higher values were observed beneath tree canopies than in control sites. Available phosphorus and potassium were comparatively high, particularly beneath *Prosopis cineraria*. Among micronutrients, Zn (1.21–1.61 ppm) was generally adequate, Fe (7.63–9.57 ppm) was abundant, Cu (0.20–0.35 ppm) was comparatively low, and Mn (0.84–1.22 ppm) remained deficient. These findings are consistent with observations from arid regions of Rajasthan, where alkaline and non-saline soil conditions have been reported (Dular and Kanchan, 2022; Parihar and Choudhary, 2017). The presence and mobility of Fe, Cu, Zn, and Mn in soils have also been reported to be influenced by soil physicochemical conditions (Veena et al., 2017).

The low organic carbon content observed in the present study is comparable with findings reported by Dular and Kanchan (2022), Parihar and Choudhary (2017), Kumar et al. (2020), Bhunwal et al. (2023), and Dular and Solanki (2022). However, greater organic carbon and nutrient concentrations beneath tree canopies indicate the contribution of vegetation, litter deposition, and root biomass to soil organic matter and nutrient cycling. Higher phosphorus and potassium concentrations beneath tree canopies, together with their general decline with increasing soil depth, were consistent with Parihar and Choudhary (2017), while Bhunwal et al. (2023) and Dular and Solanki (2022) emphasized the role of organic matter in nutrient availability. The micronutrient results showed adequate Zn and Fe, comparatively low Cu, and low Mn, with vegetation, particularly *Prosopis cineraria*, associated with improved nutrient status. Seasonal variations, including higher nutrient and organic carbon levels during the rainy season and relatively higher EC during summer, were comparable with Kumari et al. (2018) and Sharma et al. (2025). Overall, the findings confirm distinct seasonal and depth-wise variations in soil properties.

4. Conclusion: -

The study demonstrated that the soils of the Jorbeer Conservation Reserve are moderately alkaline and non-saline, with relatively low organic carbon and manganese availability. Soil nutrient concentrations varied considerably with habitat, tree species, soil depth, and season. Tree-covered soils generally exhibited greater nutrient enrichment than control sites, indicating a positive association between vegetation and soil nutrient status. Among the studied species, *Prosopis cineraria* showed the most favorable influence on soil nutrient conditions, with comparatively better nutrient enrichment in the associated soils. These findings highlight the important role of native vegetation in maintaining soil fertility, promoting nutrient cycling, and improving soil quality in the arid environment. *Prosopis cineraria* therefore emerge as an important species for conservation and sustainable ecosystem management in the fragile desert environment of the Western Thar Desert.

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