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Comparative Analysis of Macronutrient, Soil Sulphur Availability and Micronutrient Dynamics across Diverse Land Use Types of Indo-Gangetic plains of India

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ABSTRACT

This study investigates the macronutrient, soil sulphur availability, and micronutrient dynamics across five land use types in Samastipur District, Bihar: mango orchard, forest land, sugarcane field, dhab land, and uncultivated land. Soil samples were collected from two depths (0–20 cm and 20–40 cm) to assess nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and key micronutrients such as zinc (Zn), boron (B), and iron (Fe). Mango orchard soils exhibited the highest macronutrient concentrations, with available N reaching 325.57 kg ha^{-1}, P at 19.08 kg ha^{-1}, and K at 190.13 kg ha^{-1}. Sulphur availability was highest in mango orchards (19.80 mg kg^{-1}), while micronutrient availability was also superior compared to other land use types. Conversely, uncultivated and dhab lands recorded significantly lower nutrient levels, highlighting soil fertility challenges. This study encountered challenges related to the variability in soil properties across land use types, which influenced nutrient availability and required rigorous sampling and analytical procedures. Despite these challenges, the study provides critical insights into macronutrient, sulphur, and micronutrient dynamics in diverse land use systems. The findings highlight the impact of organic matter inputs and land management on soil fertility, offering valuable recommendations for sustainable soil management practices in the Indo-Gangetic Plains. These findings underscore the critical role of land use in influencing soil nutrient dynamics and emphasize the need for tailored soil management strategies to optimize land productivity and sustainability.

Keywords: *Soil, Nutrient, Land Use Type, Mango orchard, Sugarcane, Dhab land, Uncultivated land*

Introduction

Soil fertility, a cornerstone of agricultural productivity and ecosystem sustainability, is profoundly influenced by land use practices [16].Macronutrients-nitrogen (N), phosphorus (P), and potassium (K) are essential for plant growth and yield [14,28]. Similarly, secondary nutrients like sulphur (S) and micronutrients such as zinc (Zn), boron (B), and iron (Fe) play pivotal roles in enzymatic functions [2], photosynthesis, and protein synthesis [7, 8]. The dynamics of these nutrients in soil are governed by a combination of intrinsic factors, such as soil type and organic matter content, and extrinsic factors, including land use and management practices [26]. Samastipur District, located in the Indo-Gangetic Plains of Bihar, India [19], is characterized by diverse land use systems, including mango orchards, forest lands, sugarcane fields, dhab lands (low-lying flood-prone areas), and uncultivated lands [12]. These land use types exhibit varying vegetation cover, organic matter inputs

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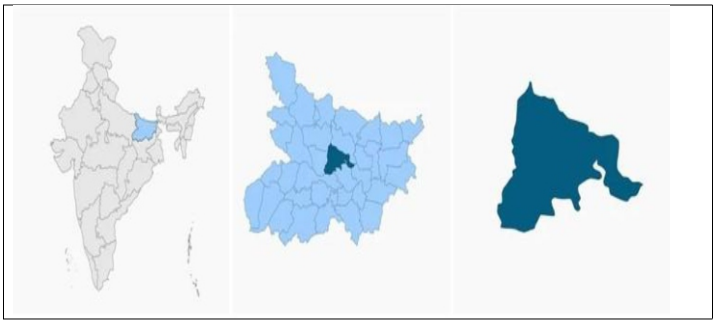
[31], and anthropogenic interventions, all of which significantly influence soil nutrient availability. For instance, mango orchards and forest lands, with their perennial vegetation and litter deposition, are likely to exhibit higher nutrient availability compared to more disturbed or unmanaged systems such as dhab lands and uncultivated areas [3].Macronutrient availability in soil, particularly N, P, and K, is critical for sustaining crop yields [25]. Nitrogen, the primary driver of vegetative growth, is often the most limiting nutrient in agricultural soils [21]. Phosphorus and potassium are equally vital, supporting energy transfer and osmotic regulation in plants [17]. Sulphur, a secondary nutrient, is essential for protein synthesis [22, 30] and is often deficient in intensively cultivated soils [35]. Micronutrients like Zn, B and Fe although required in trace amounts are indispensable for plant metabolism and growth [1].Despite their importance, the status and dynamics of these nutrients under different land use systems in Samastipur remain underexplored. Understanding these dynamics is crucial for devising sustainable land management practices and addressing soil fertility challenges [15]. This study aims to fill this gap by conducting a comparative analysis of macronutrient, soil sulphur, and micronutrient dynamics across five land use types. By quantifying nutrient concentrations and analyzing their spatial variability, the study provides insights into the interplay between land use and soil fertility [11]. The findings are expected to inform targeted soil management strategies, contributing to enhanced agricultural productivity and environmental sustainability.

Materials and Methods

Study Area

The study was conducted in Samastipur District, Bihar, situated between latitudes 25¸50'N and 26°15'N and longitudes 85¸45'E and 86¸20'E and at an altitude of 53m /174 feet above the mean sea level (MSL) in the Gangetic plain of Bihar. Samastipur is an important agricultural zone, which comes under North West Alluvial Plain Zone with a semi-arid to sub-tropical climate. The district is surrounded by Darbhanga in North, Khagaria in the East, Muzaffarpur and Vaishali in the west and Begusarai and Patna in the south. The location of the study area in map of India as well as Bihar is depicted in the fig. 1.



India Bihar Samastipur

Fig.1 Location map of the study area

Climatic conditions

The district experiences a subtropical climate, with an average annual rainfall of 1,200 mm and a mean temperature of 26°C. The soils are predominantly alluvial, with variations in texture and fertility across land use systems. The climate is warm and temperate in Samastipur district of Bihar. In winter, there is much less rainfall in Samastipur than in summer. The Koppen-Geiger climate classification is Cwa. The average annual temperature is 25.2 °C in Samastipur. The annual rainfall is 1236 mm. The driest month is November and the most precipitation falls in July. The warmest month of the year is May while January has the lowest average temperature. Average weekly data of different weather parameters have been presented in fig.2.

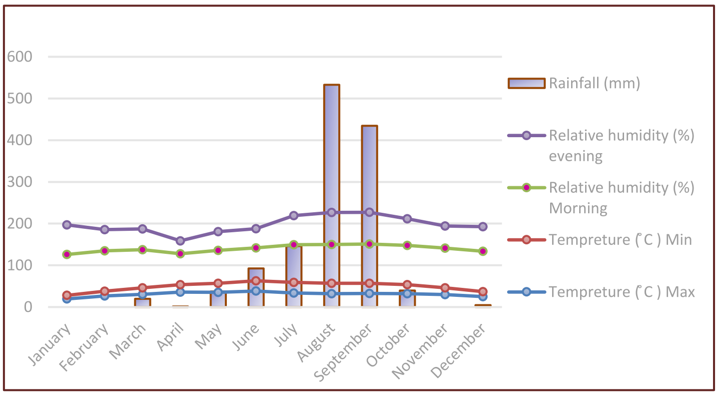


Fig. 2 Monthly meteorological data (2023) of study area

Soil Sampling

Soil samples were collected from five land use types: mango orchards, forest land, sugarcane field, dhab land, and uncultivated land. Sampling was conducted at two depths (0–20 cm and 20–40 cm), with five replicates per site. Samples were air-dried, sieved (2 mm), and stored for laboratory analysis following the standard procedure.

Analytical Methods:

Nitrogen (N)was determined using the Kjeldahl method,The quantities of available nitrogen, were determined according to the Alkaline potassium permanganate method [34], The quantities of available phosphorus and potassium were determined, usingthe Ascorbic acid method [36], and the Flame photometry method [10] respectively.The available sulfur (S) were extracted with 0.15% calcium chloride and analyzed using a turbidimetric method [6].Boron was extracted from the soil using the hot water extraction method [5]. Micronutrient cations (Zn and Fe) were extracted from the soil using the DTPA method [23].

Statistical Analysis

Data were subjected to ANOVA to determine the effects of land use and soil depth on nutrient concentrations. Tukey's HSD test was used for post hoc comparisons.

Results and Discussion

Macronutrient Dynamics

Mango orchards exhibited the highest macronutrient concentrations, with available N, P, and K recorded at 325.57 kg ha^{-1}, 19.08 kg ha^{-1}, and 190.13 kg ha^{-1}, respectively, at 0–20 cm depth (Table 1). Forest land also demonstrated relatively high nutrient levels, reflecting the positive impact of organic matter deposition. In contrast, uncultivated and dhab lands recorded significantly lower macronutrient concentrations, underscoring the need for soil fertility enhancement in these systems.The lowest value of available nitrogen (120.89 kg ha^{-1}), available Phosphorus (10.49kg ha^{-1}), available Potassium (100.89kg ha^{-1}) was found in Dhab land at 0-20 cm depths of soil while the lowest value of available Sulphur (8.02 mg kg^{-1}) was recorded in Uncultivated Land the than other land use patterns.Across all the land use patterns available nitrogen content tends to decrease with depth, it might be due to in surface layers generally have more organic matter content, root activity and microbial population [24] which contribute to higher nitrogen content as compare to deeper layer of soil. Similar result also obtained by Sinha et.al., 2024a [33].Dhab land was recorded lowest available nitrogen content among all land use patterns due to lack of vegetation and organic matter input contributes to lower nitrogen levels. In mango orchard was highest available nitrogen content among all depths and land use patterns it might be due to continuous leaf litter decomposition, higher the organic matter content and microbial biomass that resulting enhance the nitrogen mineralization. And also mango orchard show maximum available nitrogen in deeper layer of the soil. The similar results were reported by several authors [13, 27, 29,].

Table 1:Macronutrient Concentrations across Land Use Types

Land Use Type	Depth (cm)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Sulphur (mg kg^{-1})
Mango Orchard	0–20	325.57	19.08	190.13	19.80
Forest Land	0–20	289.45	17.32	175.67	18.45
Sugarcane Field	0–20	210.76	14.45	150.34	15.23
Dhab Land	0–20	120.89	10.49	100.89	9.67
Uncultivated Land	0–20	135.45	11.78	120.45	8.02

Soil Sulphur Availability

Sulphur availability followed a similar trend, with mango orchards exhibiting the highest values (19.80 mg kg^{-1}) and uncultivated lands the lowest (8.02 mg kg^{-1}). The available sulphur of different land use patterns of Samastipur district ranged from 8.02 to 19.80 mg kg^{-1}.Forest land also exhibited relatively high sulfur levels, particularly at shallower (0-20 cm) depth, while uncultivated land showed the significantly lowest sulfur (8.02 mg kg^{-1}) at all depths of soil. Across all the land use patterns, available sulphur decreased with the increased depth, it might be due organic matter content and microbial activities are increased in surface layer of soil which is directly related with the available sulfur, hence the decreasing sulphur content with increasing depth. The similar results have been also reported by Scientists [18, 20]. The strong correlation between sulfur and organic matter highlights the importance of organic inputs in sulphur dynamics.The similar results were reported by Sinha et al., 2024b [32].

Micronutrient Dynamics

Micronutrient availability varied significantly across land use types (Table 2). Mango orchards and forest lands recorded the highest levels of Zn, B, and Fe, while uncultivated and dhab lands exhibited deficiencies. These variations are attributed to differences in organic matter inputs and soil management practices.The similar results were reported in scientific literature [32].

Table 2:Micronutrient Concentrations Across Land Use Types

Land Use Type	Depth (cm)	Zinc (mg kg^{-1})	Boron (mg kg^{-1})	Iron (mg kg^{-1})
Mango Orchard	0–20	1.98	0.75	16.43
Forest Land	0–20	1.87	0.72	15.68
Sugarcane Field	0–20	1.45	0.60	12.34
Dhab Land	0–20	0.89	0.35	8.54
Uncultivated Land	0–20	0.75	0.30	7.89

Discussion

The findings emphasize the critical role of land use in shaping soil nutrient dynamics. Perennial systems like mango orchards and forest lands enhance soil fertility through organic matter deposition and minimal disturbance. In contrast, unmanaged systems such as uncultivated and dhab lands exhibit nutrient deficiencies, highlighting the need for targeted interventions. These results align with previous studies that underscore the importance of organic inputs and sustainable management practices in improving soil health.

The higher nutrient levels in mango orchards highlight the positive impact of organic inputs and minimal soil disturbance on soil fertility. In contrast, forest land serves as a baseline for natural nutrient cycling, emphasizing the importance of biodiversity and organic matter in maintaining soil health. These findings align with previous studies that underscore the role of sustainable land management practices in enhancing soil quality [4, 9].

Conclusions

The study demonstrates that land use significantly influences soil nutrient dynamics. Perennial systems like mango orchards and forest lands have higher macronutrient and micronutrient concentrations due to organic matter deposition and minimal disturbance. Conversely, unmanaged systems like uncultivated and dhab lands exhibit nutrient deficiencies, emphasizing the need for targeted soil management. Mango orchards showed the highest levels of nitrogen (325.57 kg ha^{-1}), phosphorus (19.08 kg ha^{-1}), and potassium (190.13 kg ha^{-1}), while uncultivated and dhab lands recorded the lowest levels, indicating varying soil fertility across land use types. Sulfur levels were highest in mango orchards (19.80 mg kg^{-1}), with similar trends observed for zinc, boron, and iron. The findings highlight the importance of organic inputs in maintaining nutrient availability and soil health. The study also observed significant nutrient variability between soil depths, underlining the importance of considering vertical soil profiles in soil fertility assessments. These conclusions serve as a foundation for developing effective interventions to restore soil health and ensure long-term agricultural sustainability in diverse land use systems.

Recommendations for Soil Management:

Tailored soil management strategies, such as integrated nutrient management and organic amendments, are recommended to address nutrient deficiencies in unmanaged land use systems and enhance soil productivity.The findings emphasize the need for sustainable land management practices to optimize soil fertility and support agricultural productivity in the Indo-Gangetic plains.

Future Scope of Study

The future scope of studies includes exploring the long-term effects of land use changes on nutrient dynamics, investigating the role of microbial activity in nutrient cycling across different land use systems, and developing site-specific nutrient management strategies to enhance soil fertility and productivity. Additionally, it involves assessing the potential of integrated nutrient management practices in restoring degraded lands.

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Conflict Of Interest The authors declare that they have no conflict of interest.

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