International Journal of Plant & Soil Science

Volume 38, Issue 8, Page 252-266, 2026; Article no.IJPSS.161913
ISSN: 2320-7035

Comparative Analysis of Physicochemical Properties and Micronutrient Distribution Pattern in Different Soil Profiles of Balangir, Odisha, India

Samapika Dash [a], Arupa Nanda [a], Amisha Sahu [a] and Monty Kujur [a*]

[a] *School of Biotechnology, Gangadhar Meher University, Sambalpur, Odisha, 768001, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i86215

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/161913

Original Research Article

Received: 03/05/2026
Accepted: 07/07/2026
Published: 22/07/2026

Abstract

The current study investigated the variation in soil physicochemical properties and nutrient distribution across different depth (0 -60 cm) in agricultural soil (AS), Pesticide treated soil (PTS) and forest soil (FS) of Patanagarh, Balangir district, Odisha. Soil samples were collected from four depth intervals (0, 15, 30 and 60 cm) to analyse the vertical changes in soil characteristics and fertility status. The result showed that, the key physicochemical properties such as, pH, electrical conductivity, organic carbon and total nitrogen increased gradually from surface layer to 30 cm depth layer followed by decline in 60 cm layer. Similarly, available nutrients including phosphorous, potassium and sulphur exhibits increasing trend from 0 to 30 cm layer, where their concentration were highest and decreased at deeper layer, especially in pesticide treated soil. Micronutrients such as zinc, manganese, copper, iron and boron also followed a similar distribution pattern. Coefficient of correlation revealed strong positive relationships among soil properties, macro and

**Corresponding author: E-mail: mkujur@gmuniversity.ac.in;*

Cite as: *Dash, S., Nanda, A., Sahu, A., & Kujur, M. (2026). Comparative Analysis of Physicochemical Properties and Micronutrient Distribution Pattern in Different Soil Profiles of Balangir, Odisha, India. International Journal of Plant & Soil Science, 38(8), 252–266. https://doi.org/10.9734/ijpss/2026/v38i86215*

micronutrients, indicating their interdependence. Organic carbon, total nitrogen, and available phosphorus showed high correlation with micronutrients, highlighting their crucial role in enhancing soil fertility. Multivariate analysis of variance (MANOVA) shown the nutrient availability were most favourable at around 30 cm soil depth riched in improves soil features.

Keywords: Physicochemical; pesticide treated soil; electrical conductivity; micronutrients.

1. Introduction

Land degradation has increased exponentially as a result of substantial intensification of industrial activity in emerging nations like India (Feng *et al.,* 2022). Presently, the land accessible to humans comprises 30% of the total global land area, with India holding less than 2–3% but supporting 16% of the world's human population (Sahu & Dash, 2011). The primary factor in fulfilling human requirements is the land. Soil is an essential component in agriculture. Indian agriculture has a significant part in the worldwide production of wheat, rice, jowar, legumes, sugarcane, vegetables, and fruits. The physical and chemical properties of the land are crucial for the successful implementation of other management measures. Numerous factors, such as pH, electrical conductivity, texture, moisture, temperature, soil organic matter, and the availability of nitrogen, phosphorus, and potassium, are the foundation of this physico-chemical analysis of soil.

The growth of forests and agricultural output are determined by physico-chemical characteristics of the soil. The soil quality study entails the examination of characteristics and processes influencing soil efficacy within a resilient ecosystem (Tale and Ingole, 2015). Soil quality may encompass water retention capacity, carbon sequestration, plant production, waste remediation, and other functions, or it may be defined more restrictively. Some report represents the evolution of the land quality concept, examines the utilisation of soil chemical and physical properties as indicators of soil quality, identifies challenges and opportunities for forest soil scientists to substantially enhance the assessment and improvement of sustainable forest management through the application of soil quality as a sustainability metrics. The comprehensive assessment involves monitoring certain processes or attributes that indicate alterations in ecosystem functionality as indicators of sustainability (Kekane *et al.,* 2015). Plants, animals, and humans need micronutrients to grow. Plants need zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni); animals need Zn, Fe, Mn, Cu, selenium (Se), iodine (I), and cobalt (Co); and humans need Zn, Cu, Fe, Mn, Mo, Co, I, Se, fluoride (F), and chromium (Cr). Boron is a trace element that helps animals and humans to retain calcium and magnesium. Micronutrients played an essential role in plant, animal, and human metabolism, and replacing them with other elements cannot fix their deficit (Shukla *et al.,* 2018). Organo-Cu compounds increase Cu recovery from the initial 0-20 cm layer after repeated use of fertilizers (Maqueda *et al.,* 2011). Organic carbon concentration is the main soil characteristic affecting micronutrient availability to the plants. To feed an expanding population, agricultural output is important to increase productivity and for that soil fertility must be checked. Thus, understanding micronutrient distribution across land use systems is essential for sustainable development. Based on the foregoing facts, this study assesses the physicochemical features of different land uses and their effects on micronutrient accumulation in different soil depths across agricultural soil, pesticide treated soil and forest soil.

2. Materials and Methods

2.1 Soil Sampling

The current study used soil samples from agricultural soil (AS), pesticide-treated soil (PTS), and forest soil (FS) Patanagarh, Balangir, Odisha. Sampling was done according to methods of Dash and Kujur (2024). Sampling was done in the month of March included Agricultural soil, Pesticide treated soil and Forest soil at local area of Patanagarh, Balangir. For sampling, each site is divided into 5 blocks and five soil samples need to be collected randomly from 0-15 cm soil depth by spading pits of (15 x 15 x 15) cm^3 size in each block (without considering small rocks, pebbles or fragments) and referred to as sub-samples, form composite sample by mixing thoroughly. To avoid any mixing, the samples were aseptically packed in polypropylene vials, labelled individually and brought for laboratory analysis. These samples were air dried, homogenized and subjected to sieving (2mm mesh size) and stored at 4^{o}C for further characterization.

Agricultural soil in the study was collected from local farmer land area cultivated with Brinjal (*Solanum melongena*), Tomato (*Solanum lycopersicum*), Cauliflower (*Brassica oleracea*), Pumpkin (*Cucurbita pepo*) like vegetables and rice. Blue pea (*Clitoria ternatea*), Marigold (*Calendula officinalis*), Datura (*Datura stramonium*) like flowers were also cultivated along with vegetables. To induce fertility of soil, vegetable pills, vermicompost and green manure (1: 1: 1; 1 part green manure; 1 part vegetable pills; 1 part cattle dung) was applied in the field. Pesticide treated soil was exposed to Streptocycline (Composition: Streptomycin Sulphate (90 % v/v; Tetracycline hydrochloride 10% v/v) pesticide thrice at every 15 days of interval at local farmer land cultivated with Cauliflower, Solanaceous vegetables at Ravi season followed by rice as kharif crop. Forest soil chosen for current study was red soil type surrounded by plants like *Bambusa vulgaris, Diospyros melanoxylon, Butea monosperma, Tectona grandis* etc.

2.2 Physico-chemical and Micronutrients Analysis

The soil pH was measured to estimate acidity and basicity (ISSS 2002). The soil electrical conductivity was measured to detect soluble salts (ISSS 2002). The Walkley and Black titration method was used to measure soil organic carbon (Mishra, 1968). Total nitrogen (TN), available phosphorus (AP), and available potassium (AK) was quantified in soil profiles at different depths (ISSS 2002). Micronutrient concentrations were measured following acid digestion methods of Dash and Kujur (2024) earlier described by Latif *et al.* (2018).

2.3 Statistical Analysis

Analysis of variance (ANOVA) was conducted to assess the significance between and among variables using software SPSS 16.0. The Pearson correlation coefficient was utilized to assess the link between micronutrients, physicochemical parameter using SPSS 16.0. Multivariate Analysis of Variance (MANOVA) was performed to know the effective size of physicochemical variables at different depths using software SPSS 16.0.

3. Results

3.1 Physicochemical Analysis from Different Soil

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 in the top layer was determined to be neutral (7.21±0.01) and was increased from 15 cm depth (7.42±0.001), indicating mild alkalinity, and was higher at 30 cm depth of soil (7.51±0.005). The pH was 6.42±0.003 in the 60 cm layer of soil, categorizing it as somewhat acidic. In pesticide-treated soil, the pH was 6.813±0.005 at the surface layer, followed by 7.086±0.065 at a depth of 15 cm, and 7.33±0.05 at a depth of 30 cm. A low pH was observed at a depth of 60 cm in pesticide-treated soil, indicating a somewhat acidic soil conditions. The pH of forest soil was measured to be mildly alkaline, at 7.43±0.026 in the top layer, 7.52±0.011 at a depth of 15 cm, and 7.59±0.001 at a depth of 30 cm. The forest soil exhibited somewhat acidic characteristics (6.221± 0.012) at a depth of 60 cm, as illustrated in the Table 1 and Fig. 1.

Table 1. Variation in physicochemical properties of three distinct type of soil of different depth

		PH	EC	OC	TN
AS	0cm	7.21±0.01	0.276±0.011	1.838±0.053	3.166±0.043
	15cm	7.42±0.001	0.306±0.005	2.078±0.055	3.903±0.066
	30cm	7.51±0.005	0.323±0.005	2.873±0.046	3.866±0.04
	60cm	6.42±0.003	0.213±0.005	1.119±0.011	1.143±0.048
PS	0cm	6.813±0.005	0.273±0.005	1.661±0.039	2.243±0.483
	15cm	7.086±0.065	0.296±0.005	1.826±0.006	2.933±0.045
	30cm	7.33±0.05	0.286±0.005	1.916±0.001	3.033±0.058
	60cm	6.153±0.055	0.186±0.005	0.951±0.013	1.108±0.006
FS	0cm	7.43±0.026	0.306±0.005	2.255±0.034	3.360±0.156
	15cm	7.52±0.011	0.333±0.015	2.325±0.005	3.874±0.0513
	30cm	7.59±0.001	0.351±0.026	2.431±0.052	3.969±0.636
	60cm	6.221±0.012	0.193±0.015	1.116±0.0064	1.201±0.002

Values are Mean± STDEV

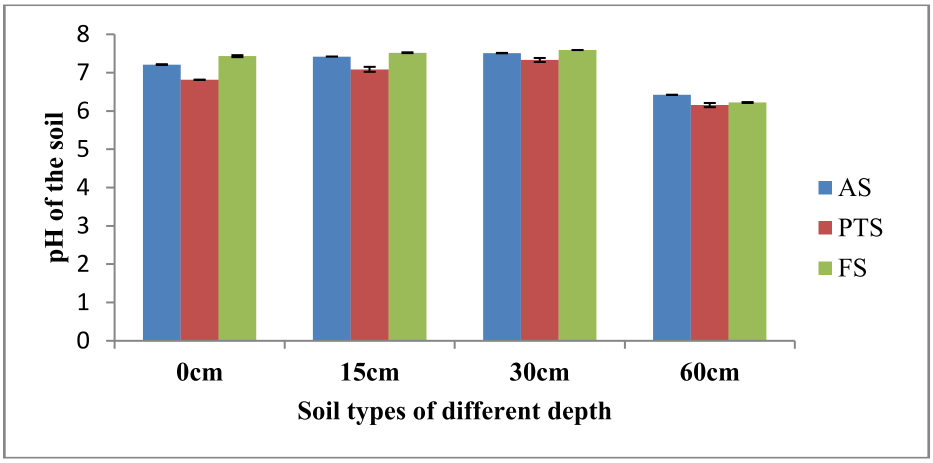

Fig. 1. P^H of three distinct type of soil of different depth (0 cm, 15 cm, 30cm, 60 cm)

In agricultural soil, electrical conductivity measured 0.276±0.011 mS/cm at the surface layer, 0.306±0.005 mS/cm at a depth of 15 cm, and 0.323±0.005 mS/cm at a depth of 30 cm. The results indicated an increasing trend in electrical conductivity from the surface layer to a depth of 30 cm, followed by a decline to 60 cm (0.213±0.005 mS/cm). In pesticide-treated soil, electrical conductivity measured 0.273±0.005 mS/cm in the top layer, climbed to 0.296±0.005 mS/cm at a depth of 15 cm, and reached a maximum of 0.286±0.005 mS/cm at 30 cm depth. The minimum electrical conductivity (0.186±0.005 mS/cm) was observed at a soil depth of 60 cm. In forest soil, electrical conductivity increased from the top layer (0.306±0.005 mS/cm) to 15 cm (0.333±0.015 mS/cm) and reached its highest concentration at 30 cm (0.351±0.026 mS/cm). Electrical conductivity was measured at a depth of 60 cm, yielding a value of 0.193±0.015 mS/cm, which is relatively low (Fig. 2).

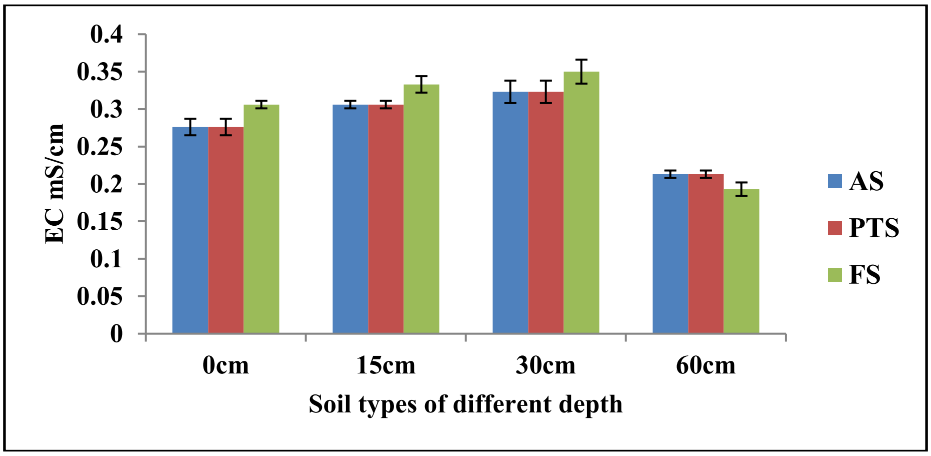

Fig. 2. Electrical conductivity of three distinct type of soil of different depth

The organic carbon content in agricultural soil was measured as 1.838±0.005% in the top layer, increasing to 2.078±0.055% at a depth of 15 cm, and reaching a maximum of 2.873±0.046% at a depth of 30 cm (Fig. 3). Organic carbon accumulated at a concentration of (1.119±0.011%) within a soil depth of 60 cm. In pesticide-treated soil, a modest accumulation of organic carbon was observed in the 60 cm soil profile, namely 0.915±0.013%. The organic carbon concentration in pesticide-treated soil samples increased from the top layer of soil (1.661±0.039%) to a depth of 15 cm (1.826±0.006%), with the greatest concentration seen at 30 cm (1.916±0.001%). In forest soil, organic carbon accumulation rises from the surface layer (2.255± 0.034%) to 15 cm (2.325± 0.005%), peaking at a depth of 30 cm (2.431±0.052%) and it was declining with increasing depth to 60 cm (1.116±0.006%) (Fig. 3).

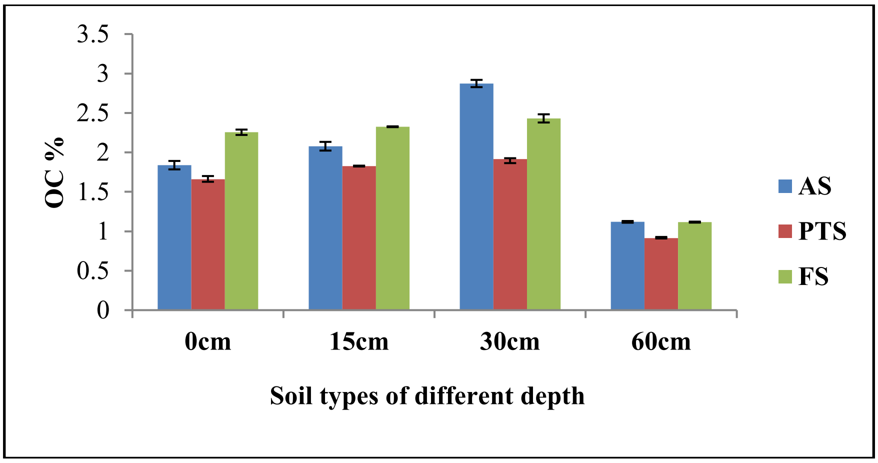

Fig. 3. Organic carbon of three distinct type of soil of different depth

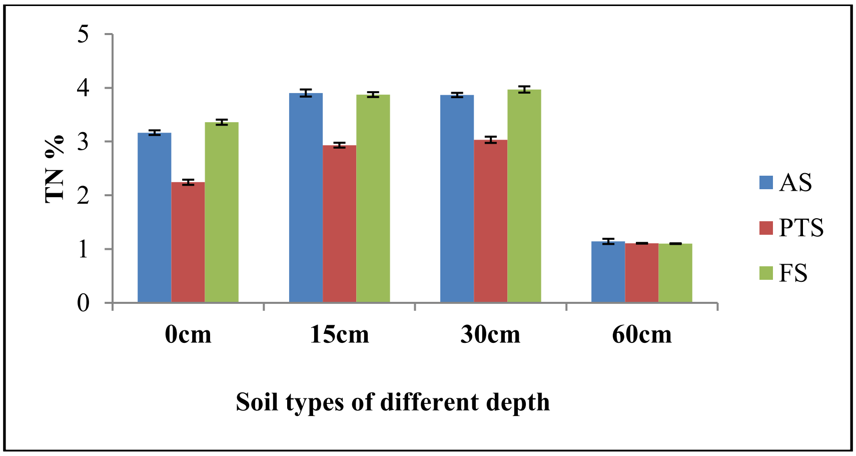

Fig. 4. TN content of three distinct type of soil of different depth

The concentration of total nitrogen was greater at a depth of 30 cm in the soil, measuring 3.866± 0.04% (Fig. 4). The total nitrogen concentration increased from the top layer (3.166± 0.043%) to 15 cm depth (3.903± 0.066%), with highest concentration observed at 30 cm depth (3.866±0.04%). A reduced nitrogen content of 1.108±0.006% was noted at a depth of 60 cm in pesticide-treated soil, while a higher concentration of 3.033±0.058% was recorded at a depth of 30 cm. The top layer has 2.243±0.483% nitrogen, while the soil at a depth of 15 cm contained 2.933±0.045% nitrogen. In forest soil, elevated total nitrogen levels were restricted to a depth of 30 cm (3.969±0.636%), while diminished nitrogen concentrations were seen at a depth of 60 cm (1.201±0.002%). The top layer contained 3.360±0.156% nitrogen, while 3.874±0.513% nitrogen was detected at a depth of 15 cm in forest soil (Fig. 4).

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

		AP	AK	S
AS	0 cm	102.32±1.23	248 ±0.188	18.466±0.438
	15 cm	123.28±1.93	289±0.232	22.67±0.491
	30 cm	142.1±0.781	290±0.194	24.606±0.401
	60 cm	93.233±1.184	2111±0.166	14.75±0.3877
PTS	0 cm	96.94± 1.175	234±1.366	17.753±0.39
	15 cm	105.28±0.856	269±1.788	20.75±0.476
	30 cm	118.52±0.84	275±1.861	22.53±0.522
	60 cm	86.862±0.676	194±1.875	11.194±0.388

		AP	AK	S
FS	0 cm	117.38±1.101	276±1.366	32.773±0.227
	15 cm	123.31±0.844	282±1.788	34.74±0.358
	30 cm	141.76±0.529	285±1.861	40.12±0.885
	60 cm	104.35± 1.001	174±1.875	31.433±0.364

**Values are Mean± STDEV*

The concentration of phosphorus in agricultural soil was higher at a depth of 30 cm, measuring 142.1 ± 0.781 mg/kg (Table 2; Fig. 5). The concentration rose from the top layer (102.32 ± 1.23 mg/kg) to 15 cm depth (123.28 ± 1.93 mg/kg), reaching a maximum at 30 cm depth (142.1 ± 0.781 mg/kg). At a soil depth of 60 cm, the phosphorus concentration measured 93.223 ± 1.184 mg/kg. A reduced phosphorus concentration was noted at a depth of 60 cm (86.862±0.676 %) in pesticide-treated soil, while a higher concentration was detected at a depth of 30 cm (118.52 ± 0.058%). In the uppermost layer, 96.94±1.175 mg/kg of phosphorus was detected, while the soil at a depth of 15 cm contained 105.28±0.856 mg/kg of phosphorus. In forest soil, elevated phosphorus levels were restricted to a depth of 30 cm (141.76±0.529 mg/kg), while reduced phosphorus concentrations were seen at a depth of 60 cm (104.35±1.001%). The upper layer includes 117.38±1.101 mg/kg of phosphorus, while 123.31±0.844% of phosphorus was detected at a depth of 15 cm in forest soil.

As shown in the table 2 available potash was measured in mg/kg at different depths in forest, pesticide, and agricultural soils. The potash concentration in agricultural soil was elevated at a depth of 30 cm, recorded as 290 ± 0.194 mg/kg. The concentration increased from the surface layer (248 ± 0.188 mg/kg) to a depth of 15 cm (289 ± 0.232 mg/kg), peaking at 30 cm depth (290 ± 0.194 mg/kg). At a soil depth of 60 cm, the potash concentration was recorded as 211.1 ± 0.166 mg/kg. A reduced potash concentration was observed at a depth of 60 cm (194±1.875 mg/kg) in pesticide-treated soil, whereas an elevated concentration was found at a depth of 30 cm (275 ± 1.861 mg/kg). In the top layer, 234±1.366 mg/kg of potash was identified, whereas the soil at a depth of 15 cm contained 269±1.788 mg/kg of potash. Reduced potash concentrations were seen at a depth of 60 cm (174±1.875 mg/kg) in forest soil, whereas enhanced potash levels were limited to a depth of 30 cm (285±0.1.788 mg/kg),(Table 2; Fig. 6).

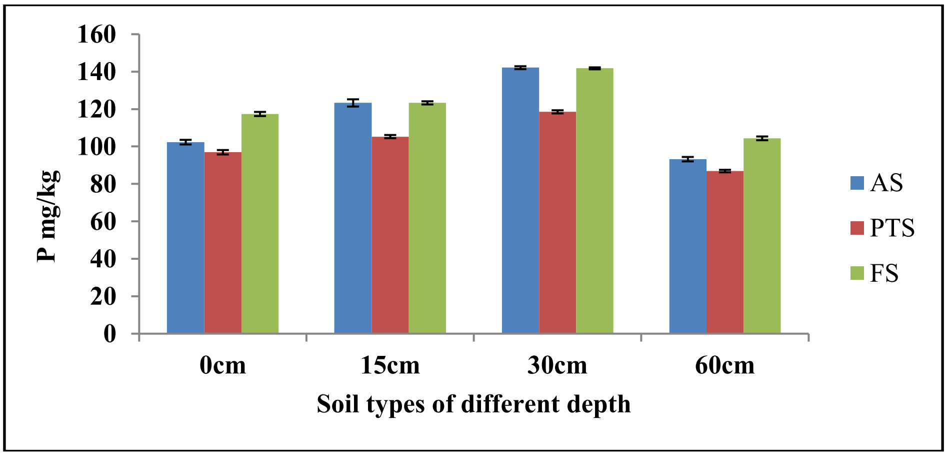

Fig. 5. P content of three distinct soil types with different depth

The concentration of sulphur in agricultural soil was elevated at a depth of 30 cm, recorded at 24.606 ± 0.401 mg/kg (Table 2; Fig. 7). The concentration increased from the surface layer (18.466 ± 0.438 mg/kg) to a depth of 15 cm (22.67 ± 0.491 mg/kg), peaking at 30 cm deep (24.606 ± 0.401 mg/kg). At a soil depth of 60 cm, the sulphur concentration was measured at 14.75 ± 0.387 mg/kg. A diminished sulphur concentration was seen at a depth of 60 cm (11.194±0.388 mg/kg) in pesticide-treated soil, whereas an elevated concentration was identified at a depth of 30 cm (22.53 ± 0.522 mg/kg). In the top layer, 17.753±0.391 mg/kg of sulphur was identified, whereas the soil at a depth of 15 cm had 20.75±0.476 mg/kg of sulphur. In forest soil, increased sulphur concentrations were confined to a depth of 30 cm (40.12±0.885 mg/kg), where as diminished sulphur levels were seen at a depth of 60 cm (31.331±0.364 mg/kg).The surface layer contains 32.773±0.227 mg/kg of sulphur, whereas 34.74±0.358 mg/kg of sulphur was observed at a depth of 15 cm in forest soil (Fig. 7).

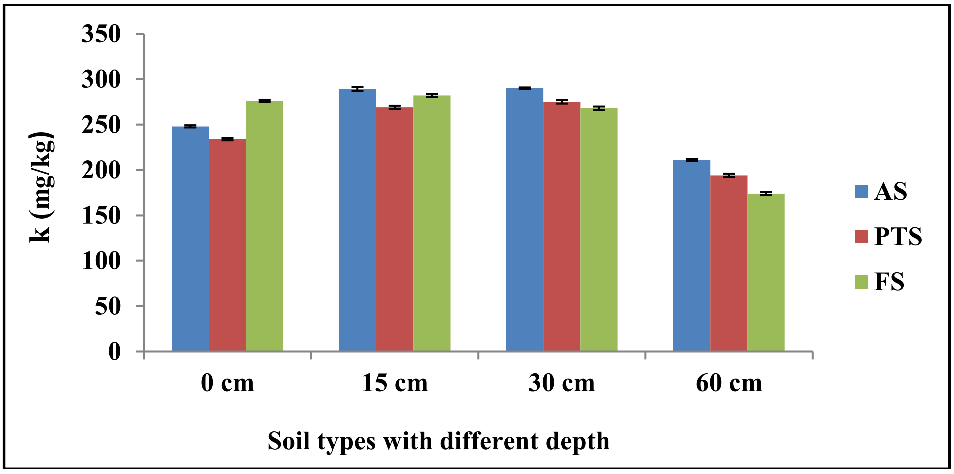

Fig. 6. K content of three distinct soil types with different depth

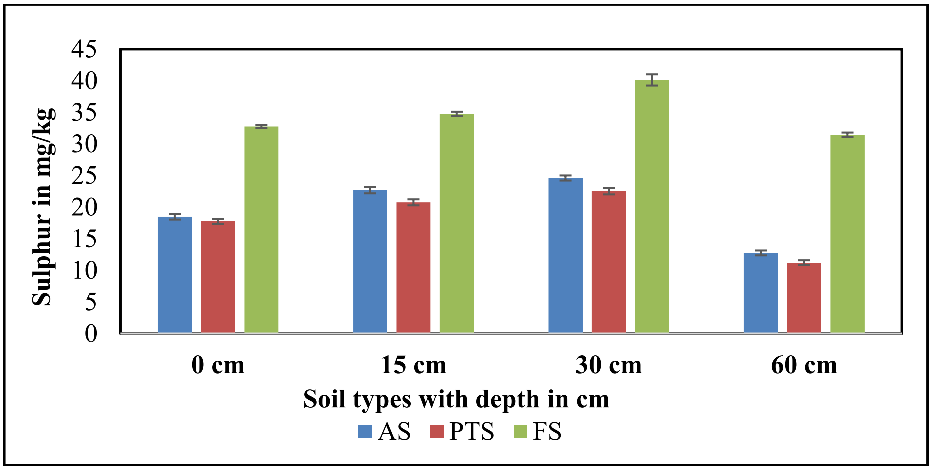

Fig. 7. S content of three distinct type of soil with different depth

3.2 Estimation of Micronutrients Concentration from Different Depth of Soil

The present study estimated micronutrients concentration in mg/kg from soil samples collected at various depths from sampling sites, as provided in the Table 3 and Fig. 8.

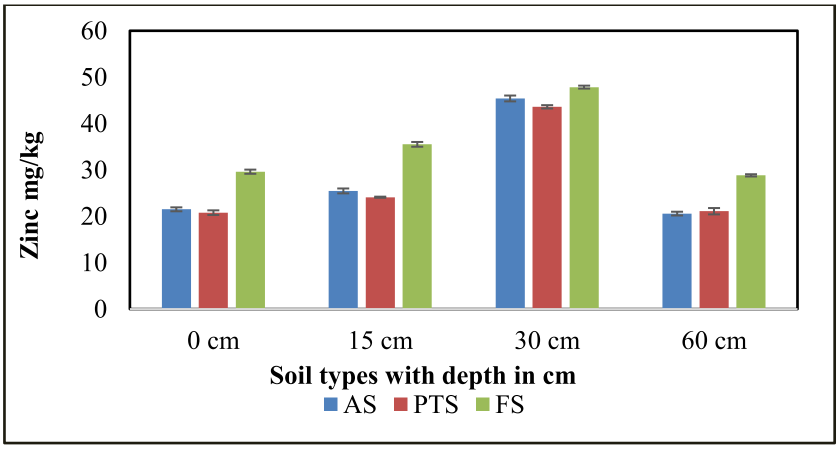

Fig. 8. Zn content of three distinct type of soil with different depth

Table 3. Variation in the concentration of micronutrients in three types of soil with different depth

	Depth	Zinc	Manganese	Copper	Iron	Boron
AS	0 cm	21.505±0.427	19.606±0.447	21.15±0.167	39.563±0.377	3.6±0.089
	15 cm	25.473±0.529	29.63±0.3776	23.78±0.295	45.4766±0.153	7.6±0.228
	30 cm	45.406±0.63	35.73±0.487	35.25±0.408	52.666±0.302	8.4±0.178
	60 cm	20.5833±0.4033	23.726±0.312	20.85±0.316	38.3767±0.289	2.76±0.136
PS	0 cm	20.786±0.503	39.2933±0.233	18.91±0.306	41.43±0.172	3.433±0.186
	15 cm	24.116±0.12	48.5733±0.425	24.38±0.3021	46.553±0.423	4.633±0.136
	30 cm	43.6±0.359	50.425±0.389	27.523±0.405	57.323±0.167	7.766±0.136
	60 cm	21.0967±0.686	38.389±0.502	21.263±0.185	40.167±0.344	3.266±0.186
FS	0 cm	29.616±0.45	30.563±0.525	24.366±0.302	51.526±0.385	4.2±0.186
	15 cm	35.513±0.516	33.563±0.446	26.506±0.2831	55.65±0.135	6.7±0.236
	30 cm	47.853±0.319	41.606±1.375	28.48±0.434	59.59±0.421	7.4±0.1788
	60 cm	28.826±0.243	21.446±0.442	23.516±0.388	50.466±0.2779	3.733±0.186

Values are Mean ± STDEV

The zinc concentration in agricultural soil was measured as 45.406± 0.529 mg/kg at a depth of 30 cm. The concentration escalated from the surface layer (21.505 ± 0.427 mg/kg) to a depth of 15 cm (25.473 ± 0.529 mg/kg), reaching a maximum at 30 cm depth (45.406 ± 0.63 mg/kg). At a soil depth of 60 cm, the zinc concentration was quantified at 20.583 ± 0.4033 mg/kg. A reduced Zn content was observed at a depth of 60 cm (21.096±0.686 mg/kg) in pesticide-treated soil, while an increased concentration was detected at a depth of 30 cm (43.66 ± 0.359 mg/kg). In the uppermost layer, 20.786±0.503 mg/kg of zinc was detected, while the soil at a depth of 15 cm contained 24.11±0.12 mg/kg of zinc. In forest soil, elevated zinc concentrations were restricted to a depth of 30 cm (47.853±0.319 mg/kg), while reduced zinc levels were seen at a depth of 60 cm (28.826±0.243 mg/kg).The surface layer contained 29.616±0.45 mg/kg of zinc, while 35.513±0.516 mg/kg of zinc was detected at a depth of 15 cm in forest soil (Table 3, Fig. 8).

Total Mn concentration was measured in mg/kg at different depths of agricultural, pesticide, and forest soils, as depicted in the table 3 and figure 9. At a depth of 30 cm, agricultural soil contained 35.73±0.487 mg/kg of Mn. The concentration rises from surface layer (19.606 ± 0.447 mg/kg) to a depth of 15 cm (29.63 ± 0.377 mg/kg) before peaking at 30 cm (35.73 ± 0.487 mg/kg). At a soil depth of 60cm, the Mn concentration was 23.72±0.0.312 mg/kg. Pesticide-treated soil had lower Mn concentrations at 60 cm (38.389 ± 0.502 mg/kg), but higher concentrations at 30cm (50.425±0.389 mg/kg). The top layer contained 39.29±0.233 mg/kg of Mn, while the soil at 15 cm depth had 48.573±0.425 mg/kg of Mn. Mn concentrations in forest soil were higher at a depth of 30 cm (41.60±0.375 mg/kg), but lower at 60 cm (21.44±0.442 mg/kg).The surface layer has 30.563±0.525 mg/kg of Mn, while 33.563±0.446 mg/kg was found at a depth of 15 cm in forest soil (Table 3; Fig. 9).

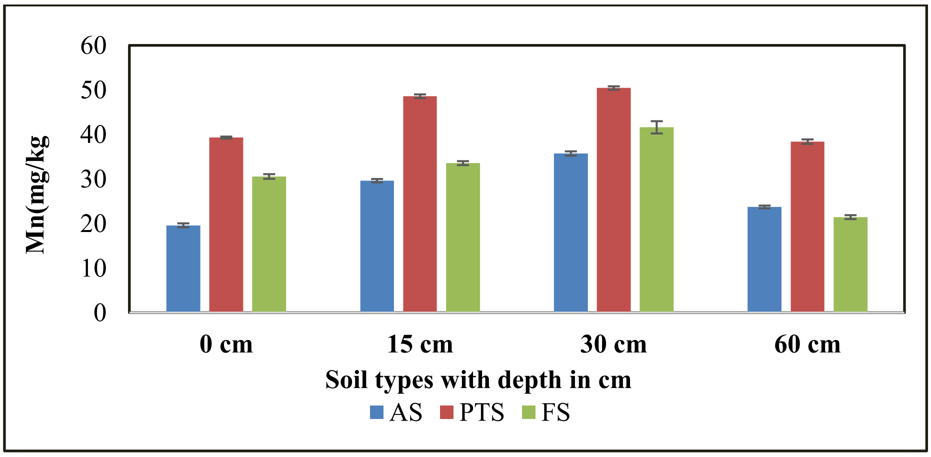

Fig. 9. Mn content in three distinct type of soil of different depth

Cu content in agricultural soil at 30 cm depth was 35.25±0.408 mg/kg (Table 3; Fig. 10) The concentration rises from the surface layer (21.15 ± 0.167 mg/kg) to a depth of 15 cm (23.48 ± 0.295 mg/kg), culminating at 30 cm (35.25 ± 0.408 mg/kg).The Cu concentration at 60cm soil depth was 20.85 ± 0.316 mg/kg. Pesticide-treated soil had a lower Cu concentration at 60 cm (21.26±0.185 mg/kg), but a higher concentration at 30 cm (27.52±0.405 mg/kg). The top layer had 18.91±0.503 mg/kg of Cu, while the soil below 15 cm contained 24.38±0.302 mg/kg of Cu. Cu concentrations in forest soil were higher at a depth of 30 cm (28.48 ±0.319 mg/kg) and lower at 60 cm (23.51 ±0.0.388 mg/kg). In forest soil, the surface layer contains 24.366±0.302 mg/kg of Cu, whereas a depth of 15 cm yields 26.506±0.283 mg/kg of Cu (Fig. 10).

At a depth of 30 cm, agricultural soil had a higher Fe concentration of 52.66±0.302 mg/kg (Table 3; Fig. 11). The concentration rose from the surface layer (39.563 ± 0.377 mg/kg) to a depth of 15 cm (45.47 ± 0.153 mg/kg) and peaked at 30 cm (52.666 ± 0.302 mg/kg). At a soil depth of 60cm, the Fe concentration was 38.376 ± 0.289 mg/kg. Pesticide-treated soil had a lower Fe concentration at 60 cm (40.167 ± 0.344 mg/kg), but a higher concentration at 30 cm (57.323 ± 0.167 mg/kg). The top layer contained 41.43±0.172 mg/kg of Fe, while the soil at 15 cm had 46.55±0.0.423 mg/kg. Forest soil had higher Fe concentrations at 30 cm (59.59±0.0.421 mg/kg) and lower values at 60 cm (50.466±0.277 mg/kg).The surface layer has 51.526±0.385 mg/kg of Fe, while 55.65±0.135 mg/kg of Fe was found at a depth of 15 cm in forest soil (Fig. 11).

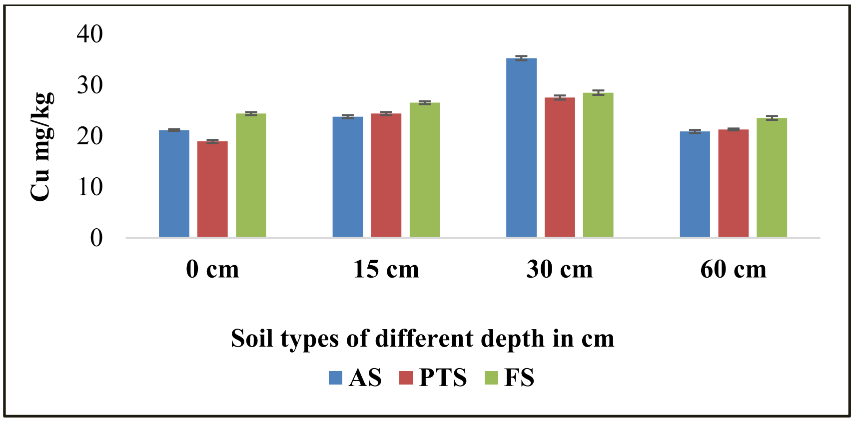

Fig. 10. Cu Content in three distinct type of soil of different depth

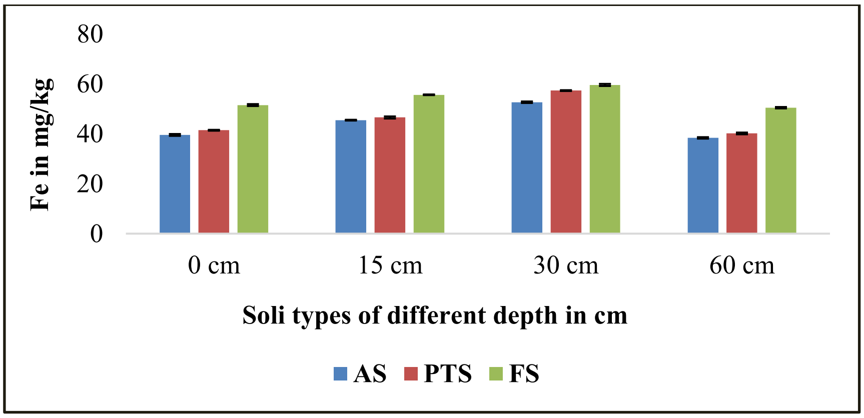

Fig. 11. Fe Content in three distinct type of soil of different depth

At a depth of 30 cm, agricultural soil contained 8.4±0.0.178 mg/kg of B. The concentration gradually increased from the surface layer (3.6 ± 0.089 mg/kg) to a depth of 15 cm (7.6 ± 0.228 mg/kg), peaking at 30 cm (8.4 ± 0.178 mg/kg). At a soil depth of 60cm, B content was 2.76 ± 0.136 mg/kg. Pesticide-treated soil had a lower B concentration at 60 cm (3.26 ± 0.186 mg/kg), but a higher concentration at 30 cm (7.766 ± 0.136 mg/kg). The top layer contained 3.43±0.186 mg/kg of B, while the soil at a depth of 15 cm had 4.63±0.136 mg/kg. B concentrations in forest soil were higher at a depth of 30 cm (7.4±0.178 mg/kg), but lower at 60 cm (3.73±0.186

mg/kg).The surface layer has 4.2±0.186 mg/kg of B, while 6.7±0.236 mg/kg of B was found at a depth of 15 cm in forest soil (Fig. 12).

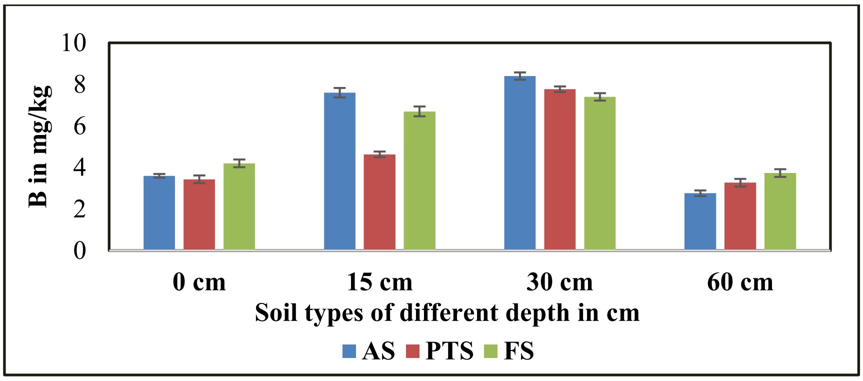

Fig. 12. B content of three distinct soil types of different depth

4. Discussion

Micronutrient cycle and distribution in soils vary with land-use change from forest to agricultural systems (Han *et al.,* 2007). Soil micronutrient availability is influenced by pH, EC, OC, clay, $CaCO_3$ concentration, land use, and depth (Shukla *et al.,* 2014). The current study aims to ascertain the physicochemical parameters of various land use patterns (AS, PTS and FS) and evaluate the influence of these properties on the accumulation of micronutrients at different soil depths.

The soil reaction, indicated by pH, ranged from acidic to mildly alkaline at 6.42-7.51 in agricultural soil, slightly acidic to neutral at 6.15-7.33 in pesticide-treated soil, and slightly acidic to mildly alkaline at 6.22-7.52 in forest soil across various depths. Minor soil acidification was seen in pesticide-treated soil (Jha and Singh, 1991) due to mineral deposition (Sahani and Behera, 1998). The pH in the upper layer of all three soil types fell within the neutral range due to the presence of organic matter and accessible nutrients. Organic matter content increased from the top layer (neutral) to a depth of 30 cm (alkaline) in the soil. Consequently, soil organic matter stabilizes soil pH, exhibiting a positive correlation (r= 0.939; p<0.01), which is essential for regulating nutrient input and availability for plant uptake (Campbell *et al.,* 1996).

Table 4. Pearson's coefficient of correlation physicochemical variables and micronutrients across three distinct soil profiles (0cm, 15cm, 30cm, 60cm 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 0.01level *Significance at 0.05 level*

The current investigation revealed that electrical conductivity (EC) was lower at a soil depth of 60 cm compared to a depth of 30 cm, because of more favourable pH (r= 0.958; p< 0.01). Elevated electrical conductivity (EC) demonstrates a positive link with available nutrients (total nitrogen: r= 0.948; available phosphorus: r= 0.814; available potassium: r= 0.910; p<0.01) and aids in forecasting soil fertility. The evaluation of electrical conductivity (EC) alongside pH yields comprehensive insights into the soil's chemical composition (Kumar *et al.,* 2012; Kekane *et al.,* 2015; Kirkham *et al.,* 2017). The current study reveals that agricultural soil has an electrical conductivity of 0.213 to 0.323 mS/cm, while pesticide-treated soil shows conductivity between 0.186 and 0.296 mS/cm, with an additional measurement ranging from 0.193 to 0.351 mS/cm in forest soil. The electrical conductivity (EC) of pesticide-treated soil was less to that of agricultural and forest soils, because of its slightly acidic pH of soil, a crucial indicator of soil quality, and its reduced organic matter.

The organic carbon content displayed an increasing trend from the top layer to a depth of 30 cm, with notable heterogeneity across three different profiles. At a depth of 60 cm, the organic matter content was lowered due to soil acidity, leading to decreased nutrient availability for plant growth. Soil organic carbon rises from the upper layer, facilitating macroaggregation development that diminishes compaction risk and improves soil water retention capacity. Moreover, increased SOC levels stabilize soil pH ($r = 0.939$; $p<0.01$) and enhance soil electrical conductivity ($r = 0.925$; $p<0.01$) (Canqui *et al.,* 2013). The acidic pH at 60cm depth vulnerable to cation leaching, hence diminishing the availability of organic matter for plant sustenance (Goswami, 2009).The AS (1.119-2.873%) demonstrated a higher concentration of organic carbon compared to PS (0.951-1.826%). Reduced organic carbon concentration in PS due to the increased use of pesticides, leading to soil contamination with toxic chemicals, thereby altering microbial populations, enzyme activities, and soil processes (Jayamadhuri *et al.,* 2005).

Increasing concentration of organic carbon markedly elevates total nitrogen concentration (TN: $r = 0.938$) concentration from the top layer to a depth of 30 cm, with variation observed at a significance level of $p<0.01$. The AS exhibited elevated levels of OC and TN compared to PTS, maybe because to the increased application of pesticides resulting in soil contamination with hazardous chemicals (Jayamadhuri *et al.,* 2005).The total nitrogen content at a depth of 60 cm was lower, necessitates the formulation of effective management techniques to rehabilitate the physicochemical and biological features of the soil.

The available phosphorus concentration was highest at a depth of 30 cm in forest soil (55.658 mg/kg) compared to other soils. Forest soil was enriched in available phosphorus due to the development of phosphate-mobilizing bacteria or the creation of mycorrhizal associations. In AS and PTS, the concentration of AP increases up to a depth of 30 cm, after which it declines due to shallower distribution, indicating nutrient shortage with increasing depth. Furthermore, organic carbon exhibits a significant correlation with accessible phosphorus ($r = 0.901$; $p<0.01$), suggesting the incorporation of organic carbon into soil enhances phosphorus availability due to the chelation of polyvalent cations present in the soil. Consequently, soil organic carbon (SOC) influences the assessment of available phosphorus (AP) in soil (Rashidi and Seilsepour, 2008). A comparable tendency was observed with potassium from the upper layer, that known for the regrowth of vegetation in disturbed habitats (Qiu *et al.,* 2018). AK exhibited a positive association with organic carbon ($r = 0.895$), electrical conductivity (EC) ($r = 0.910$; $p<0.01$), as indicated in the table 4. Additionally, sulphur indicated positive correlation with available nutrients OC ($r=0.589$), TN ($r = 0.574$), AP ($r = 0.731$) and assisted in plant growth. Additionally, TN ($r = 0.584$; $p< 0.01$) and S ($r = 0.839$) positively regulates the concentration of Fe in soil (Das, 2014).

Zn content was increasing from upper layer to a depth of 30 cm across all soil types due to favourable interactions among soil physicochemical factors, including pH ($r = 0.620$), EC ($r = 0.604$), OC ($r = 0.701$), and S ($r = 0.668$). The distribution of nutrients in soil is mostly dependent on soil characteristics, including pH, electrical conductivity (EC), and organic carbon (OC) concentration (Dhaliwal *et al.,* 2023). At a depth of 60 cm, the concentration of Zn diminished, possibly due to a little increase in manganese accumulation in the soil (Das, 2014). The concentration of manganese (Mn) among micronutrients exhibited a modest increase from the surface layer to a depth of 30 cm, suggesting that an optimal concentration can beneficially regulate plant metabolism. In PTS, manganese concentration rose to the 30 cm layer, attributed to positive associations with pH ($r=0.669$), EC ($r=0.629$), OC ($r=0.729$), TN ($r=0.735$), and AP ($r=0.685$; $p<0.01$). At a depth of 60 cm, concentration was elevated relative to other depths, potentially due to somewhat acidic pH and reduced nutrient levels.

Acidic pH promotes the exposure of more metals on the surface by the leaching of basic cations (Swain *et al.,* 2023). Liu et al. (2020) noted that elevated Mn levels may be the principal factor for decrease concentration of Cu and Zn in soil at greater depths, specifically at 60 cm . Thus, the concentration of Cu escalated from the top layer to a depth of 30 cm across all three soil types, but accumulation at 60 cm was diminished due to a marginally acidic pH. The concentration of copper in the pesticide treated soil was increasing at a depth of 30 cm, possibly attributable to the use of organic and inorganic fertilisers (Oti *et al.,* 2017). Increased manganese concentrations in soil promote the mobilisation of iron to the surface ($r = 0.626$, $p < 0.01$).Thus, the concentration of iron was increasing until depth of 30 cm, subsequently experiencing a slight decline at 60 cm depth. At a depth of 60 cm, the iron concentration in pesticide-treated soil exceeded that of agricultural soil, presumably due to the application of agrochemicals to enhance productivity. Boron participates in the precipitation of surplus cations, buffering actions, 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 (Das, 2014). In the present study, B shown favourable associations with pH ($r = 0.751$), EC ($r = 0.718$), OC ($r = 0.779$), TN ($r = 0.789$), and AP ($r = 0.891$), and facilitated plant development metabolism.

Table-5. Partia Eta Square value of all variables in three distinct soil profiles from Multi Variate Analysis of variance (MANOVA; p<0.05)

	0cm	15cm	30cm	60cm
P^H	0.977*	0.984*	0.997*	0.936*
EC	0.559*	0.699*	0.767*	0.493
OC	0.941*	0.951*	0.999*	0.593*
AN	0.951*	0.978*	0.988*	0.797*
AP	0.962*	0..986*	0.993*	0.586*
AK	0.721*	0.858*	0.869*	0.595*
S	0.628*	0.699*	0.714*	0.359*
Zn	0.895*	0.916*	0.995*	0.801*
Mn	0.815*	0.915*	0.998*	0.895*
Cu	0.789*	0.845*	0.915*	0.715*
Fe	0.896*	0.925*	0.936*	0.899*
B	0.715*	0.799*	0.845*	0.529*

** Significant at 0.05 level*

Multivariate analysis of variance (MANOVA) was employed to clarify the effectiveness of variables throughout the study area in relation to differing depths. Wilk's Lambda score shown statistical significance of variations in physicochemical attributes and micronutrient distribution at $p<0.05$ level of significance across three different soil profiles. Additionally, partia eta square value for Wilk's Lambda accounts for variance of 91.3% (0.913) shown that attributes are well segregated in different depth of agricultural, pesticide-treated, and forest soils. The partial eta square values for Wilk's Lambda, recorded at 90.3%, 95.9%, and 98.9%, signify a substantial contribution to variance in the top layer, as well as the 15 cm and 30 cm soil layers, illustrating successful optimization of physicochemical variable across different depth with increasing trend. Availability of adequate resources such as organic carbon, nitrogen, phosphorous and potassium promotes accessibility of micro and macronutrients in different depth of agricultural soil, pesticide treated soil and forest soil. Among all variables pH contributes 97.7%, 98.7% and 99.7% from top layer to 30 cm indicates gradual improvement in soil characteristics with increasing depth i.e from neutral to alkaline. This improvement in pH promotes accumulation of more organic carbon (94.1%, 95.1%, 99.9%) across different layers. Suitable pH also facilitates accession of available nutrients AN (95.1%, 97.8%, 98.8%), AP (96.2%, 98.6%, 99.3%) accumulates more from top soil to 30 cm depth for successful plant establishment. In 60cm value of partia eta square was less because of less effective size of physicochemical variables. In 60 cm depth, slightly acidic pH and less organic carbon concentration makes soil unsuitable for aggregation of more nutrients across whole layer. Among micronutrients, effective size of Zn and Fe was higher in top layer which was increasing upto 30cm depth and positively associated with plant metabolism. Mn and Cu has partia eta square value of 0.815 and 0.789 on top soil which was increased upto 30cm depth that makes soil more nutritionally enriched for establishment of vegetation.

5. Conclusion

The study compared physicochemical characteristics and micronutrient distribution in agricultural soil, pesticide-treated soil and forest soil from different depths in Patnagarh, Balangir district, Odisha. The results showed that pH, electrical conductivity, organic carbon and total nitrogen generally increased from the surface layer to 30 cm depth, followed by a decline at 60 cm. Available phosphorus, potassium, sulphur and micronutrients such as zinc, manganese, copper, iron and boron also showed higher accumulation around 30 cm in most soil profiles. Forest soil showed comparatively better fertility status for several parameters, while pesticide-treated soil showed lower organic carbon and nutrient availability in some layers. The correlation results indicated that organic carbon, total nitrogen and available phosphorus were positively associated with several micronutrients, suggesting their role in nutrient retention and availability. The findings highlight the importance of depth-wise soil testing for understanding nutrient distribution and planning soil management. Further work is required to verify pesticide effects and long-term nutrient transformation processes.

6. Limitation

This study was limited to three soil-use categories and four sampling depths from one locality in Balangir district. The number of sampling sites, field replicates, crop history, pesticide type, pesticide dose and duration of exposure were not clearly described. The study measured selected physicochemical properties and micronutrients but did not include pesticide residues, microbial activity, soil texture, bulk density or seasonal variation. Some interpretations are based on correlation and cannot establish causation. Further studies should include larger sampling coverage, detailed land-use history, repeated seasonal sampling and direct assessment of pesticide contamination.

Acknowledgement

The authors express gratitude to the Vice Chancellor of Gangadhar Meher University, Sambalpur, Odisha, India, for the essential advice and support. The research was facilitated by the assistance of the Soil Testing Lab in Sambalpur.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Blanco-Canqui, H., Shapiro, C. A., Wortmann, C. S., Drijber, R. A., Mamo, M., Shaver, T. M., & Ferguson, R. B. (2013). Soil organic carbon: The value to soil properties. *Journal of Soil and Water Conservation*, *68*(5), 129-134. https://doi.org/10.2489/jswc.68.5.129A

Campbell, C. A., McConkey, B. G., Zentner, R. P., Selles, F., & Curtin, D. (1996). Tillage and crop rotation effects on soil organic C and N in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. *Soil and Tillage Research*, *37*(1), 3-14. https://doi.org/10.1016/0167-1987(95)01002-5

Das, S. K. (2014) Role of Micronutrient in Rice Cultivation and Management Strategy in Organic Agriculture-A Reappraisal. *Agricultural Sciences*, **5**, 765-769. https://doi.org/10.4236/as.2014.59080

Dash, S., & Kujur, M. (2024). Comparative Assessment of Nutrient Mobilisation and Heavy Metal Indices in Chronosequence of Manganese Mine Spoil. *International Journal of Ecology and Environmental Sciences*, *50*(4), 601-609. https://doi.org/10.55863/ijees.2024.0139

Dhaliwal, J. K., Galbraith, M. E., Leung, C. K., & Tan, D. (2023). A data discovery and visualization tool for visual analytics of time series in digital agriculture. In *2023 27th International Conference Information Visualisation (IV)* (pp. 268-271). IEEE. https://doi.org/10.1109/IV60283.2023.00053

Esteban, G. (2001). A microbial missing-link found at Sourhope. *Soil Biodiversity NERC Thematic Programme Newsletter*, (7), 3-3. https://staffprofiles.bournemouth.ac.uk/display/gesteban

Feng, S., Zhao, W., Zhan, T., Yan, Y., & Pereira, P. (2022). Land degradation neutrality: A review of progress and perspectives. *Ecological Indicators*, *144*, 109530. https://doi.org/10.1016/j.ecolind.2022.109530

Goswami, S. B., & Das, S. K. (2009). Effect of bio-mulches on soil nutrient availability and microbial population in summer rice. *Oryza*, *46*(2), 103-107. https://www.indianjournals.com/ijor.aspx?target=ijor:oryza&type=toc&volume=46&issue=2

Han, F. X., Kingery, W. L., Hargreaves, J. E., & Walker, T. W. (2007). Effects of land uses on solid-phase distribution of micronutrients in selected vertisols of the Mississippi River Delta. *Geoderma*, *142*(1-2), 96-103. https://doi.org/10.1016/j.geoderma.2007.08.006

Indian Society of Soil Science (2002) Fundamentals of Soil Science. http://www.isss-india.org/

Jayamadhuri, R., Rangaswamy, V., Ramudu, A. C., Jaffer Mohiddin, G., & Srinivasulu, M. (2005). Influence of orghorous and carbamate insecticides on enzymatic activities of amylase, cellulase and invertase in two groundnut soil. *Nature, Environment and Pollution Technology*, *4*, 385-393. https://neptjournal.com/

Jha, A. K., & Singh, J. S. (1991). Spoil characteristics and vegetation development of an age series of mine spoils in a dry tropical environment. *Vegetation*, *97*(1), 63-76. https://doi.org/10.1007/BF00033902

Kekane, S. S., Chavan, R. P., Shinde, D. N., Patil, C. L., & Sagar, S. S. (2015). A review on physico-chemical properties of soil. *International Journal of Chemical Studies*, *3*(4), 29-32. https://www.chemijournal.com/archives/2015/vol3issue4/PartA/3-3-9.1.pdf

Kirkham, M. B., Ok, Y. S., Sarkar, B., Wijesekara, H., Mandal, S., Singh, M., & Bolan, N. S. (2017). Characterization and improvement in physical, chemical, and biological properties of mine wastes. In *Spoil to soil: Mine site rehabilitation and revegetation* (pp. 3-15). CRC Press. https://doi.org/10.1201/9781351247337-3

Kumar, R. A. K. E. S. H., Rawat, K. S., & Yadav, B. (2012). Vertical distribution of physico-chemical properties under different topo-sequence in soils of Jharkhand. *Journal of Agricultural Physics*, *12*(1), 63-69. http://www.agrophysics.in/

Latif, A., Bilal, M., Asghar, W., Azeem, M., Ahmad, M. I., Abbas, A., & Shahzad, T. (2018). Heavy metal accumulation in vegetables and assessment of their potential health risk. *Journal of Environmental Analytical Chemistry*, *5*(234), 2380-2391. https://doi.org/10.4172/2380-2391.1000234

Liu, K., Zhang, H., Liu, Y., Li, Y., & Yu, F. (2020). Investigation of plant species and their heavy metal accumulation in manganese mine tailings in Pingle Mn mine, China. *Environmental Science and Pollution Research*, *27*(16), 19933-19945. https://doi.org/10.1007/s11356-020-08514-9

Maqueda, C., Herencia, J. F., Ruiz, J. C., & Hidalgo, M. F. (2011). Organic and inorganic fertilization effects on DTPA-extractable Fe, Cu, Mn and Zn, and their concentration in the edible portion of crops. *The Journal of Agricultural Science*, *149*(4), 461-472. https://doi.org/10.1017/S0021859610001085

Mishra, R. (1968). Ecology Work Book. Oxford IBH, New Delhi. https://www.worldcat.org/title/ecology-workbook/oclc/101241

Oti, N., Agomuo, R., & Ekpe, I. I. (2017). Assessment of depth distribution of micronutrients (Cu, Fe, Mn and Zn) in soils under a long term fertilizer use in Imo, southeast Nigeria. *Nigeria Agricultural Journal*,.48(2), 141-150. https://www.ajol.info/index.php/naj/issue/view/16944

Qiu, K., Xie, Y., Xu, D., & Pott, R. (2018). Ecosystem functions including soil organic carbon, total nitrogen and available potassium are crucial for vegetation recovery. *Scientific Reports*, *8*(1), 7607. https://doi.org/10.1038/s41598-018-25875-x

Rashidi, M., & Seilsepour, M. (2008). Soil available phosphorus pedotransfer function for calcareous soils of Varamin Region. *American-Eurasian Journal of Sustainable Agriculture*, 2(1): 98-103. http://www.aensiweb.com/AEJSA/

Sahani, U. and Behera, N. (1998). Impact of deforestation on physico-chemical properties of tropical soil. Indian J. Env. Ecoplan. 1: 33-38.

Sahu, H. B., & Dash, S. (2011). Land degradation due to mining in India and its mitigation measures. Proceedings of Second International Conference on Environmental Science and Technology, February 26-28. http://hdl.handle.net/2080/1411

Shukla, A. K., Behera, S. K., Pakhre, A., & Chaudhari, S. K. (2018). Micronutrients in soils, plants, animals and humans. *Indian Journal of Fertilisers*, *14*(3), 30-54. https://www.faidelhi.org/

Shukla, A. K., Tiwari, P. K., & Prakash, C. (2014). Micronutrients deficiencies vis-a-vis food and nutritional security of India. *Indian J. Fert*, *10*(12), 94-112. https://www.faidelhi.org.in/

Swain, S., Khanam, R., Bhaduri, D., Dash, P. K., Padhy, S. R., Nayak, A. K., & Bhattacharyya, P. (2023). Comparative assessment of soil properties and heavy metals indices at rehabilitated and non-rehabilitated sites in coal mine spoils. *International Journal of Environmental Science and Technology*, *20*(12), 13769-13782. https://doi.org/10.1007/s13762-022-04710-x

Tale, K. S., & Ingole, S. (2015). A review on role of physico-chemical properties in soil quality. *Chemical Science Review and Letters*, *4*(13), 57-66. https://chesci.com/volume-4-issue-13/

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/161913