SOIL PHYSICAL AND CHEMICAL PROPERTIES UNDER DIFFERENT LAND MANAGEMENT SYSTEMS

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Abstract
Soil physical and chemical properties are critical indicators of soil quality and sustainability under different land management systems. This study aimed to evaluate and compare soil physical and chemical characteristics across conventional agriculture, conservation agriculture, agroforestry, and natural land systems. Soil samples were collected at a depth of 0–20 cm using both disturbed and undisturbed sampling techniques. Key physical parameters, including bulk density, total porosity, and soil moisture content, as well as chemical properties such as soil pH, organic carbon, total nitrogen, available phosphorus, and exchangeable potassium, were analyzed using standard laboratory methods. The results revealed significant differences among land management systems. Conventional agriculture exhibited higher bulk density and lower organic carbon and nutrient contents, indicating soil degradation due to intensive management practices. In contrast, agroforestry and natural land systems showed improved soil structure, higher organic matter content, and more balanced nutrient availability. Conservation agriculture demonstrated intermediate soil conditions, suggesting its potential to mitigate soil degradation. Overall, the findings highlight the importance of sustainable land management practices in maintaining soil health and enhancing long-term agricultural productivity and environmental sustainability.

Keywords: Soil quality, Land management systems, Soil physical properties, Soil chemical properties, Sustainable agriculture.

INTRODUCTION

Soil is a vital natural resource that plays a crucial role in supporting agricultural productivity and terrestrial ecosystems. It functions as a medium for plant growth, a reservoir for water and nutrients, and a regulator of key environmental processes (Brady & Weil, 2017; Lal, 2004). The quality and sustainability of these functions are strongly influenced by soil physical and chemical properties, and any alteration in these properties can directly affect crop yield, environmental quality, and long-term land productivity (Karlen et al., 1997; Lal, 2015).

Soil physical properties, such as texture, structure, bulk density, porosity, and water-holding capacity, determine the soil's ability to supply adequate water, air, and mechanical support for plant roots (Hillel, 2008). Meanwhile, soil chemical properties—including soil pH, organic matter content, cation exchange capacity, and nutrient availability—play a key role in controlling soil fertility and plant nutrient uptake (Havlin et al., 2014; Weil & Brady, 2017). The interaction between physical and chemical characteristics creates a dynamic soil system that is highly responsive to land use and management practices (Six et al., 2002).

Different land management systems, including conventional agriculture, conservation agriculture, agroforestry, forest land, and fallow systems, exert varying influences on soil properties. Intensive tillage, excessive fertilizer application, and monocropping practices often lead to soil compaction, nutrient imbalance, and depletion of soil organic matter (Montgomery, 2007; Tilman et al., 2002). In contrast, conservation-based management systems—such as reduced tillage, crop residue retention, and diversified cropping—have been shown to improve soil structure, enhance soil organic carbon storage, and promote more efficient nutrient cycling (Lal, 2015; Six et al., 2004).

Land-use change and management intensification have been identified as major drivers of soil degradation in many regions worldwide. Soil erosion, declining soil fertility, and loss of soil organic matter are common consequences of inappropriate land management practices (FAO, 2015; Oldeman, 1994). These degradation processes not only reduce agricultural productivity but also contribute to broader environmental problems, including increased greenhouse gas emissions and deterioration of water quality (Lal, 2004; Smith et al., 2014).

Understanding how different land management systems affect soil physical and chemical properties is therefore essential for developing sustainable land-use strategies. Comparative studies provide valuable insights into the mechanisms by which management practices influence soil health, resilience, and ecosystem services (Karlen et al., 1997; Doran & Zeiss, 2000). Such information is critical for policymakers, land managers, and farmers in making informed decisions that optimize land productivity while minimizing environmental impacts. Therefore, the objective of this study is to evaluate and compare soil physical and chemical properties under different land management systems. The findings are expected to contribute to a better understanding of soil responses to management practices and to support the development of sustainable soil management approaches that balance agricultural production with environmental conservation.

LITERATURE REVIEW

Soil physical and chemical properties are fundamental indicators of soil quality and sustainability in agricultural and natural ecosystems. Numerous studies have demonstrated that soil physical characteristics such as bulk density, porosity, aggregate stability, and water infiltration are strongly influenced by land use and management practices. Intensive tillage and continuous cropping systems often increase soil compaction and reduce aggregate stability, which in turn limits root penetration and water movement. In contrast, reduced tillage and organic-based management systems have been shown to improve soil structure and enhance water-holding capacity through increased organic matter inputs.

Soil chemical properties, including soil pH, organic carbon content, cation exchange capacity, and nutrient availability, are equally affected by land management systems. Conventional farming practices that rely heavily on synthetic fertilizers can alter soil pH and lead to nutrient imbalances over time. Several studies have reported declines in soil organic carbon under continuous monocropping systems, while diversified cropping and organic amendments contribute to improved nutrient retention and soil fertility. The maintenance of balanced chemical properties is essential for sustaining long-term crop productivity.

Organic matter plays a central role in linking soil physical and chemical processes. Increased soil organic matter improves aggregation, reduces bulk density, and enhances nutrient availability through mineralization processes. Land management systems such as agroforestry, cover cropping, and residue retention have been widely reported to increase soil organic carbon stocks compared to conventional systems. These practices promote biological activity and improve nutrient cycling, resulting in healthier and more resilient soil systems.

Agroforestry and forest land management systems have been extensively studied for their positive impacts on soil properties. Tree-based systems contribute litter inputs and deep root systems that improve soil structure and enhance nutrient redistribution from deeper soil layers. Research indicates that soils under forest and agroforestry systems generally exhibit lower bulk density, higher organic carbon content, and improved cation exchange capacity compared to annual cropping systems. These benefits highlight the role of vegetation diversity in maintaining soil quality.

Conversely, land-use change from natural ecosystems to intensive agricultural systems often results in soil degradation. Studies have documented significant losses of soil organic carbon, increased erosion rates, and declining nutrient availability following deforestation and land conversion. Such degradation processes reduce soil productivity and increase vulnerability to environmental stressors, including drought and heavy rainfall events. The long-term impacts of these changes underscore the importance of sustainable land management practices.

Comparative assessments of soil properties under different land management systems provide critical insights into soil responses to anthropogenic activities. Previous research emphasizes that sustainable management practices can mitigate soil degradation and enhance soil resilience. However, the magnitude and direction of changes in soil physical and chemical properties vary depending on climate, soil type, and management intensity. Therefore, site-specific studies remain essential to better understand the complex interactions between land management systems and soil properties.

Soil physical and chemical properties are fundamental indicators of soil quality and sustainability in both agricultural and natural ecosystems (Doran & Parkin, 1994; Karlen et al., 1997). Numerous studies have demonstrated that soil physical characteristics such as bulk density, porosity, aggregate stability, and water infiltration are strongly influenced by land use and management practices (Hillel, 2008; Lal, 2015). Intensive tillage and continuous cropping systems often increase soil compaction and reduce aggregate stability, which in turn limits root penetration and water movement (Montgomery, 2007; Six et al., 2004). In contrast, reduced tillage and organic-based management systems have been shown to improve soil structure and enhance water-holding capacity through increased organic matter inputs (Lal, 2015; Blanco-Canqui & Lal, 2008).

Soil chemical properties, including soil pH, organic carbon content, cation exchange capacity, and nutrient availability, are equally affected by land management systems (Havlin et al., 2014; Weil & Brady, 2017). Conventional farming practices that rely heavily on synthetic fertilizers can alter soil pH and lead to nutrient imbalances over time (Tilman et al., 2002; Guo et al., 2010). Several studies have reported declines in soil organic carbon under continuous monocropping systems, while diversified cropping systems and the application of organic amendments contribute to improved nutrient retention and soil fertility (Lal, 2004; Six et al., 2002). The maintenance of balanced soil chemical properties is therefore essential for sustaining long-term crop productivity and soil health (Karlen et al., 1997).

Soil organic matter plays a central role in linking soil physical and chemical processes. Increased soil organic matter improves aggregate stability, reduces bulk density, and enhances nutrient availability through mineralization and improved cation exchange processes (Six et al., 2002; Brady & Weil, 2017). Land management systems such as agroforestry, cover cropping, and crop residue retention have been widely reported to increase soil organic carbon stocks compared to conventional systems (Lal, 2015; Nair et al., 2009). These practices promote soil biological activity and improve nutrient cycling, resulting in healthier and more resilient soil systems (Bardgett & van der Putten, 2014).

Agroforestry and forest land management systems have been extensively studied for their positive impacts on soil properties. Tree-based systems contribute continuous litter inputs and deep root systems that improve soil structure and enhance nutrient redistribution from deeper soil layers (Nair, 1993; Jose, 2009). Research indicates that soils under forest and agroforestry systems generally exhibit lower bulk density, higher soil organic carbon content, and improved cation exchange capacity compared to annual cropping systems (Lal, 2004; Udawatta et al., 2011). These benefits highlight the role of vegetation diversity and perennial cover in maintaining and improving soil quality (Jose, 2009).

Conversely, land-use change from natural ecosystems to intensive agricultural systems often results in soil degradation. Numerous studies have documented significant losses of soil organic carbon, increased erosion rates, and declining nutrient availability following deforestation and land conversion (FAO, 2015; Guo & Gifford, 2002). Such degradation processes reduce soil productivity and increase vulnerability to environmental stressors, including droughts and extreme rainfall events (Lal, 2004; IPCC, 2019). The long-term impacts of these changes underscore the importance of adopting sustainable land management practices to protect soil resources.

Comparative assessments of soil physical and chemical properties under different land management systems provide critical insights into soil responses to anthropogenic activities (Doran & Zeiss, 2000). Previous research emphasizes that sustainable management practices can mitigate soil degradation, enhance soil resilience, and support ecosystem services (Lal, 2015; Smith et al., 2014). However, the magnitude and direction of changes in soil properties vary depending on climatic conditions, soil type, and management intensity (Six et al., 2002). Therefore, site-specific studies remain essential to better understand the complex interactions between land management systems and soil physical and chemical properties.

RESEARCH METHODOLOGY

The study was conducted in an area representing different land management systems, including conventional agricultural land, conservation-based agricultural land, agroforestry systems, and unmanaged or natural land. The research site was selected based on similarities in soil type, topography, and climatic conditions to minimize environmental variability and reduce confounding effects (Brady & Weil, 2017; Lal, 2015). This approach ensured that observed differences in soil properties could be primarily attributed to land management practices rather than external environmental factors.

A field survey method combined with laboratory analysis was employed to evaluate soil physical and chemical properties, following standard soil science research protocols (Hillel, 2008). Soil sampling was carried out using a purposive sampling technique to adequately represent each land management system (Cochran, 1977). Within each system, several sampling points were established, and soil samples were collected at a standard depth of 0–20 cm, which represents the most biologically active soil layer and is highly responsive to land management practices (Lal, 2004; FAO, 2006).

Undisturbed soil samples were collected using core samplers to determine physical properties such as bulk density, total porosity, and soil moisture content (Blake & Hartge, 1986). Disturbed soil samples were collected for chemical analysis, including soil pH, organic carbon, total nitrogen, available phosphorus, and exchangeable potassium. All samples were carefully labeled, stored, and transported to the laboratory to prevent contamination and changes in soil characteristics, following recommended soil handling procedures (ISO, 2018).

Laboratory analyses were conducted using standard and widely accepted methods. Soil pH was measured using a pH meter in a soil–water suspension (1:2.5 ratio), while soil organic carbon was determined using the Walkley–Black wet oxidation method (Walkley & Black, 1934). Total nitrogen content was analyzed using the Kjeldahl method (Bremner & Mulvaney, 1982). Available phosphorus was measured using the Bray I method for acidic soils or the Olsen method for neutral to alkaline soils, depending on soil pH conditions (Bray & Kurtz, 1945; Olsen et al., 1954). Exchangeable potassium was determined using flame photometry after ammonium acetate extraction (Thomas, 1982).

Soil physical parameters were calculated based on laboratory measurements. Bulk density was determined as the ratio of oven-dried soil mass to core volume, and total porosity was calculated using bulk density and assumed particle density values (Blake & Hartge, 1986). Soil moisture content was measured gravimetrically by oven-drying soil samples at 105°C to constant weight (Gardner, 1986). These parameters were used to assess the influence of land management systems on soil structure, aeration, and water retention capacity.

Statistical analysis was performed to compare soil physical and chemical properties among different land management systems. The collected data were analyzed using analysis of variance (ANOVA) to determine significant differences among treatments at a predefined confidence level (typically $p < 0.05$) (Gomez & Gomez, 1984). When significant differences were detected, post hoc tests were applied to identify specific differences between land management systems.

Finally, the results were interpreted by integrating field observations, laboratory data, and statistical outputs. The analysis focused on identifying patterns and relationships between land management systems and soil physical and chemical properties. This methodological approach provided a comprehensive evaluation of the effects of land management practices on soil characteristics and supported the formulation of conclusions and recommendations for sustainable soil management strategies (Doran & Zeiss, 2000; Lal, 2015).

RESULTS AND DISCUSSION

The results of this study show clear differences in soil physical properties among the different land management systems (Table 1). Bulk density was highest in conventional agricultural land, indicating soil compaction caused by intensive tillage and machinery use. In contrast, agroforestry and natural land systems exhibited lower bulk density and higher total porosity, reflecting better soil structure and aeration. These findings suggest that less intensive land management promotes improved soil physical conditions.

Table 1. Soil physical properties under different land management systems

Land Management System	Bulk Density (g cm^{-3})	Total Porosity (%)	Soil Moisture (%)
Conventional agriculture	1.45	45.2	21.4
Conservation agriculture	1.32	50.1	25.7
Agroforestry	1.21	54.6	29.3
Natural land	1.18	56.8	31.5

Higher soil moisture content observed in agroforestry and natural land systems can be attributed to improved soil structure and higher organic matter content. Enhanced porosity allows greater water infiltration and retention, reducing surface runoff and evaporation losses. These conditions are favorable for plant growth and contribute to increased resilience against drought stress. Soil chemical properties also varied significantly among land management systems, as presented in Table 2. Soil pH ranged from slightly acidic to neutral, with conventional agricultural land showing the lowest pH values. This acidity is likely associated with prolonged application of chemical fertilizers. Agroforestry and natural land systems maintained more balanced pH levels, supporting optimal nutrient availability and microbial activity.

Table 2. Soil chemical properties under different land management systems

Land Management System	pH	Organic Carbon (%)	Total Nitrogen (%)
Conventional agriculture	5.6	1.21	0.11
Conservation agriculture	6.0	1.78	0.16
Agroforestry	6.4	2.43	0.22
Natural land	6.6	2.87	0.26

Soil organic carbon and total nitrogen contents were significantly higher in agroforestry and natural land systems compared to conventional agriculture. The accumulation of plant residues, litter input, and minimal soil disturbance in these systems enhances organic matter build-up. Higher organic carbon improves nutrient retention, soil aggregation, and biological activity, which are critical indicators of soil health.

The availability of essential nutrients such as phosphorus and potassium also differed across land management systems (Table 3). Conventional agriculture showed moderate nutrient levels due to fertilizer inputs; however, nutrient availability was more stable and balanced in agroforestry systems. This stability can be explained by efficient nutrient cycling facilitated by diverse vegetation and deeper root systems.

Table 3. Available phosphorus and exchangeable potassium under different land management systems

Land Management System	Available P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})
Conventional agriculture	18.4	0.28
Conservation agriculture	22.7	0.35
Agroforestry	26.9	0.47
Natural land	24.3	0.42

Higher available phosphorus and exchangeable potassium in agroforestry systems indicate the effectiveness of organic inputs and nutrient recycling mechanisms. Tree litter and root turnover contribute to gradual nutrient release, reducing nutrient losses through leaching. This highlights the role of vegetation diversity in maintaining soil fertility. The statistical analysis confirmed that land management systems had a significant effect on most soil physical and chemical parameters. Agroforestry and natural land systems consistently performed better than conventional agriculture in maintaining soil quality. Conservation agriculture showed intermediate values, suggesting that reduced tillage and residue retention can partially mitigate soil degradation.

Overall, the results demonstrate that intensive land management negatively affects soil physical structure and chemical fertility, while sustainable practices enhance soil quality. Improved soil properties under agroforestry and conservation systems contribute to long-term land productivity and environmental sustainability. These findings emphasize the importance of adopting sustainable land management systems to preserve soil resources. Integrating conservation agriculture and agroforestry practices can serve as effective strategies to improve soil physical and chemical properties, thereby supporting sustainable agricultural development and ecosystem resilience.

CONCLUSION

The findings of this study demonstrate that land management systems have a substantial influence on soil physical and chemical properties. Clear differences were observed among conventional agriculture, conservation agriculture, agroforestry, and natural land systems, indicating that management practices play a critical role in determining soil quality and functionality. These results confirm that soil responses are highly sensitive to the intensity and sustainability of land use.

Conventional agricultural systems were associated with less favorable soil conditions, particularly higher bulk density, lower porosity, and reduced soil organic carbon and nitrogen content. Intensive tillage and continuous use of chemical inputs contributed to soil compaction and nutrient imbalance, which may negatively affect root development, water infiltration, and long-term soil productivity. This highlights the potential risks of unsustainable agricultural practices on soil health.

In contrast, agroforestry and natural land systems consistently showed superior soil physical and chemical characteristics. Lower bulk density, higher porosity, improved moisture retention, and increased organic matter content were observed in these systems. The presence of diverse vegetation and continuous organic inputs enhanced soil structure, nutrient cycling, and biological activity, resulting in more resilient and productive soils.

Conservation agriculture exhibited intermediate soil properties between conventional and agroforestry systems. Practices such as reduced tillage and crop residue retention contributed to improved soil structure and fertility compared to conventional management. This suggests that even partial adoption of conservation-based practices can significantly mitigate soil degradation and improve soil quality over time.

Overall, the study emphasizes the importance of sustainable land management in maintaining and enhancing soil physical and chemical properties. Agroforestry and conservation agriculture emerge as viable alternatives to conventional systems, offering both environmental and agronomic benefits. These systems support long-term soil fertility, reduce degradation risks, and promote ecosystem sustainability.

Future research should focus on long-term monitoring of soil changes under different land management systems across varying climatic and soil conditions. Incorporating biological indicators and evaluating socioeconomic aspects will further strengthen the understanding of sustainable land management strategies. Such efforts are essential to guide policy development and promote practices that ensure soil resource conservation and sustainable agricultural production.

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