Impact of Acacia nilotica on Soil Organic Carbon: Implications for Arid Agroforestry with a Case Study of Sardarshahar, Rajasthan, India

Laxmi Pareek[1], Shilpa Yadav[2]

[1,2]Department of Botany, Government Dungar College, Bikaner

Abstract:
Soil organic carbon (SOC) is an important indicator of soil quality and plays a significant role in carbon sequestration and climate-change mitigation, particularly in arid ecosystems. In arid ecosystems, maintenance and enhancement of soil organic carbon is particularly important because low rainfall, high temperature, high evapotranspiration and sparse vegetation constrain organic matter accumulation. Agroforestry systems can improve soil organic carbon through litter deposition, root biomass, nutrient cycling and modification of soil microclimatic conditions. The present study evaluates the influence of Acacia nilotica on soil organic carbon in the arid region of Sardarshahar, Rajasthan, India. Soil samples were collected from beneath the tree canopy and from comparatively open areas at two soil depths, 0–15 cm and 15–30 cm. The study compares spatial and depth-wise variation in SOC associated with A. nilotica and examines its implications for carbon management in arid agroforestry systems. The results are expected to demonstrate the role of A. nilotica in improving soil carbon status and maintaining soil fertility under water-limited conditions. SOC under Acacia nilotica was 47.4% higher than the open area at 0-15 cm depth and 43.3 % higher than the open area at 15-30 cm depth. The observed variation in SOC may be associated with litter accumulation, root- derived organic inputs, nutrient cycling and modification of the soil microenvironment beneath the tree canopy. The findings suggest that A. nilotica can contribute to maintaining soil organic carbon.

Keywords: Acacia nilotica, soil organic carbon, arid agroforestry, carbon sequestration, soil fertility, Sardarshahar, Rajasthan.

1. Introduction

Soil organic carbon is an important indicator of soil quality and plays a significant role in nutrient cycling, soil structure and climate-change mitigation (Lal, 2004; Lal, 2005). Arid and semi-arid ecosystems are characterized by low and irregular precipitation, high evapotranspiration, elevated temperature and limited soil organic matter. These environmental constraints often result in low soil organic carbon and reduced soil fertility. Soil organic carbon is a fundamental component of soil quality because it contributes to nutrient cycling, aggregate stability, water-holding capacity and microbial activity.

Agroforestry provides an important approach for improving soil properties in dryland environments. Trees incorporated into agricultural and grazing landscapes can contribute organic matter through leaf litter, fine-root turnover and decomposition. Tree canopies may also reduce soil temperature, wind velocity and evaporation while creating localized zones of enhanced soil biological activity.

Acacia nilotica is an important multipurpose tree occurring in different parts of India and is well adapted to relatively dry environments. Its litter and root system can contribute organic residues to the soil, potentially increasing SOC beneath the canopy compared with adjacent open areas.
The present study focuses on Acacia nilotica in Sardarshahar, Rajasthan, with particular emphasis on the variation of SOC under tree canopies and in open areas and between two soil depths (0–15 and 15–30 cm).

2. Materials and Methods

2.1 Study Area

The study was conducted in **Sardarshahar, Rajasthan, India**, representing an arid environment of north-western Rajasthan. The region is characterized by low and erratic rainfall, high summer temperatures and prolonged dry periods. These conditions make soil organic matter conservation particularly important.

2.2 Soil Sampling

Soil samples associated with mature Acacia nilotica trees were collected from the study sites. Samples were obtained from two soil depths, and five replicate.

- **0–15 cm**
- **15–30 cm**

For comparison, soil samples were also collected from open areas outside the influence of the tree canopy.

2.3 Estimation of Soil Organic Carbon

Estimation of carbon stocks can follow the methodological framework provided by IPCC (2006, 2019). Soil organic carbon was estimated using the analytical procedure Walkley and black method (Walkley & Black, 1934). The SOC values were expressed as appropriate concentration units and compared between canopy and open-soil conditions.

3. Results

The soil organic carbon (SOC) stock associated with Acacia nilotica was evaluated at two soil depths (0–15 cm and 15–30 cm) under the tree canopy and in the corresponding control area. The observed values showed a consistent canopy effect as well as a depth-wise decline in SOC stock.

Treatment	**0–15 cm**	**15–30 cm**	**Two-depth mean**
A. nilotica canopy	11.5	8.6	10.05
Control	7.8	6.0	6.90

Under the A. nilotica canopy, SOC stock was highest in the 0–15 cm layer (11.5 Mg C ha^{-1}) and decreased to 8.6 Mg C ha^{-1} at 15–30 cm. The corresponding control values were 7.8 and 6.0 Mg C ha^{-1}, respectively. At 0–15 cm depth, the canopy contained 3.7 Mg C ha^{-1} more SOC than the control, representing a 47.4% higher SOC stock relative to the control. At 15–30 cm, the canopy contained 2.6 Mg C ha^{-1} more SOC, equivalent to a 43.3% higher stock.
Within the canopy soil, SOC decreased by 2.9 Mg C ha^{-1} from 0–15 to 15–30 cm, corresponding to a 25.2% decline. In the control soil, the decline was 1.8 Mg C ha^{-1} (23.1%).

3.1 Descriptive statistical interpretation

The mean SOC stock across the two sampled depths was 10.05 Mg C ha^{-1} under A. nilotica and 6.90 Mg C ha^{-1} in the control. Thus, the two-depth mean under the canopy was 3.15 Mg C ha^{-1} higher, or approximately 45.7% higher than the control.

Comparison	**Canopy**	**Control**	**Interpretation**

0–15 cm	11.5	7.8	Canopy +3.7 Mg C ha^{-1}; +47.4%
15–30 cm	8.6	6.0	Canopy +2.6 Mg C ha^{-1}; +43.3%
Two-depth mean	10.05	6.90	Canopy +3.15 Mg C ha^{-1}; +45.7%

The data therefore show two clear descriptive patterns: (i) SOC stock was greater under the A. nilotica canopy than in the control at both depths, and (ii) SOC stock decreased with increasing soil depth in both treatments.

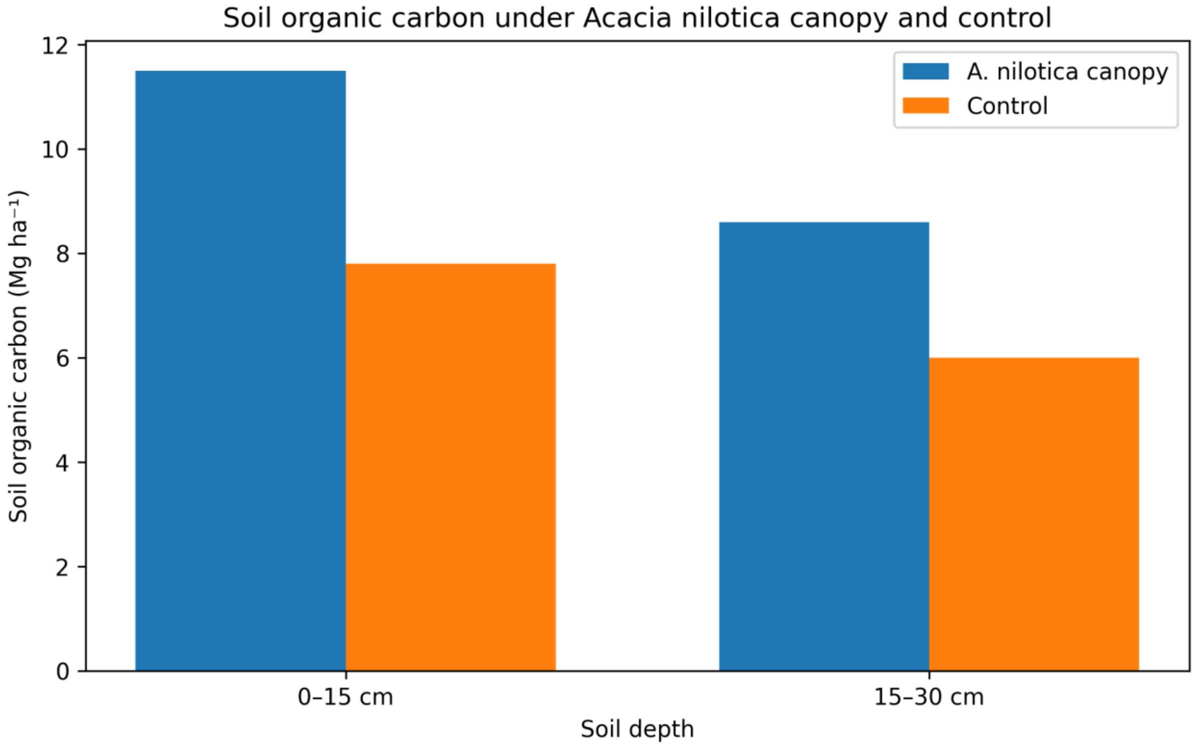

Figure 1. Comparison of soil organic carbon stock under A. nilotica canopy and control at two soil depths.

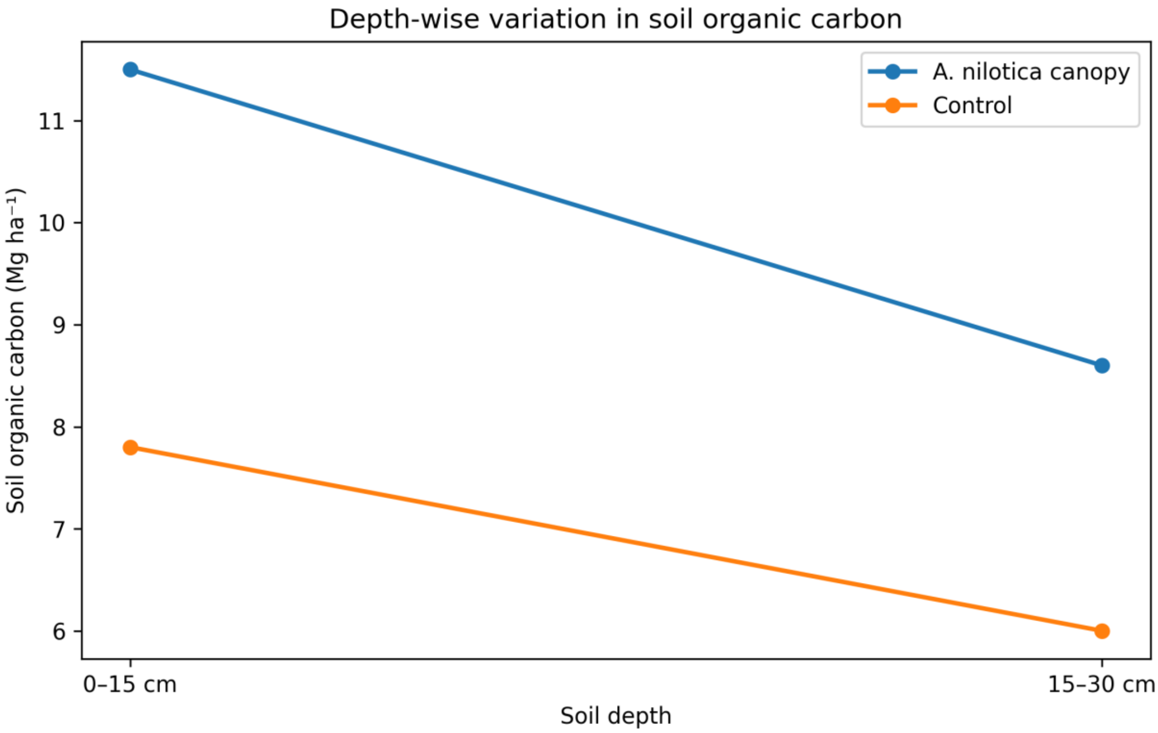

Figure 2. Depth-wise variation in soil organic carbon stock under A. nilotica canopy and control

4. Discussion

Higher SOC under tree canopies may be associated with litter deposition, root turnover and improved microclimatic conditions (Jose, 2009; Nair et al., 2010). Higher SOC beneath Acacia nilotica canopies, where observed in the field data, may be attributed to the accumulation and decomposition of leaf litter and other organic residues. Trees also contribute carbon through root growth, fine-root turnover and rhizosphere processes.

The canopy creates a comparatively favourable microenvironment by reducing direct solar radiation and modifying soil temperature and moisture conditions. These changes can influence decomposition and microbial activity and may promote organic matter accumulation.

The expected higher SOC in the **0–15 cm layer** compared with the 15–30 cm layer is consistent with the fact that most fresh plant residues and litter-derived organic matter enter the upper soil layer. With increasing depth, organic inputs generally decline, resulting in lower SOC concentrations.

Seasonal variation may also occur because rainfall and soil moisture influence decomposition, microbial activity and plant productivity. In arid ecosystems, the rainy season can temporarily increase biological activity and organic matter inputs, whereas prolonged summer dryness can restrict decomposition and plant growth.

5. Implications for Arid Agroforestry

Agroforestry systems can contribute substantially to carbon sequestration through biomass production and soil-carbon accumulation (Montagnini & Nair, 2004; Nair et al., 2010). The findings of this study have important implications for dryland management. Acacia nilotica can potentially contribute to:

- enhancement of soil organic carbon,
- improvement of soil fertility,

- reduction of soil degradation,
- improvement of soil structure,
- carbon sequestration,
- nutrient cycling,
- protection of soil from wind erosion, and
- long-term sustainability of tree-based land-use systems.

Thus, conservation and appropriate integration of suitable native trees such as A. nilotica may be an important component of climate-resilient agroforestry in arid Rajasthan.

6. Conclusion

The present study emphasizes the potential importance of Acacia nilotica in maintaining and enhancing soil organic carbon in the arid environment of Sardarshahar, Rajasthan. The comparison of canopy and open areas, together with the depth-wise assessment of SOC, provides an indication of the influence of tree cover on soil carbon dynamics. The upper soil layer is particularly important because it receives substantial inputs of litter and root-derived organic matter.

Overall, A. nilotica-based agroforestry has potential as a nature-based approach for improving soil quality and enhancing carbon storage in arid landscapes. Integrating suitable native tree species with agricultural and land-management practices may therefore contribute to sustainable soil management and climate-change mitigation in Rajasthan.

7. Acknowledgement

I express my sincere gratitude to CSIR-UGC JRF, which facilitated the successful conduct of this research work.

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