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Physico-chemical soil attributes associated with *Bambusa* plantation at Rana Safari Park, Head Balloki

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Abstract

Bamboo (Bambusa spp.) plantations can change soil physical and chemical characteristics. This impacts nutrient cycling, moisture retention, and soil fertility. This study evaluated soil properties under Bambusa plantations at Rana Safari Park, Head Balloki, Punjab, Pakistan. The park spans 250 acres, with roughly 200 acres covered by bamboo forest. Six representative plantation sites were sampled at standard depths to assess physical attributes, such as texture, moisture content, and saturation percentage, along with chemical attributes, including pH, electrical conductivity, and macro- and micro-nutrients. Soil analyses followed standard protocols, and we evaluated results using Redundancy Analysis (RDA). Soils showed slight alkalinity, with pH levels between 7.51 and 8.72. Electrical conductivity varied from 0.324 to 1.796 dS m^{-1}. The contents of sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and nitrogen (N) ranged from 11 to 47 mg g^{-1}, 14 to 32 mg g^{-1}, 3 to 38 mg g^{-1}, and 0.196 to 0.294 mg g^{-1}, respectively. Moisture content ranged from 8.35% to 29.6%, and saturation percentage varied from 33% to 45%. Textures ranged from sandy loam to sandy clay loam. The findings show that Bambusa plantations improve soil nutrient levels and water retention. They play a crucial role in soil conservation and sustainable land management in semi-arid ecosystems.

Keywords: Bambusa, Soil, Nutrients, pH, Conductivity, Moisture, Fertility

Introduction

Bamboo (*Bambusa* spp.) belongs to the Poaceae family and the subfamily Bambusoideae. It is well-known for its rapid growth, reaching maturity in 3 to 5 years. It significantly helps with carbon capture, soil stabilization, and restoring ecosystems (Partey *et al.* 2017; Emamverdian *et al.* 2020). Bamboo is gaining attention for its economic benefits in construction, handicrafts, and agroforestry. It also plays a crucial role in reducing land degradation and the effects of climate change (Dwivedi *et al.* 2019; Solomon *et al.* 2021).

Bamboo stands greatly improve soil health. Their fibrous roots enhance soil structure, decrease erosion, and help water soak in (Kaushal *et al.* 2020). Regular litterfall increases soil organic matter and nutrient cycling. These advantages are particularly important in semi-arid and degraded areas (Paudel *et al.* 2015; Zaninovich *et al.* 2017). Moreover, bamboo plantations have shown positive changes in soil microbial activity and enzyme behavior, indicating better soil nutrition and ecosystem function (Tu *et al.* 2013; Emamverdian *et al.* 2020).

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However, site-specific studies, especially in Pakistan's unique semi-arid ecosystems, are limited. Recent regional research highlights how plant types affect soil properties (Majeed *et al.* 2022). For example, studies in Punjab's lowland districts show that the distribution of woody species strongly correlates with differences in soil qualities like nutrient availability and moisture (Waheed *et al.* 2022). Similar findings from South Asian drylands indicate that tree and grass species can enhance nutrient cycling and soil water retention, thereby improving soil structure and biological activity (Sharma *et al.* 2021). Yet, while forest plantations such as *Acacia*, *Dalbergia*, and *Eucalyptus* have been extensively studied for their impacts on soil fertility, comparable investigations on bamboo-based ecosystems are scarce. This knowledge gap is significant because bamboo's rapid growth, dense rooting system, and high litter turnover may uniquely influence soil quality in ways that differ from other woody perennials (Kaushal *et al.* 2020). Therefore, conducting site-specific assessments of bamboo plantations in Pakistan is essential for developing effective strategies to enhance soil fertility, moisture conservation, and sustainable land management in semi-arid environments.

Rana Safari Park at Head Balloki, ~54 km from Lahore, contains a ~200-acre *Bambusa* plantation that serves as a natural laboratory for assessing bamboo–soil interactions in semi-arid conditions. This study evaluated key soil properties (pH, EC, moisture content, saturation percentage, and macronutrients: Na^+, K^+, Ca^{2+}, N) across plantation sites to identify spatial differences and assess bamboo's influence on fertility and moisture retention. The findings provide insights for sustainable soil and land management in Pakistan's semi-arid parklands and address a broader knowledge gap on bamboo-dominated landscapes in South Asia.

EXPERIMENTAL

The Study Area

The study took place at Rana Luxury Resort and Safari Park, situated at Head Balloki, Punjab, Pakistan, about 48 km from Lahore. The park covers around 250 acres, with roughly 200 acres taken up by a thick *Bambusa* plantation. This site was chosen because it has a mostly undisturbed natural habitat and a dense bamboo jungle that creates a special microenvironment. The climate in the area is semi-arid, featuring hot summers, mild winters, and an average annual rainfall of 500 to 700 mm, mostly during the monsoon season.

Soil Analysis

Soil samples were collected from six locations within the bamboo plantation, each with three replications, from a depth of 0 to 15 cm using a stainless-steel auger. The three cores from each site were combined, mixed, and air-dried at room temperature. Samples were carefully crushed and passed through a 2 mm sieve before analysis. Soil texture was determined using the soil textural triangle method, filling about one-quarter of a 1000 mL graduated cylinder with a known weight of soil. Distilled water was added to fill the cylinder, and the mixture was shaken for 10 to 15 min to break up aggregates. The suspension was allowed to settle, and the layers of sand, silt, and clay were measured after specific intervals (1 min for sand, 2 h for silt). The percentage of clay was found by calculating the difference, and the soil texture class was identified using the USDA soil texture triangle (Table 1).

Table 1: Soil characteristics of *Bambusa* plantation selected at the Rana Safari Park Head Balloki.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Sand	78%	66%	86%	77%	62%	38%
Silt	11%	14%	2%	4%	15%	27%
Clay	9.60%	19%	11%	18%	22%	33%
Soil Texture	Sandy Loam	Sandy Loam	Loamy Sand	Sandy Loam	Sandy Clay Loam	Clay Loam

Electrical conductivity (EC) and pH

Electrical conductivity (EC) and pH were measured from saturation extracts following the methods of Rhoades (1982) and Jackson (1967). Saturation pastes were made by adding distilled water to dry soil samples, which were then filtered under vacuum to get extracts. A calibrated pH meter measured pH, while a conductivity meter measured ECe.

Moisture content

Moisture content was determined by following the procedure proposed by Reynolds and Topp (2008). The fresh soil samples weighed right after collection using a portable digital balance. Samples were put in labeled paper envelopes and oven-dried at 65 °C until they reached a constant weight. Moisture content was calculated as the percentage loss in weight compared to the initial fresh weight.

Macro- and micronutrients

Macro- and micronutrient concentrations were measured using the acid digestion method described by Wolf (1982). Dried, ground soil samples (0.1 g) were placed in digestion tubes, and 2 mL of concentrated H_2SO_4 was added. The samples were incubated overnight, then 0.5 mL of 35% H_2O_2 was added. The tubes were heated at 350 °C until the mixture became clear, adding more H_2O_2 as needed. The digested material was diluted to 50 mL with distilled water, filtered, and used for nutrient analysis.

Nutrient analysis

Sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}) amounts were measured using a flame photometer (Jenway PFP-7) calibrated with standard solutions from 10 to

100 ppm. The concentrations were determined by comparing sample readings with standard curves (Estefan *et al.* 2013).

Nitrogen content

Nitrogen content was estimated using the micro-Kjeldahl method (Bremner, 1965). For distillation, 5 mL of the digested sample was placed in a Kjeldahl unit, and 5 mL of 40% NaOH was added. Ammonia distilled into 5 mL of 3% boric acid with a mixed indicator. Distillation continued until about 40 mL of distillate was collected, which was then titrated with 0.01 N H_2SO_4 until a pink endpoint appeared. Nitrogen content was calculated with the formula:

$$\text{Nitrogen (\%)} = [\{(V_2 - V_1) \times N \times 0.014\} / W] \times 100$$

where V_2 is the volume of H_2SO_4 for the sample, V_1 is the volume for the blank, N is the normality of H_2SO_4, and W is the sample weight in grams.

Statistical analysis

All analyses were conducted in triplicate, and mean values were used for statistical evaluation. Descriptive statistics and bar graphs were prepared in Microsoft Excel 2010 to compare site-specific variations. Multivariate analysis was performed using Redundancy Analysis (RDA) in R software with the *vegan* package (Oksanen *et al.* 2022). Data were log-transformed [log(x+1)] before ordination, and the significance of explanatory variables was assessed through 999 Monte Carlo permutations ($p < 0.05$), allowing a robust assessment of relationships among soil properties across sites.

RESULTS AND DISCUSSION

Soil pH

The soil pH at the six Bambusa plantation sites varied from 7.51 at Site 3 to 8.72 at Site 6, showing slightly to moderately alkaline conditions (Figure 1). The higher pH values in Sites 4 to 6 (greater than 8.4) might affect the solubility and availability of micronutrients like Fe, Mn, and Zn (Rengel, 2014). The alkalinity in these sites could be due to the calcareous parent material and low leaching rates typical of semi-arid to sub-humid environments (Alnaimy *et al.* 2023). Similar alkaline trends

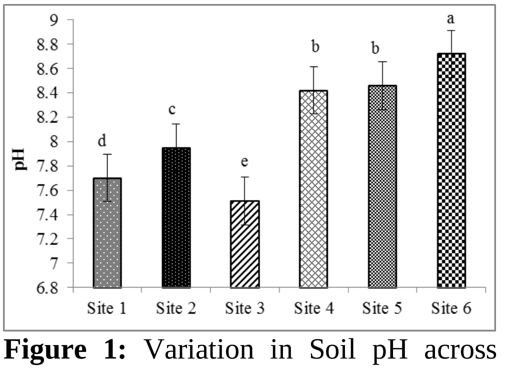

Figure 1: Variation in Soil pH across sites with *Bambusa* plantations at Rana Safari Park, Head Baloki.

have also been seen in bamboo plantations in various regions of south Asia, where high rates of evapotranspiration contribute to the build up of carbonates in the soil (Zhang *et al.* 2023). To keep the pH within the optimal range for bamboo growth (6.0-7.5), management practices might need to include organic amendments or acidifying agents.

Electrical Conductivity (EC)

Electrical conductivity (EC) values showed significant differences among sites. The highest readings were at Sites 1 (1.796 dS/m) and 2 (1.788 dS/m), while Site 3 had the lowest at 0.324 dS/m (Figure. 2). The higher ECe at Sites 1 and 2 suggests larger amounts of soluble salts, possibly due to nearby groundwater or occasional irrigation (Stavi *et al.* 2021). The low EC in Site 3 indicates little salinity stress, which is favourable for bamboo establishment. Bamboo can tolerate some salinity (Pulavarty and Sarangi, 2018), but consistently high EC could hurt growth rates by disrupting osmotic balance. Managing salinity, like leaching with low-salinity water, might be important in areas with higher EC (Othaman *et al.* 2020).

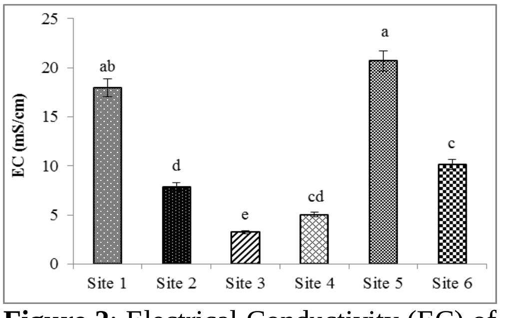

Figure 2: Electrical Conductivity (EC) of soils from different sites with *Bambusa* species at Rana Safari Park, Head Balloki.

Sodium (Na^+) Content

Sodium (Na^+) content showed a wide range, from 11 mg/g at Site 5 to 47 mg/g at Site 2 (Figure 3a). Sites 1 and 2 had both high Na^+ and high EC, which matches sodicity-salinity interactions found in other subtropical bamboo areas (Yin *et al.* 2023). Elevated Na^+ levels may affect soil structure by dispersing clay particles, which can reduce infiltration and aeration (Rengasamy *et al.* 2018). Bamboo's fibrous root system can help improve aggregate stability (Ma'ruf *et al.* 2012), but on-going sodicity could still harm soil health without corrective actions like applying gypsum.

Potassium (K^+) Content

Potassium (K^+) content was highest at Site 2 (32 mg/g) and lowest at Site 5 (14 mg/g) (Figure 3b). Potassium is essential for managing stomatal activity and stress resistance in bamboo (Wang *et al.* 2013). The higher K^+ availability at Site 2 might be related to its sandy loam texture and lower ability to hold clay, which allows more K^+ to move. The lower K^+ at Site 5 may be due to higher clay content and possible fixation by elite-type minerals (Hamoud *et al.* 2019). Regular K^+ supplementation might boost resilience in areas with low K^+.

Calcium (Ca^{2+}) Content

Calcium (Ca^{2+}) concentrations ranged from 3 mg/g in Site 3 to 38 mg/g in Site 2 (Figure 3c). The higher levels of Ca^{2+} concentration in Sites 1 and 2 showed the calcareous nature of the soil, which help in root development and cell wall stability (White *et al.* 2003). However, too much Ca^{2+} in alkaline soils can lead to precipitation with phosphates, lowering available P (Penn and Camberato, 2019). This interaction may need targeted P management in areas with high Ca^{2+}.

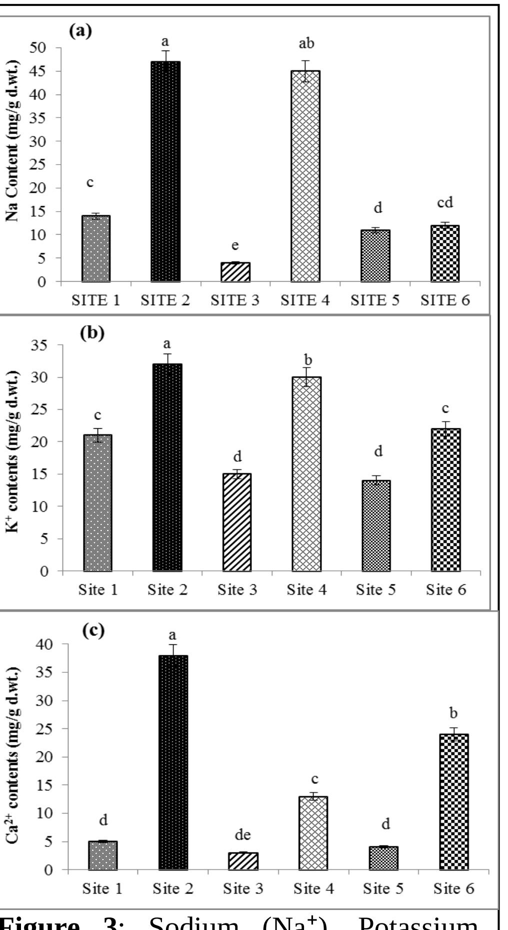

Figure 3: Sodium (Na^{+}), Potassium (K^{+}), and Calcium (Ca^{2+}) Contents in *Bambusa* species across different sites at Rana Safari Park, Head Balloki.

Moisture Content (MC)

Moisture content was highest at Site 3 (29.6%) and lowest at Site 1 (8.35%) (Figure 4). The high MC at Site 3 may connect to its loamy sand texture and microtopography, which help retain moisture even with low clay content (Guo *et al.* 2022). In contrast, low MC at Site 1 might stem from its coarse texture and higher bulk density, which limit water-holding capacity (Rasheed *et al.* 2022). Bamboo's dense canopy decreases evaporation, but in low-MC sites, additional irrigation may be necessary during long dry spells.

Saturation Percentage (%)

Saturation percentage values ranged from 33% at Site 6 to 45% at Sites 2 and 5 (Figure 5). A higher saturation percent usually indicates finer textures and greater micropore volume (Sun *et al.* 2023). This was evident in Site 5 (sandy clay loam), where increased clay content improved water retention. Bamboo plantations thrive in soils with moderate to high saturation percentage since they can resist short-term droughts.

Nitrogen content

Nitrogen content ranged from 0.196 mg/g at Site 1 to 0.294 mg/g at Site 2 (Figure 6). The higher nitrogen levels in Site 2 might result from more litter deposition and quicker mineralization rates under favorable moisture and temperature (Zhang *et al*. 2022). Nitrogen cycling is crucial for bamboo productivity, as greater leaf litter inputs play a significant role in improving soil fertility (Padgurschi *et al.* 2018). Low N sites may need organic or inorganic N supplements for ongoing growth.

Soil Texture

The texture analysis showed sandy loam at Sites 1, 2, and 4; loamy sand at Site 3; sandy clay loam at Site 5; and clay loam at Site 6 (Table 1). The high sand content at Site 3 (86%) decreases nutrient retention but allows for quick drainage. Meanwhile, the higher clay content at Site 6 (33%) increases nutrient retention but could hinder aeration. Previous studies show that bamboo grows best in loamy textures that balance drainage and nutrient-holding ability, suggesting that management practices should consider texture (Emamverdian *et al.* 2020; Zhou *et al*. 2022; Chen *et al*. 2022).

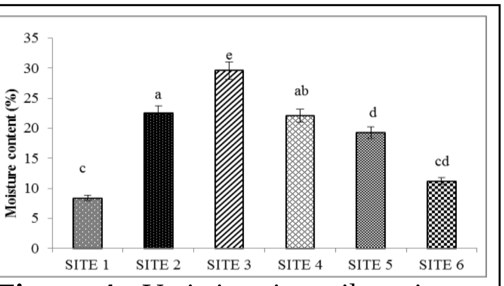

Figure 4: Variation in soil moisture content across sites with *Bambusa* plantations at Rana Safari Park, Head Balloki.

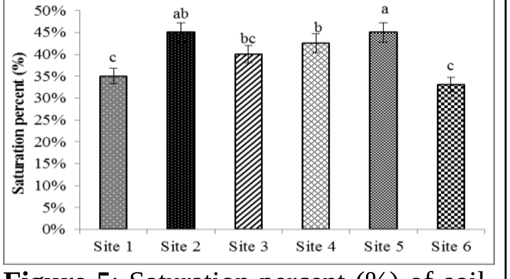

Figure 5: Saturation percent (%) of soil at different sites with *Bambusa* plantation at Rana Safari Park, Head Balloki.

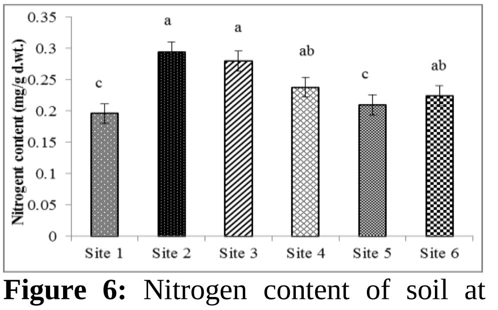

Figure 6: Nitrogen content of soil at different sites with *Bambusa* plantation at Rana Safari Park, Head Balloki.

Multivariate Analysis (RDA)

Redundancy Analysis (RDA) grouped the six sites based on their soil chemical and physical profiles (Figure 7). Sites 1 and 2 clustered together due to high Na^{+}, Ca^{2+}, and ECe levels, while Site 3 was distinct for having high MC and low EC. Sites 4 to 6 formed another cluster in between. Strong positive links were found between EC and Na^{+} (Tavakkoli *et al.* 2010), and between clay content and MC (Zhou *et al.* 2022), highlighting connections between texture, moisture, and

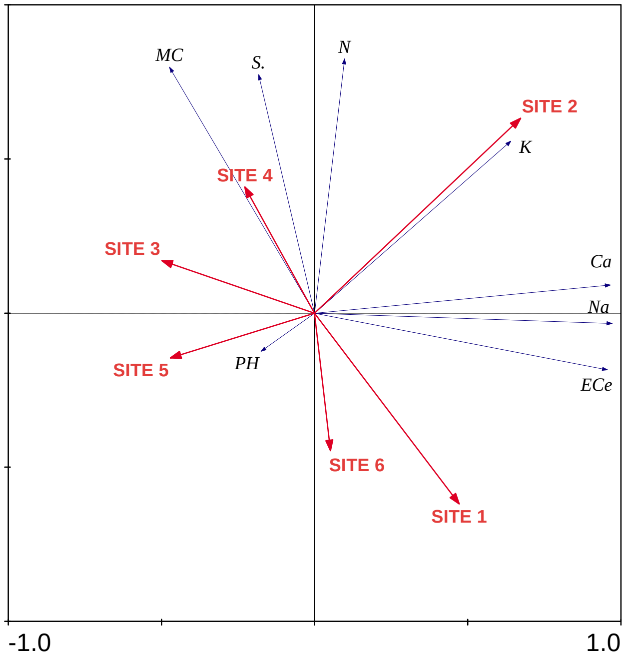

Figure 7: RDA (Redundancy Analysis) ordination biplot showing the effect of *Bambusa* plantation on biochemical attributes of soil collected from of Rana Safari Park near Head Balloki.

nutrients. Similar multivariate patterns have been seen in bamboo plantations in South Asia, emphasizing that variability in soil conditions is a primary factor in nutrient dynamics (Chantarat *et al.* 2023).

Conclusion

This study showed that soils in the Bambusa plantation at Rana Safari Park, Head Balloki, have notable differences in their physical and chemical properties across various locations, affected by texture and nutrient levels. Soil pH was slightly to moderately alkaline, with some sites having higher than ideal levels for nutrient availability. Sites with higher electrical conductivity (ECe), sodium (Na^+), and calcium (Ca^{2+}), particularly Sites 1 and 2, clustered closely in the multivariate analysis. In contrast, Site 3 was distinguished by its higher moisture content and lower salinity. The texture varied from sandy loam to clay loam, which affected moisture retention and nutrient processes. Overall, bamboo plantations in this area support soils that are rich in certain macronutrients, such as Na^+, K^+, and Ca^{2+}. However, some lower-value sites may need additional nitrogen and potassium. Site-specific soil management, including pH adjustment, salinity control, and irrigation planning based on texture, can improve both bamboo growth and soil health. These findings serve as a starting point for sustainable management of bamboo-dominated ecosystems in semi-arid subtropical regions of Pakistan and similar areas.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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