International Journal of Environment, Agriculture and Biotechnology
Vol-9, Issue-6; Nov-Dec, 2024
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Impact of *Prosopis cineraria* on Soil organic carbon: Implication for arid agroforestry with a case study of Sardarshahar, Rajasthan

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Received: 20 Sep 2024; Received in revised form: 18 Oct 2024; Accepted: 25 Oct 2024; Available online: 04 Nov 2024

Abstract— *Prosopis cineraria (P. cineraria), commonly known as Khejri, plays a significant role in enhancing soil health, particularly in arid and semi-arid regions. This study investigates the impact of Prosopis cineraria on soil organic carbon (SOC) levels in the context of agroforestry systems in Sardarshahar, Rajasthan. The analysis reveals that the presence of this species positively influences SOC concentrations, contributing to improved soil fertility and structure. The deep root system and high biomass production of P. cineraria facilitate the accumulation of organic matter in the soil, leading to higher carbon sequestration potential compared to non-forested areas. Additionally, the integration of this species into arid agroforestry systems can support sustainable agricultural practices in these challenging environments. This case study highlights the ecological benefits of P. cineraria in maintaining soil health in arid regions and discusses about the dynamics of SOC along seasons and soil depth. The findings advocate the importance of incorporating native tree species like Prosopis cineraria into agroforestry practices to enhance soil organic carbon stocks and promote sustainable land management in Rajasthan and similar arid landscapes.*

Keywords— ***Soil organic carbon; Prosopis cineraria; Arid; agroforestry; soil fertility***

I. INTRODUCTION

Agroforestry, the practice of integrating trees and shrubs into agricultural landscapes, has gained considerable attention as a sustainable land-use strategy, particularly in arid and semi-arid regions (Ntawuruhunga *et al.*, 2023). The incorporation of native tree species into these systems not only enhances biodiversity but also plays a crucial role in improving soil quality, increasing productivity, and mitigating the adverse effects of climate change (Gomes *et al.*, 2020). In this context, soil organic carbon (SOC) is a key indicator of soil health, directly influencing soil fertility, water retention, and nutrient cycling (Solanki *et al.*, 2024). Enhancing SOC levels in arid regions is a significant challenge due to low biomass production and the harsh environmental conditions that limit organic matter accumulation (Visconti *et al.*, 2024).

Prosopis cineraria, commonly known as Khejri, is a drought-resistant tree species native to the Indian subcontinent, particularly prevalent in the arid and semi-arid regions of Rajasthan (Verma *et al.*, 2010). It is widely recognized for its ability to thrive in harsh environments, where it provides a range of ecological and economic benefits in the form of ecosystem services (Yadav *et al.*, 2021). *P. cineraria* have deep root systems and a high biomass production capacity, which makes it particularly effective in stabilizing soils and improving their structure. Additionally, the species is known to contribute significantly to SOC levels by adding organic matter through leaf litter, root turnover, and other biological processes (Verma *et al.*, 2010). *P. cineraria* provide good fuelwood and charcoal. The wood is favoured for cooking and domestic heating (Mahoney, 1990). Village people remain dependent on local and nearby trees for fuelwood and fodder (Yadav *et al.*, 2022).

In arid ecosystems, arbuscular mycorrhizal fungi (AMF) are essential components of the rhizosphere microflora. These fungi play a vital role in breaking down soil organic matter, facilitating nutrient mineralization, and recycling nutrients within the soil (Tarafdar and Rao, 1997; Pare *et al.*, 2000). The distribution and diversity of AMF populations are highly variable and are influenced by several factors, including soil properties, environmental conditions, host plant species, and farming practices (Sanders, 1990; McGongle and Miller, 1996).

Despite the acknowledged benefits of *Prosopis cineraria in* agroforestry, its specific impact on SOC dynamics in arid environments like those found in Rajasthan remains underexplored. Understanding how *P. cineraria* influence SOC in these regions can provide valuable insights into sustainable land management practices and carbon sequestration strategies, which are critical in the face of climate change (Gomes *et al.*, 2020). By promoting *P. cineraria,* land managers can enhance soil fertility, biodiversity, and ecosystem resilience (Yadav and Yadav, 2023).

This study focuses on Sardarshahar, an arid region in Rajasthan, to evaluate the impact of *Prosopis cineraria on* soil organic carbon levels. By comparing SOC concentrations in soils under *P. cineraria* with those in non-vegetated areas, the research aims to elucidate the role of this species in enhancing soil fertility and promoting sustainable agroforestry practices. The findings of this study will help to inform strategies for integrating native tree species into agroforestry systems to optimize soil health and carbon storage in arid landscapes.

II. MATERIAL AND METHODS

Study area

The study was conducted in Sardarshahar, a town located in the Churu district of Rajasthan, India (Figure: 1). Sardarshahar is situated in the northwestern part of the state and falls within the arid region of the Thar Desert (Wikipedia contributors, 2024). The geographical coordinates of the study area are approximately 28.44° N latitude and 74.49° E longitude, with an average elevation of about 312 meters above sea level. The region experiences extreme climatic conditions characterized by high temperatures, low and erratic rainfall, and significant variations in day and night temperatures (Wikipedia contributors, 2024).

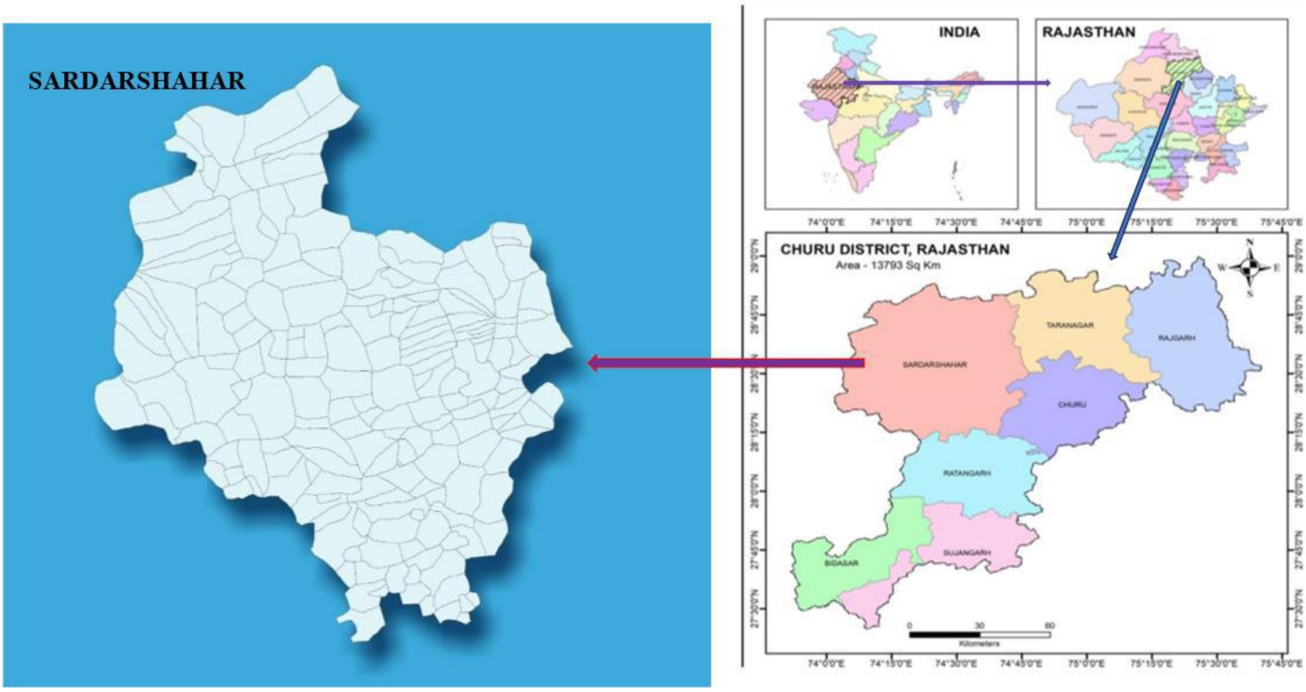

Fig.1: Map of SARDARSHAHAR (Not to scale)

The climate of Sardarshahar is typically arid, with an average annual rainfall of around 250-300 mm, most of which is received during the monsoon months of July to September. The temperatures in the region can soar as high as 48°C during the summer and drop to as low as 2°C in the winter, reflecting the high thermal amplitude typical of desert climates (Ground water department, 2013). The soils in this area are predominantly sandy, with low organic matter content, poor fertility, and limited water-holding capacity, which pose significant challenges to agricultural productivity.

Despite these harsh conditions, the presence of native species like *Prosopis cineraria has* enabled the development of traditional agroforestry systems that support local livelihoods. *Prosopis cineraria,* also known as Khejri, is well adapted to the arid climate and sandy soils of Sardarshahar, making it a vital component of the region's agricultural and ecological landscape (Samadia *et al.*, 2021). This tree species plays a crucial role in sustaining local agroecosystems by providing shade, reducing soil erosion, enhancing soil fertility, and serving as a source of fodder, fuelwood, and other non-timber products.

The choice of Sardarshahar as the study area is particularly relevant due to its representative conditions of Rajasthan's arid regions, where soil degradation and declining soil organic carbon levels are critical concerns. Understanding the impact of *P. cineraria* on soil organic carbon in this context is essential for developing sustainable agroforestry practices that can enhance soil health and agricultural productivity in similar arid and semi-arid landscapes. The study sites were selected to include areas under the influence of *P. cineraria* as well as adjacent non-vegetated plots for comparative analysis of soil organic carbon levels.

Site selection

Soil samples were collected from two distinct sites within Sardarshahar:

- **Site A**: Areas with established *Prosopis cineraria* plantations, representing agroforestry systems.
- **Site B**: Adjacent non-vegetated or open agricultural lands without *Prosopis cineraria* presence, serving as control plots.

The selection criteria included similar soil types, land-use practices, and environmental conditions to minimize variability that could influence SOC measurements.

Soil Sampling

Soil samples were collected from both study sites quarterly during December (winter), march (spring), June (summer) and September (rainy) to capture baseline SOC levels. The following procedures were followed:

- **Sampling Depth**: Soil samples were taken from two depth ranges: 0-15 cm (topsoil) and 15-30 cm (subsoil) to assess the vertical distribution of SOC.
- **Sampling Technique**: A systematic sampling approach was employed. Five soil cores were collected randomly from each depth range at each site, using a soil auger. The cores were mixed to form a composite sample for each depth range, resulting in a total of four samples per site (two depths per site).

Soil Preparation and Analysis

The collected soil samples were processed in the laboratory following these steps:

- **Air-Drying**: The samples were air-dried and sieved through a 2 mm mesh to remove debris and aggregate clumps.
- **Soil Organic Carbon Determination**: SOC were assessed using core sampler technique (Blake and Hartge, 1986) and modified Walkley and Black (1934) which involves oxidizing organic matter with potassium dichromate in sulfuric acid. The SOC content was calculated based on the amount of dichromate reduced during the reaction. Data were subjected to statistical analysis to assess the differences in SOC levels between the two sites.

Statistical Analysis: SPSS and MS Excel were used for statistical analysis.

III. RESULTS AND DISCUSSION

The average SOC at top soil (0-15cm depth) under the *P. cineraria* canopy was observed 0.20% compared to 0.11% at control area where as at sub soil depth 15-30cm depth under the *P. cineraria* was observed 0.18% with compared to 0.11% at control area (Table-1 and Figure- 2).

Table:1- Annual average SOC under Agroforestry of P. cineraria with control area

Condition	Soil depth	Average SOC± SE (in percent)
***P.cineraria* (Site A)**	0-15cm	0.2 ± 0.03
	15-30cm	0.18 ± 0.02
Control (Site B)	0-15cm	0.11 ± 0.03
	15-30cm	0.11 ± 0.02

Abbreviation: SE- Standard error

The variations in soil organic carbon (SOC) concentrations for different depths and conditions are highlighting the significant impact of *Prosopis cineraria* in enhancing SOC levels compared to control plots across all seasons (Table-2). The presence of *Prosopis cineraria* substantially increases SOC concentrations in both topsoil and subsoil compared to control plots, across all seasons.

Table:2: Soil organic carbon along soil depth and season in percent

Condition	soil depth	Spring	Summer	Rainy	Winter
P. cineraria	**Top soil**	0.2	0.18	0.17	0.24
	Sub soil	0.17	0.2	0.19	0.17
Control	**Top soil**	0.1	0.09	0.08	0.15
	Sub soil	0.09	0.12	0.11	0.13

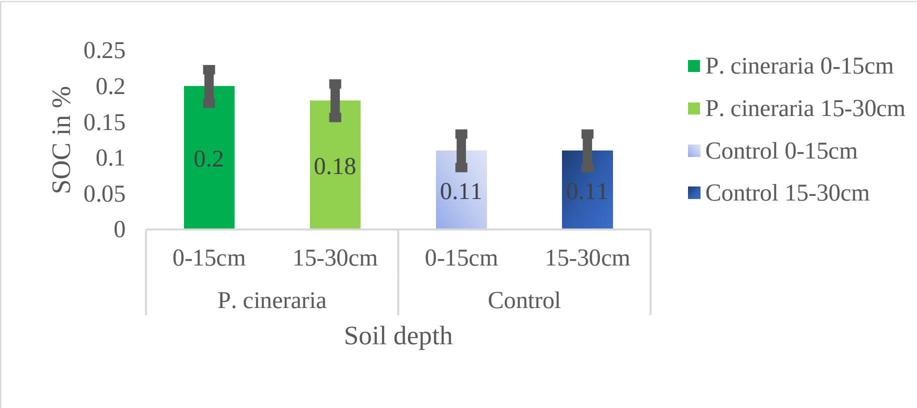

Fig.2- Annual average SOC under P. cineraria agroforestry along soil depths

Seasonal fluctuations were more pronounced in soils under *Prosopis cineraria*, with the highest SOC levels observed during the winter season in the topsoil (0.24%) followed by during spring (0.20%), Summer (0.18%) and least was during rainy season (0.17%) in top soil, whereas in sub soil maximum soc was observed during summer season (0.20%) which may be due to biodegradations of biomass during this season's favourable environmental condition at sub soil depth. In summer and rainy season SOC was observed higher in subsoil than top soil whereas in Spring and winter SOC was observed higher in top soil (Fig.-3).

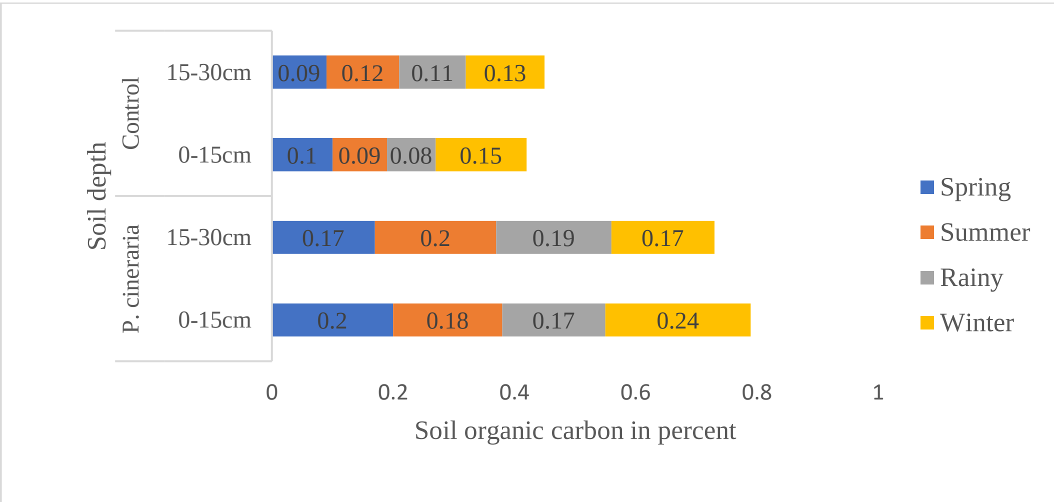

Fig.3- SOC (in %) along soil depth and season under the canopy of P. cineraria

The SOC concentration at lower depths declined with increasing soil depth, and was unaffected by changes in land use from fields without plantations to fields with tree plantations (Yuefeng *et al.*, 2014). In contrast, the control plots showed consistently lower SOC levels with minimal seasonal variations, underscoring the limited natural input of organic carbon without the influence of vegetation like *Prosopis cineraria*.

The trend line shows (figure 4) the dynamics of SOC retention in top soil under the *P. cineraria* canopy with the R^2 value of 0.91 and figure 5 shows the trend line of SOC retention at sub soil with R^2 value of 0.93. The trend line reveals that when top soil has higher SOC than sub soil has lower SOC (Spring and winter seasons) whereas when top soil has lower SOC than subsoil have higher SOC (summer and rainy).

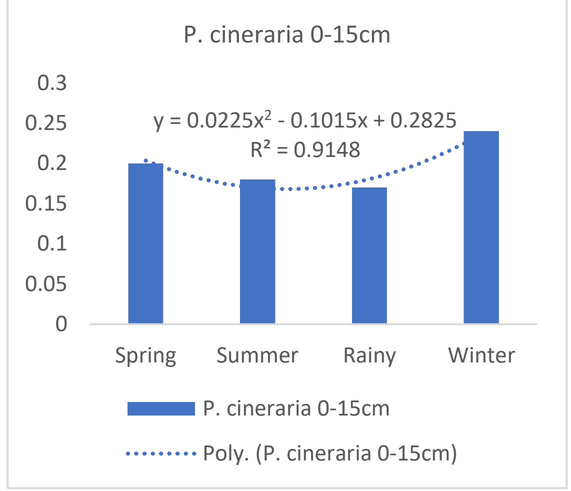

Fig :4- SOC trend in top soil

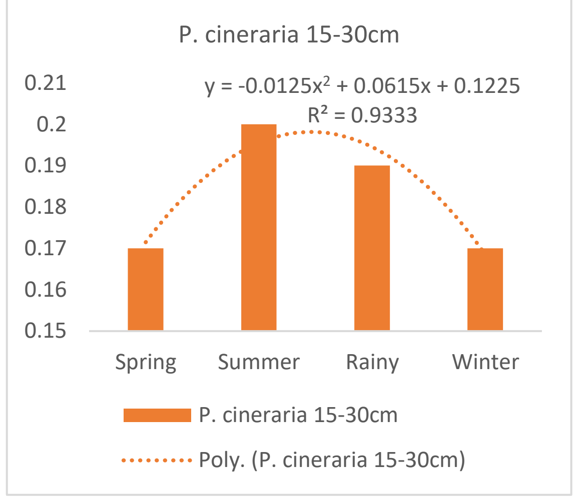

Fig :5- SOC trend in subsoil

A two-way Analysis of Variance (ANOVA) was performed to assess the significance of the differences in SOC levels between *Prosopis cineraria* and control plots across the different seasons. The ANOVA results yielded a p-value of $\mathbf{7.98 \times 10^{-6}}$, indicating a highly significant difference in SOC levels between areas under *Prosopis cineraria* and the control plots. The significantly lower p-value suggests that the presence of *Prosopis cineraria* has a statistically significant effect on increasing SOC levels compared to the control plots across all seasons. Seasonal variations in SOC levels are more pronounced in areas with *Prosopis cineraria*, with winter showing the highest levels of SOC in the topsoil. This analysis highlights the substantial influence of *Prosopis cineraria* in enhancing soil organic carbon levels, contributing to improved soil health in arid regions like Sardarshahar, Rajasthan.

Seasonal variations in land management, along with biological and climatic conditions, primarily influence the structure of the soil at the surface of agricultural soils (Parvin *et al.*, 2021). The present findings are partial in line with the findings of Raina (2003), Singh *et al.* (2007), and Singh and Gill (2014). Changes in soil organic carbon (SOC) are primarily influenced by inputs of organic matter, favorable temperature and moisture conditions, the amount of litter fall, and the chemical composition of tree roots and litter fall under varying climate and soil conditions (Saha *et al.*, 2007; Yuefeng *et al.*, 2014),). Lower temperatures in winter can slow down the decomposition of organic matter, allowing more carbon to accumulate in the soil. *P. cineraria* might also reduce soil temperatures by providing shade, further contributing to higher SOC retention. During the winter, *P. cineraria* shed more leaves, leading to increased organic inputs into the soil. This additional leaf litter provides a continuous supply of carbon, enhancing soil organic matter levels during the colder months. Seasonal differences in root growth and microbial activity under *P. cineraria* may also play a role in SOC dynamics, with more root biomass and associated microbial interactions leading to enhanced carbon stabilization in the soil.

The significantly higher SOC levels under *P. cineraria* compared to the control plots underscore the tree's role in enhancing soil fertility. The tree's deep-rooting system, extensive leaf litter production, and ability to fix atmospheric nitrogen are likely key factors contributing to the higher SOC concentrations observed. The leaf litter from *P. cineraria* decomposes, enriching the soil with organic matter, which not only increases carbon content but also improves the soil's structure and nutrient-holding capacity (Alrajhi *et al.*, 2024).

In contrast, the consistently low SOC levels in control plots suggest a lack of organic matter inputs, highlighting the importance of *P. cineraria* in promoting carbon sequestration in soils where natural vegetation is sparse. This supports the idea that integrating *P. cineraria* into arid agroforestry systems can significantly enhance soil quality and productivity.

The results of this study have important implications for land management and agroforestry practices in arid regions. Incorporating *P. cineraria* into farming systems could serve as a practical approach to improving soil health and combating soil degradation in such environments. The enhanced SOC levels under *P. cineraria* not only improve soil fertility but also contribute to greater soil moisture retention, nutrient cycling, and resilience against erosion.

The ability of *P. cineraria* to stabilize SOC levels across different soil depths and seasons indicates its potential to maintain soil productivity even under adverse climatic conditions. This is particularly relevant in arid regions like Sardarshahar, where soil organic matter is naturally low, and the risk of desertification is high. The tree's contribution to carbon sequestration also aligns with broader global goals of mitigating climate change by enhancing terrestrial carbon sinks (Yadav *et al.,* 2021).

IV. LIMITATIONS OF THE STUDY

While this study provides valuable insights into the role of *P. cineraria* in enhancing SOC, it is limited by its focus on a single location and a specific set of soil depths. Future research should consider exploring the effects of *P. cineraria* across a broader range of soil types and climatic conditions to better understand its potential for wider-scale applications in agroforestry. Additionally, investigating the long-term impact of *P. cineraria* on soil microbial communities and nutrient dynamics would help elucidate the mechanisms driving SOC accumulation. Such studies could provide a more comprehensive understanding of how to optimize the use of *P. cineraria* for sustainable soil management and carbon sequestration in arid and semi-arid regions.

V. CONCLUSION

The study demonstrates that *Prosopis cineraria* plays a critical role in enhancing soil organic carbon levels, particularly in arid agroforestry systems. Its ability to significantly increase SOC concentrations in both the topsoil and subsoil, along with its impact on seasonal carbon dynamics, makes it a valuable species for improving soil health and promoting sustainable land use in regions prone to soil degradation. Integrating *P. cineraria* into agroforestry practices can provide a practical strategy for soil restoration, increased carbon storage, and enhanced agricultural productivity in dryland areas like Sardarshahar, Rajasthan.

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