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Comparative study of physicochemical properties and micronutrients concentrations in different soil profiles of Western Odisha

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Abstract
Soil micronutrients play a vital role in maintaining soil fertility, plant growth, and agricultural productivity. However, increasing agricultural intensification, continuous cropping, and imbalanced nutrient management have led to widespread micronutrient deficiencies in soils. The present study was undertaken to conduct a comparative analysis of micronutrient distribution in different soil profiles and to evaluate the influence of soil physicochemical properties and land use patterns on their availability. Total concentration of micronutrients including iron (45.4766±0.153 mg/kg), zinc (25.473± 0.529 mg/kg), copper (23.78±0.295 mg/kg), manganese (29.63±0.3776 mg/kg), and boron (7.6±0.228 mg/kg) was found to be in adequate concentration in 15cm depth of agricultural soil because of high accumulation of organic matter, nitrogen and phosphorus in soil. Soil organic carbon increases in the upper layer, promoting macroaggregation formation that reduces compaction risk and enhances soil water retention capacity. Furthermore, Pearson's coefficient of correlation shown positive correlation between soil organic carbon (SOC) with all physicochemical variables that represents, elevated SOC levels stabilizes soil pH ($r = 0.939$; $p< 0.01$) and improve soil electrical conductivity ($r = 0.925$; $p< 0.01$). Micronutrients such as Zn, Fe, Mn, Cu and B positively influenced physicochemical attributes such as pH, electrical conductivity and SOC. The current study helps to develop suitable management strategies to improve soil quality and health across different land use patterns.

Keywords: Agricultural soil, pesticide treated soil, soil organic carbon, electrical conductivity, physicochemical attributes

1. Introduction

As the base of terrestrial ecosystems and agricultural productivity, soil is without a doubt one of the most essential and fundamental natural resources. It functions as a substrate for plant growth, a vital reserve of nutrients, a regulator of water flow, and a habitat for a varied range of microorganisms. Soil fertility and quality are essential for both the equilibrium of our ecosystems and the viability of agricultural systems. The ability of the soil to supply plants with the necessary nutrients in enough amounts and appropriate ratios is the clear definition of soil fertility (Alloway, 2008) [1]. The solubility, mobility, and bioavailability of micronutrients in soil is determined by complex physicochemical factors. Soil pH is the primary determinant affecting micronutrient dynamics. As soil pH increases, the availability of micronutrients decreases, particularly in alkaline conditions where elements like iron, zinc, and manganese form insoluble hydroxides or carbonates. On the other hand, acidic soils make some elements more soluble, which could lead to dangerous quantities (Brady and Weil, 2016) [2].

Soil characteristics have a major impact on the distribution of accessible Fe, Mn, Cu, and Zn in agricultural soil (Yi *et al*., 2012) [3]. The presence of organic matter significantly increases the availability of micronutrients by supplying soluble chelating agents that boost their solubility. According to Maqueda *et al*. (2011) [6], the formation of organo-Cu complexes leads to increased concentrations of Cu retrieved from the first 0-20 cm layer after repeated fertilizing. Furthermore, they observed that soil organic matter facilitates the development of reducing conditions in fine-textured soils, hence enhancing Mn solubilization. According to several researchers, organic carbon content is the main soil factor affecting micronutrient availability (Bassirani *et al*., 2011; Yadov, 2011) [7, 8].

The necessity to meet the food demands of an expanding population has compelled the usage of the fertility of current soils. Thus, understanding the distribution of micronutrients across different land use systems is essential for achieving sustainable development objectives. This study aims to ascertain the physicochemical features of various land use patterns and evaluate the influence of these properties on micronutrient accumulation at different soil depths.

2. Materials and Methods

2.1 Soil sampling

Soil samples from a variety of Western Odisha ecosystems, including agricultural land, pesticide-treated soil, and forest soil areas, were collected for the comparative study. Soil samples were collected from the upper strata at a depth of 15 cm. Surface debris was removed at each site, and soil samples were collected from different depths using sterile spatulas. Approximately 100-200 grams of soil were collected in sterile polyethylene bags, properly labelled, and transported to the laboratory under aseptic conditions. To guarantee microbiological viability, samples were stored at 4 °C and examined within a day.

2.2 Physico-chemical and micronutrients analysis

The pH was assessed with the ISSS 2002 methodology. The ISSS 2002 methodology was utilized to assess electrical conductivity. The assessment of soil organic carbon was performed utilizing the titration technique developed by Walkley and Black (cited by Mishra, 1968) [10]. The Kjeldahl method measures total nitrogen content in various soil profiles (ISSS 2002). Available phosphorus was quantified via the Olsen technique (ISSS 2002). Available potassium was evaluated utilizing the Soil Tech Lab Manual of ISSS 2002.Micronutrients concentration was quantified using protocol of Dash and Kujur (2024) previously given by Latif *et al.,* (2018) [12, 13].

2.3 Statistical analysis

Analysis of variance (ANOVA) was conducted to assess the significance between and among variables utilizing SPSS 16.0. The Pearson correlation coefficient was utilized to assess the link between micronutrients, physicochemical parameters, and microbial populations using SPSS 16.0.

2.4 Results

In current study, physicochemical attributes were calculated from different depth of soil collected from sampling sites and presented in the table 1.

The pH of agricultural soil was determined to be neutral (7.42±0.001). The pH was highest 7.52±0.011 in FS, indicating mild alkalinity, whereas in FS pH was found to be neutral (7.086) in pesticide-treated soil. The forest soil exhibited somewhat alkaline characteristics as compare to other soil because of ideal soil characteristics of soil as illustrated in the table 2and figure 1.In agricultural soil, electrical conductivity measured 0.306±0.005 which was slightly less in PTS (0.296±0.005 mS/cm) which was increases in FS (0.333±0.015 mS/cm).The build-up of organic carbon in agricultural soil was measured at 2.078±0.055%, increasing to 2.325 ±0.005% at FS, while less concentration was seen PTS (1.826±0.006%) presented in table 1.The concentration of total nitrogen was highest in FS (3.874±0.844%) and lowest was seen in PTS (2.933±0.045%). The concentration of phosphorus in agricultural soil was in 15 cm depth (123.28±1.93 mg/kg), reaching a maximum at FS (125.31±0.844mg/kg). At PTS the concentration was 118.52 ±0.84 mg/kg of phosphorus. As shown in the table and figure, available potash was measured in mg/kg at different depths in forest, pesticide, and agricultural soils. The potash concentration in agricultural soil was 289±0.232 mg/kg, whereas in PTS the concentration was 275±1.861 mg/kg. Forest soil contains 282±1.861 mg/kg of potash was identified at a depth of 15 cm.

Table 1: Variation in physicochemical properties of three distinct type of soil

	PH	EC (mS/cm)	OC (%)	TN (%)	AP (%)	AK (%)
AS	7.42±0.001	0.306±0.005	2.078±0.055	3.903±0.066	123.28±1.93	289±0.232
PTS	7.086±0.065	0.296±0.005	1.826±0.006	2.933±0.045	118.52±0.84	275±1.861
FS	7.52±0.011	0.333±0.015	2.325±0.005	3.874±0.0513	125.31±0.844	282±1.788

Values are Mean ±STDEV

Sulphur availability was measured in mg/kg at different depths of agricultural, pesticide, and forest soils, as depicted in the table 2. The concentration of sulphur in agricultural soil was, recorded 22.67±0.491 mg/kg, higher at FS i.e. 34.74±0.358 mg/kg. In PTS sulphur concentration was slightly lower i.e. 20.75±0.476 mg/kg. The zinc concentration in agricultural soil was measured as 25.473± 0.529 mg/kg whereas higher zinc concentration was seen in FS (35.513±0.516 mg/kg). In pesticide treated soil zinc concentration was found to be 24.116±0.12 mg/kg. The Mn concentration in agricultural soil was measured as 29.63±0.3776 mg/kg whereas higher Mn concentration was seen in FS (35.513±0.516 mg/kg). In pesticide treated soil Mn concentration was found to be 24.116±0.12 mg/kg. The concentration of Cu was 23.78±0.295 mg/kg in agricultural soil, whereas, higher concentration was recorded i.e. 26.506±0.2831 mg/kg. In PTS Cu concentration was 24.38±0.3021 mg/kg across 15cm depth of soil. The Fe concentration in agricultural soil was measured as 45.4766±0.153 mg/kg whereas higher Mn concentration was seen in FS (55.65±0.135 mg/kg). In pesticide treated soil Fe concentration was found to be 46.553±0.423 mg/kg. The concentration of B was 7.6±0.228 mg/kg in agricultural soil, whereas, higher concentration was recorded i.e. 6.7±0.236 mg/kg. In PTS B concentration was 4.633±0.136 mg/kg across 15cm depth of soil.

Table 2: Variation in nutrients accumulation in three distinct type of soil of different depth

	Sulphur	Zinc	Manganese	Copper	Iron	Boron
AS	22.67±0.491	25.473±0.529	29.63±0.3776	23.78±0.295	45.4766±0.153	7.6±0.228
PTS	20.75±0.476	24.116±0.12	48.5733±0.425	24.38±0.3021	46.553±0.423	4.633±0.136
FS	34.74±0.358	35.513±0.516	33.563±0.446	26.506±0.2831	55.65±0.135	6.7±0.236

*Values are Mean ± STDEV

3. Discussion

Soil pH and organic carbon (OC) significantly influence micronutrient availability, with pH exerting a detrimental effect and OC providing a favourable effect. Micronutrients include zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and nickel (Ni) are vital for crop growth and yield, as they facilitate the synthesis of chlorophyll, proteins, lipids, nucleic acids, glucose metabolism, and stress resilience (Barker and Pilbeam, 2015) [15]. Deficiencies of micronutrients in soils can adversely impact crop yield and the food chain. This study seeks to determine the physicochemical parameters of several land use patterns (AS, PTS, and FS) and assess the impact of these features on the accumulation of micronutrients.

The soil pH was moderately alkaline at 7.42 in agricultural soil, neutral at 7.03 in pesticide-treated soil, and ranged from slightly acidic to mildly alkaline at 7.52 in forest soil across different depths (Significant $p < 0.05$ level using Analysis of Variance table 3). Minor soil acidification occurred in pesticide-treated soil (Jha and Singh, 1991) as a result of mineral deposition (Sahani and Behera, 2001) [16]. The pH in the upper layer of all three soil types remained within the neutral range owing to the presence of organic matter and available nutrients. Thus, soil organic matter stabilizes soil pH, demonstrating a strong positive association (r = 0.823; $p < 0.01$), which is crucial for regulating nutrient input (AN: r = 0.976; $p < 0.01$) and availability for plant absorption (Campbell *et al*., 1996). The electrical conductivity (EC) was diminished at a soil depth of due to a more advantageous pH (r = 0.958; $p < 0.01$). Increased electrical conductivity (EC) has a significant correlation with plant-available nutrients (organic carbon: r = 0.925; ammonium nitrogen: r = 0.948; available phosphorus: r = 0.814; available potassium: r = 0.910; $p < 0.01$; Table 4) and facilitates the prediction of soil fertility. The assessment of electrical conductivity (EC) and pH provides detailed insights into the soil's chemical composition (Kirkham *et al*., 2017) [18].

Soil organic carbon increases in the upper layer, promoting macro aggregation formation that reduces compaction risk and enhances soil water retention capacity. Furthermore, elevated SOC levels stabilize soil pH (r = 0.939; $p < 0.01$) and improve soil electrical conductivity (r = 0.925; $p < 0.01$) (Adetunji & Canqui, 2026) [19]. The increase in organic carbon significantly raises the total nitrogen (TN: r = 0.938) concentration in surface layer, with variation noted at a significance level of $p < 0.01$. Variance analysis indicates significant variation among three soil profiles at the $p < 0.05$ significance level. The AS displayed increased concentrations of OC and AN relative to PTS, potentially due to the intensified use of pesticides leading to soil contamination with toxic substances (Jayamadhuri and Rangaswamy, 2005) [20]. The phosphorus concentration was greatest in forest soil (55.658 mg/kg) relative to other soils ($p < 0.05$ significance; table 3). Additionally, organic carbon demonstrates a strong association with accessible phosphorus (r = 0.901; $p < 0.01$), indicating that the addition of organic carbon to soil increases phosphorus availability through the chelation of polyvalent cations by organic acids in the soil. Furthermore, in soil, AK demonstrated a strong correlation with organic carbon (r = 0.895) and electrical conductivity (EC) (r = 0.910; $p < 0.01$), as presented in the table. In addition, sulphur demonstrated a positive link with accessible nutrients: organic carbon (r = 0.589), total nitrogen (r = 0.574), and available phosphorus (r = 0.731), hence facilitating plant growth.

Table 3: Analysis of Variance ($p < 0.05$) between different variables of physicochemical and micronutrients across different sites

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
PH	Between Groups	9.196	11	.836	845.362	.000
	Within Groups	.024	24	.001		
	Total	9.219	35			
EC	Between Groups	.096	11	.009	67.002	.000
	Within Groups	.003	24	.000		
	Total	.099	35			
OC	Between Groups	11.430	11	1.039	882.210	.000
	Within Groups	.028	24	.001		
	Total	11.458	35			
AN	Between Groups	41.606	11	3.782	971.126	.000
	Within Groups	.093	24	.004		
	Total	41.699	35			
AP	Between Groups	10547.757	11	958.887	836.217	.000
	Within Groups	27.521	24	1.147		
	Total	10575.278	35			
AK	Between Groups	50383.316	11	4580.301	6130E4	.000
	Within Groups	1.793	24	.075		
	Total	50385.110	35			
S	Between Groups	2632.264	11	239.297	5.928E3	.000
	Within Groups	.969	24	.040		
	Total	2633.233	35			
Zn	Between Groups	3443.281	11	313.026	9.517E3	.000
	Within Groups	.789	24	.033		
	Total	3444.070	35			
Mn	Between Groups	3291.656	11	299.241	4.699E3	.000
	Within Groups	1.528	24	.064		
	Total	3293.184	35			
Cu	Between Groups	656.262	11	59.660	2.515E3	.000
	Within Groups	.569	24	.024		
	Total	656.831	35			
Fe	Between Groups	1766.564	11	160.597	3.846E3	.000
	Within Groups	1.002	24	.042		
	Total	1767.566	35			
B	Between Groups	144.841	11	13.167	332.679	.000
	Within Groups	.950	24	.040		
	Total	145.790	35			

Moreover, AN (r = 0.584; $p < 0.01$) and S (r = 0.839) positively influence the concentration of Fe in soil. Zn concentration was heightened in the higher layer, attributable to advantageous interactions among soil physicochemical factors, including pH (r = 0.620), EC (r = 0.604), OC (r = 0.701), and S (r = 0.668). The concentration of manganese (Mn) among micronutrients was slightly elevated, suggesting that an optimal quantity can beneficially regulate plant metabolism. In the PTS scenario, manganese content rose owing to positive associations with pH (r = 0.699), EC (r = 0.629), OC (r = 0.729), TN (r = 0.735), and AP (r = 0.685; $p < 0.01$). Acidic pH promotes the exposure of more metals on the surface by the leaching of basic cations (Swain *et al*., 2023) [22]. The concentration of copper in the insecticide was heightened, possibly due to the use of organic and inorganic fertilizers (Oti *et al*., 2017) [23]. Increased manganese concentrations in soil promote the mobilization of iron to the surface (r = 0.626, $p < 0.05$). Boron participates in the precipitation of surplus cations, buffer mechanisms, regulatory influences on other nutrients, the formation of new cells in meristematic tissue, the transfer of sugars, starches, and phosphorus, and is crucial for cell wall synthesis (Khokhar., 2019) [24]. The present investigation revealed that B demonstrated positive correlations with pH (r = 0.751), EC (r = 0.718), OC (r = 0.779), AN (r = 0.789), and AP (r = 0.891), significantly influencing plant growth metabolism ($p < 0.01$).

Table 4: Pearson's coefficient of correlation physicochemical variables and micronutrients across three distinct soil profiles (15cm soil depth)

	PH	EC	OC	TN	AP	AK	S	Zn	Mn	Cu	Fe	B
PH	1											
EC	.958**	1										
OC	.939**	.925**	1									
TN	.981**	.948**	.938**	1								
AP	.826**	.814**	.901**	.839**	1							
AK	.954**	.910**	.895**	.938**	.741**	1						
S	.565**	.596**	.589**	.574**	.731**	.376*	1					
Zn	.620**	.604**	.701**	.592**	.873**	.520**	.668**	1				
Mn	.669**	.629*	.729**	.735**	.685**	.676*	.634*	.619**	1			
Cu	.591**	.566**	.757**	.598**	.861**	.571**	.501**	.884**	.309	1		
Fe	.605**	.603**	.630**	.584**	.803**	.497**	.839**	.509**	.626**	.740**	1	
B	.751**	.718**	.779**	.779**	.891**	.751**	.496**	.829**	.425**	.816**	.750**	1

**Significance at 0.01 level *Significance at 0.05 level

4. Conclusion

In order to clarify the differences in physicochemical characteristics and micronutrient concentration, this study concentrated on a detailed investigation of three different soil profiles (AS, PTS, and FS). The pH, electrical conductivity, organic carbon, and total nitrogen exhibited an increasing trend from the surface layer, owing to the transition in pH from slightly acidic to alkaline circumstances. Because to improved soil physicochemical characteristics (PH, EC, OC, AN, and AP), the content of micronutrients including Zn, Fe, Cu, and Mn was higher in the top layer. In PTS, the micronutrients Mn and Fe were elevated compared to AS and FS due to pesticide exposure in the field, perhaps increasing heavy metal concentrations in the soil. The forest soil exhibited considerable fertility due to improved soil properties at various depths. Our findings show that micronutrients are superior in highly productive areas, especially at 15 cm depth. Additional study is essential to enhance comprehension of the processes and changes associated with long-term soil development, ensuring quality and health.

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