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Research Article

SOIL MICROBIAL DYNAMICS AND THEIR ASSOCIATION WITH PHYSICO-CHEMICAL PARAMETERS IN SILVOPASTORAL SYSTEMS

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ABSTRACT

Silvopastoral systems, which integrate trees, forage grasses, and livestock, are increasingly recognized as a sustainable land-use approach due to their ecological and economic benefits. This study investigates the relationship between soil physico-chemical characteristics and microbial dynamics under four treatments: *Acacia leucophloea*, Guinea grass, a combination of both, and an open plot. Soil samples were collected at 0–30 cm depth and analyzed for parameters including pH, electrical conductivity (EC), bulk density, porosity, soil organic carbon (SOC), microbial populations, and soil respiration rate. The combined treatment of *A. leucophloea* + Guinea grass exhibited the most favorable soil conditions, with the highest pH (7.1), EC (0.32 dS m^{-1}), porosity (51.7%), SOC (0.96%), and microbial activity. Microbial populations, particularly actinomycetes and soil respiration rates, were also maximized in this treatment, indicating improved microbial functioning and nutrient cycling. These results highlight the superior ecological function of integrated silvopastoral systems over monoculture or bare plots, underscoring their potential for soil health restoration and sustainable livestock production.

Keywords: Silvopastoral, Acacia leucophloea, Guinea grass, Soil properties, Microbial analysis.

INTRODUCTION

Silvopastoral systems represent a highly integrated approach within the broader framework of agroforestry, where trees, forage grasses, and livestock are managed together on the same land unit (Yadav *et al.,* 2019). These systems are gaining prominence globally due to their multifunctional benefits and sustainability. By combining woody perennials with pasture and livestock, silvopastoral systems aim to enhance land productivity while simultaneously offering ecological, economic, and social advantages (Mijail *et al.,* 2005). In contrast to conventional livestock systems, they provide a sustainable model that addresses the three fundamental pillars of sustainability planet, people, and profit—by improving environmental health, supporting local livelihoods, and enhancing economic returns (Tedeschi *et al.,* 2015; Chará *et al.,* 2019). A major ecological benefit of silvopastoral systems lies in their potential to rehabilitate degraded grasslands (Nair *et al.,* 2009). They achieve this by improving soil structure, reducing erosion, enhancing fertility, and promoting greater biodiversity. The incorporation of nitrogen-fixing legumes and deep-rooted tree species enhances nutrient cycling and increases soil nutrient availability by accessing deeper soil layers (Nair *et al.*, 2009). These complex interactions foster a more resilient and productive agroecosystem.

Silvopastoral systems are also effective in mitigating climate-related challenges. For example, the presence of trees within pastures helps moderate microclimates, reducing heat stress in livestock during hot summer months

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and improving animal welfare and productivity (Kay *et al.,* 2018; Chará *et al.,* 2019). Additionally, they contribute to improved forage quality and quantity, which supports better livestock performance (Jose and Dollinger, 2019). From a systems ecology perspective, silvopastoral landscapes function as dynamic and evolving biological-abiological complexes. According to Alonso (2003), their development involves multiple interacting elements including soil, vegetation, animals, microbial communities, air and soil fauna, and socio-economic components. These systems undergo continual changes influenced by both natural processes and human interventions.

Proper management practices are crucial for maximizing the potential of silvopastoral systems. The selection of suitable tree and grass species enhances forage yield and grazing efficiency (Broom *et al.,* 2013). The application of organic manure and fertilizers further contributes to increased productivity by improving nutrient dynamics and enhancing carbon dioxide assimilation (Blazier *et al.,* 2008; Lindgren and Sullivan, 2014). These improvements are largely driven by underlying soil biophysical processes, where microbial activity plays a central role in nutrient cycling, organic matter decomposition, and overall soil health (Ahmed *et al.,* 2023). Given their multifunctional advantages and growing relevance in climate-smart agriculture, silvopastoral systems are increasingly viewed as one of the most promising approaches for sustainable land use and livestock production (León-Sicard *et al.,* 2018). The present study aims to evaluate the role of microbial properties in relation to the physico-chemical characteristics of soil within silvopastoral systems, shedding light on their integrated ecological functioning and contribution to sustainable agriculture.

MATERIAL AND METHODS

Study area

The experiment was conducted at the Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam which is located at 11°19'24''N latitude and 76°56'19''E longitude and at an altitude of 230 m above MSL (silvipastoral system).

Soil Sampling

Soil samples were collected from agroforestry fields at three different depths: 0–15 cm, 15–30 cm, and 30–45 cm across three field types: Natural Forest, Agri-silviculture, and Silvipastoral systems. To obtain rhizosphere soil, loosely attached soil was gently shaken off the plant roots and discarded. Soil tightly adhered to the roots was then carefully brushed off and collected as rhizosphere soil. All soil samples were passed through a 2 mm sieve to remove debris and to homogenize the material. The processed samples were stored at 4 °C under refrigerated conditions and analyzed within three months of collection to ensure sample integrity.

Physico-chemical and Microbial properties

The methodologies for analyzing soil properties are given below.

Table 1. Methodologies for analyzing physic-chemical and microbial properties.

S. No.	Parameters	Methodology	Reference
1.	pH	1:2:5 soil water suspension	Jackson (1973)
2.	EC	1:2:5 soil water suspension	Jackson (1973)
3.	Bulk density	Walkley and Black wet oxidation method	Walkley and Black (1934)
4.	Porosity	-	Hillel (2013)
5.	Soil organic carbon	Degtjareff method	Walkley and Black (1934)
6.	Bacteria	Serial dilution and Plating technique	Parkinson (1971)
7.	Fungi		
8.	Actinomycetes		
9.	Soil Respiration Rate	Alkali absorption method	Coleman (1973)

RESULTS AND DISCUSSION

The soil physico-chemical properties varied significantly among the different treatments in the silvopastoral system (Table 2). The combined treatment of *Acacia leucophloea* and Guinea grass showed the most favorable soil conditions, indicated by the highest pH (7.1), electrical conductivity (0.32 dS m^{-1}), lowest bulk density (1.28 Mg/m^3), highest porosity (51.7%), and highest soil organic carbon content (0.96%). The pH values across treatments ranged from slightly acidic to near neutral (6.2 to 7.1), which is generally conducive for most microbial and plant activities. The higher pH observed in the combined treatment might be due to better organic matter inputs and nutrient cycling associated with the presence of both trees and grasses, which can enhance soil buffering capacity.

Electrical conductivity (EC) values were within a non-saline range, with the combined treatment exhibiting slightly higher EC (0.32 dS m^{-1}), reflecting increased nutrient availability from organic residues and root exudates. The open plot showed the lowest EC (0.18 dS m^{-1}), which may be linked to reduced organic inputs and limited microbial activity due to lack of vegetation cover.

Bulk density is a critical indicator of soil compaction and porosity, affecting root penetration, water movement, and microbial habitats. The combined treatment had the lowest bulk density (1.28 Mg/m³), suggesting improved soil structure and less compaction compared to the open plot (1.48 Mg/m³). Correspondingly, the highest porosity (51.7%) was recorded in the combined treatment, indicating greater pore space facilitating aeration and water retention. The open plot had the lowest porosity (44.2%), which may negatively impact soil biological processes and plant growth. Soil organic carbon (SOC) was highest under the combined treatment (0.96%), followed by *Acacia leucophloea* alone (0.88%) and Guinea grass alone (0.76%), with the open plot having the lowest SOC (0.68%). This trend highlights the positive role of integrating trees and grasses in enhancing soil organic matter through litter fall, root biomass, and rhizo deposition, which contribute to nutrient cycling and carbon sequestration. Increased SOC improves soil fertility, moisture retention, and supports diverse microbial communities. Dori *et al.* (2022) studied soil properties across different agroforestry systems and found that the highest pH and EC values were recorded in homegarden systems (6.85 and 0.39 dS m⁻¹, respectively), while the highest bulk density and organic carbon content were observed in the Ficha system (10.38% and 3.79%, respectively). The lowest values for pH, EC, bulk density, and organic carbon were recorded in the Parkland system (5.83, 0.35 dS m⁻¹, 5.36%, and 3.13%, respectively).

Overall, the silvopastoral system combining *Acacia leucophloea* and Guinea grass not only improves soil chemical properties but also enhances physical properties critical for sustainable livestock production. These improvements can lead to better pasture productivity and ecosystem health, reinforcing silvopastoral systems as an effective agroforestry practice for degraded grassland restoration.

Table 2. Physico-chemical properties of different treatments of Silvopastoral system.

S. No.	Treatments	pH	EC (dS m⁻¹)	Bulk density (Mg/m³)	Porosity (%)	Soil Organic Carbon (%)
1.	*Acacia leucophloea*	6.8	0.28	1.35	49.1	0.88
2.	Guinea grass	6.5	0.24	1.38	47.9	0.76
3.	*A. leucophloea* + Guinea grass	7.1	0.32	1.28	51.7	0.96
4.	Open plot	6.2	0.18	1.48	44.2	0.68

The microbial populations and soil respiration rate varied distinctly among the treatments in the silvopastoral system (Table 3). The bacterial population was highest in the *Acacia leucophloea* treatment (26.5 × 10^6 cfu g⁻¹ soil), closely followed by Guinea grass (25 × 10^6 cfu g⁻¹ soil). The lowest bacterial count was observed in the open plot (18 × 10^6 cfu g⁻¹ soil), indicating that vegetation cover positively influences bacterial abundance in the soil. Fungal populations ranged from 7 × 10^5 cfu g⁻¹ soil in the open plot to 17.5 × 10^5 cfu g⁻¹ soil under Guinea grass. Interestingly, the combination treatment (*A. leucophloea + Guinea grass*) showed moderate fungal counts (16.5 × 10^5 cfu g⁻¹ soil), suggesting a balanced fungal community likely supported by diverse organic inputs and root exudates from both trees and grasses. Actinomycetes populations were highest in the combined treatment (9 × 10^4 cfu g⁻¹ soil), which is significant because actinomycetes play an essential role in decomposing complex organic matter and suppressing soil pathogens. The open plot had the lowest actinomycetes count (6.5 × 10^4 cfu g⁻¹ soil), reinforcing the negative impact of bare soil or degraded land on beneficial microbial groups. Radhakrishnan and Varadharajan (2016) studied microbial activity under different agroforestry tree species and concluded that the highest bacterial population was observed in *Ailanthus excelsa*-based agroforestry, the highest fungal population in *Gmelina arborea*-based agroforestry, and the maximum actinomycetes count in *Tectona grandis*-based agroforestry. Soil respiration rate, a direct indicator of microbial metabolic activity and soil health, was also highest in the combined treatment (51.7 mg CO_2-C kg⁻¹ soil day⁻¹), indicating enhanced microbial activity and organic matter turnover. The open plot again had the lowest soil respiration rate (44.2 mg CO_2-C kg⁻¹ soil day⁻¹), reflecting limited microbial activity due to lack of vegetative cover and organic inputs. Lee and Jose (2003) examined soil respiration rates across different agroforestry components and reported the highest rate in a 47-year-old pecan/cotton alley cropping system (506.3 ± 31.4 g C m⁻²), while the lowest rate was recorded in a 3-year-old pecan/cotton alley cropping system (347.7 ± 6.7 g C m⁻²).

These results suggest that silvopastoral systems, especially those integrating trees and grasses, provide a more favorable environment for diverse and active soil microbial communities. The improved microbial population supports nutrient cycling, organic matter decomposition, and soil fertility, which are essential for sustainable pasture productivity. The higher microbial activity in combined treatments aligns with increased soil organic carbon and porosity observed, indicating an overall enhancement in soil quality.

Table 3. Microbial population under silvopastoral system.

S. No.	Treatments	Bacterial population (10^6 cfu g/soil)	Fungal population (10^5 cfu g/soil)	Actinomycetes (10^4 cfu g/soil)	Soil respiration rate mg CO_2-C kg^{-1} soil day^{-1}
1.	*Acacia leucophloea*	26.5	15	8.5	49.1
2.	Guinea grass	25	17.5	8.0	47.9
3.	*A. leucophloea* + Guinea grass	21.5	16.5	9.0	51.7
4.	Open plot	18	7	6.5	44.2

CONCLUSION

The present study confirms that silvopastoral systems, particularly those integrating both *Acacia leucophloea* and Guinea grass, substantially improve soil physico-chemical and biological properties. The combined treatment showed enhanced soil structure through lower bulk density and higher porosity, increased nutrient availability reflected in pH and EC values, and greater organic matter accumulation. Moreover, microbial populations and soil respiration rates were significantly higher in vegetated treatments compared to the open plot, indicating the positive influence of vegetation on soil biological activity. These improvements suggest that silvopastoral practices play a vital role in sustaining soil health, promoting nutrient cycling, and enhancing productivity in degraded landscapes. The findings advocate for wider adoption of such systems in agroecological land management strategies aimed at improving both ecological resilience and agricultural output.

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